DISCUSSION PAPER

February 2010 ■ RFF DP 10-07

International Fuel Tax Assessment: An Application to Chile

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RESOURCES FOR THE FUTURE

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Abstract

Most developed and developing country governments levy taxes on gasoline and diesel fuel used by motor vehicles. However, outside of the United States and Europe, automobile and heavy truck externalities have not been quantified, so policymakers have little guidance on whether prevailing tax rates are anywhere close to their corrective levels. This paper develops a general approach for roughly gauging the magnitude of motor vehicle externalities, and hence the corrective tax on gasoline and diesel, for individual countries, based on pooling local data sources with extrapolations from U.S. data. The analysis is illustrated for the case of Chile, though it could be readily applied to other countries with appropriate data collection.

Key Words: gasoline tax, diesel tax, externalities, optimal tax, welfare gains, Chile

JEL Classification Numbers: Q48, Q58, R48, H21

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1. Introduction

Motor vehicle fuels have long been one of the most, if not the most, heavily taxed of consumer products in many countries. At the same time, motor vehicle use is associated with an unusually diverse variety of externalities, including local and global pollution, traffic congestion, traffic accidents, and road damage. Growing alarm about global climate change, relentlessly increasing urban gridlock, and world oil market volatility have all heightened interest in the appropriate level of fuel taxation.

Over the last two decades, there has been a major effort to measure the external costs of motor vehicles in the United States and certain European countries.[1] However, there has been little attempt to estimate external costs for other (in particular, middle- and low-income) countries, so policymakers in many countries may have little guidance on whether their fuels are currently over- or under-priced from an externality perspective. Fuel tax assessments for one country cannot simply be inferred from optimal tax estimates for, say, the United States, as they depend on many local factors (e.g., travel delays, the incidence and composition of highway fatalities, local valuations of health and travel time, etc.).

This paper describes an approach, applied to the case of Chile, for compiling rough estimates of automobile and (commercial) truck externalities, based on combining local data with extrapolations from U.S. literature. The parameters are easily applied to formulas for (second-best) corrective gasoline and diesel fuel taxes.

Reasonable economists could debate endlessly the exact details of the calculations here, not least because required data is sometimes limited, if available at all, and therefore a number of the assumptions in the parameter calculations must be based on judgment. Nonetheless,

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* Ian Parry is at Resources for the Futre and Jon Strand is at the World Bank. The authors are very grateful to the Inter-American Development Bank for financial support and to Patricio Barra Aeloiza, Alberto Barreix, Danae Chandia, Luis Cifuentes, Michael Keen, David Noe, Luis Rizzi, Enrique Rojas, and Rodrigo Terc for extremely helpful suggestions on earlier drafts and to Javier Beverinotti for research assistance. Any views expressed in the paper are those of the authors alone.

[1] See for example, De Borger and Proost (2001), Parry et al. (2007), and Quinet (2004).

establishing a ballpark estimate of the corrective fuel tax based on plausible first-pass assumptions—one that can be refined over time with improved data availability—is in most cases far better than having no figure at all. Moreover, through sensitivity analyses we demonstrate that for most parameters alternative assumptions have relatively modest (or negligible) impacts on corrective taxes.

Chile is an interesting case study. Its gasoline tax in 2006, about U.S. $1.50/gallon, is high relative to rates prevailing in North and South America, but low by western European standards, while the lighter taxation of diesel fuel relative to gasoline is especially striking for Chile (Figure 1). And a fuel tax assessment for Chile is timely given that (to cushion the impact of high oil prices) the statutory gasoline tax was temporarily reduced by more than a third in 2008, and the effective diesel tax was temporarily reduced to only U.S. $0.10/gallon through generous rebate provisions for truck drivers (see Appendix A for more discussion of the fuel tax system in Chile).

In our benchmark case the corrective gasoline tax for Chile is $1.82 per gallon, which is substantially larger than comparable calculations for the United States (e.g., Parry and Small 2005) even though the valuation of travel time and health risk is lower in Chile. Offsetting these factors is the much higher accident externality, due to the high incidence of pedestrian fatalities, which is a common feature of lower-income countries (Kopits and Cropper 2008). Moreover, the large share of the country's population residing in Santiago implies a larger share of nationwide mileage occurs under congested conditions, and a larger share of the population is exposed to elevated pollution-heath risks. Higher average fuel economy of the car fleet in Chile (compared with the United States) also magnifies congestion and accidents benefits per gallon reduction in gasoline.

As for diesel fuel, our benchmark estimate of the corrective tax is $1.69/gallon. On a per vehicle-mile basis, external costs of trucks are much larger than for cars—for example, trucks take up more road space and contribute more to congestion and, unlike for cars, they impose significant road damage externalities. However, an offsetting factor is that the reduction in truck miles associated with a gallon reduction in diesel fuel is much smaller than the reduction in car miles associated with a gallon reduction in gasoline.

The two most important sources of uncertainty in these (probably conservative) corrective tax estimates are the valuation of global warming damages and health risks—in either case, using high values from the literature adds around $0.60-$1.15 per gallon to corrective fuel taxes. All other assumptions relating to vehicle emission rates, initial fuel economy, behavioral responses, marginal travel delays, etc. have far less significance for corrective tax rates.

Two further caveats to the analysis are that we do not explore the possibility of externality mitigation through other instruments (e.g., peak-period congestion pricing), nor linkages between fuel taxes and the broader fiscal system. These and other limitations are discussed at the end of the paper.

The rest of the paper is organized as follows. The next section provides a brief conceptual framework for corrective fuel taxes. Section 3 discusses the methodology for parameter estimation. Section 4 presents the corrective tax results and sensitivity analysis. Section 5 offers concluding remarks.

2. Externality-Correcting Fuel Taxes: Conceptual Issues

By and large in Chile gasoline is used by passenger vehicles and diesel by commercial trucks. Therefore (with one caveat noted below), corrective gasoline taxes will depend on auto externalities while diesel taxes will depend on truck externalities.

Corrective Gasoline Tax

Parry and Small (2005) derive a formula for the (long run) optimal gasoline tax using a static, homogeneous agent model, where the agent represents an aggregation over all households in the economy. We discuss, very briefly, an adapted version of their model, the most important difference being that we strip out linkages between gasoline taxes and the broader fiscal system (we do this because reliable data on labor supply responses needed to assess fiscal linkages is not currently available for Chile).

The model boils down to the following household optimization problem:

(1a) $$\underbrace{Max}_{m,vg,X}\; u(m,v,X,\, E_G(G), E_M(M)) \quad + \quad \lambda\{I + GOV - (p_G + t_G)G - c(g)v - p_X X\}$$

(1b) $$G = gM \;,\; M = mv$$

M denotes vehicle miles traveled by households, equal to the number of autos (v) times miles driven per auto (m). G is aggregate gasoline consumption, equal to gasoline combustion per mile g, or the inverse of fuel economy, times vehicle miles. $E_G(.)$ is externalities that vary in proportion to gasoline use, while $E_M(.)$ is externalities that vary in proportion to vehicle miles (see below). I is private household income (which is fixed) and GOV is a government transfer, which captures the recycling of gasoline tax revenues. $c(g)$ represents the fixed costs of vehicle ownership which are increasing with respect to reductions in g, because more fuel efficient vehicles require the incorporation of (costly) fuel-saving technologies. X is an aggregate of all other goods in the economy. p_G and p_X are the producer prices for gasoline and the general good, which are given (Chile is a price taker in the world oil market). t_G is the excise tax on gasoline.

Households maximize utility $u(.)$ with respect to v, m, g and X taking externalities as given and subject to the budget constraint equating income with spending on fuel consumption, vehicles, and other goods (λ is a Lagrange multiplier).

Fuel-related externalities E_G include CO_2 emissions, while mileage-related externalities E_M include accident risk and road congestion. Following U.S. literature, we attribute road damage externalities (i.e., the costs of roadway wear and tear) to heavy trucks, rather than cars, given that road damage is a sharply increasing function of a vehicle's axle weight (e.g., Small et al., 1989, FHWA 2000, Table 13). Energy security externalities are beyond our scope as they are difficult to define, let alone quantify.[2]

In the absence of regulation, local tailpipe emissions would be proportional to fuel use. However if all new passenger vehicles are subject to the same emissions per mile standards, regardless of their fuel economy, and emissions abatement technologies are fully maintained over the vehicle lifecycle (to satisfy emissions inspections programs for in-use vehicles), emissions become decoupled from fuel economy and vary only with vehicle mileage. The latter assumption seems reasonable for the United States with state-of-the-art emissions control technologies (Fischer et al. 2007). For Chile, where most imported automobiles are initially subject to European ("Euro III") emissions standards, we assume two-thirds of local emissions varies with mileage and one-third with gasoline combustion (the corrective fuel tax estimates results are not very sensitive to alternative assumptions).[3]

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[2] One possible external cost from dependence on a volatile world oil market is the risk of macroeconomic disruptions from oil price shocks that might not (due to market frictions) be fully internalized by the private sector. For the United States, Leiby (2007) estimates these external costs are fairly modest, in the order of about $0.10/gallon.

[3] Upstream, local emissions leakage during petroleum refining and fuel distribution is an externality that varies with fuel use but the damages are small relative to those from tailpipe emissions, (e.g., NRC 2002, pp. 85-86). These emissions are excluded from our pollution damage estimates.

The corrective gasoline tax in the above model, denoted t_G^C, is given by (see Appendix B):

(2a) $$t_G^C = e_G + \beta \cdot e_M / g$$

(2b) $$e_G = -u_{E_G} E'_G / \lambda \, , e_M = -u_{E_M} E'_M / \lambda \, , \beta = g \frac{dM / dt_G}{dG / dt_G}$$

e_G and e_M denote the marginal external costs (or monetized disutility) from gasoline use and mileage in \$ per gallon and \$ per mile, respectively (it is reasonable to assume e_G and e_M are constant over the range of fuel reductions considered below).

The corrective tax in (2a) consists of the marginal external cost from gasoline combustion. It also includes externalities that are proportional to vehicle miles driven, multiplied by two factors. One is fuel economy (averaged across the on-road automobile fleet), which converts costs from \$ per mile into \$ per gallon. Fuel economy rises with higher taxes as households demand more fuel efficient vehicles over the longer run. The second factor, denoted β, is the fraction of the incremental reduction in gasoline use that comes from reduced miles driven, as opposed to improved fuel economy. The smaller is this fraction, the smaller the reduction in mileage-related externalities per gallon reduction in fuel use, implying a smaller contribution of mileage-related externalities to the optimal tax. (In an extreme case, if all of the incremental reduction in fuel use comes from improved fuel economy, and none from reduced driving, then $\beta = 0$ and mileage-related externalities would play no role in the corrective gasoline tax).

We assume the following functional forms:

(3) $$\frac{M}{M^0} = \left(\frac{p_G + t_G}{p_G + t_G^0} \right)^{\eta_M} , \frac{g}{g^0} = \left(\frac{p_G + t_G}{p_G + t_G^0} \right)^{\eta_g}$$

η_M and η_g denote, respectively, the elasticity of miles driven, and gasoline/mile, with respect to gasoline prices and 0 denotes an initial (currently prevailing) value. The overall gasoline demand elasticity, denoted η_G, is the sum of these individual elasticities, $\eta_G = \eta_M + \eta_g$ (this is easily verified through differentiating the expression for gasoline in (1b)). We take all elasticities as constant (a common assumption), which in turn implies β is also constant.

The welfare gains (W_G) from raising the gasoline tax from an initial level to its corrective level are given by (see Appendix B):

$$(4) \qquad W_G = -\int_{t_G^0}^{t_G^C} (t_G^C - t_G)\frac{dG}{dt_G}dt_G$$

W_G is the difference between the corrective and prevailing tax rate, integrated over the reduction in gasoline demand.

Corrective Diesel Tax

Our corrective diesel fuel tax is also derived from a highly simplified model. In particular, we ignore the feedback effect of reduced truck driving on encouraging automobile use via a reduction in road congestion (Calthrop et al. 2007). However, the resulting increase in automobile externalities has a relatively modest impact on the corrective diesel fuel tax, especially if gasoline taxes are raised in tandem with diesel taxes (Parry 2008, Table 3).[4]

In this model, the household optimization problem is given by:

$$(5a) \qquad \underbrace{Max}_{T,X}\, u(T, X, E_F(F), E_T(T)) \quad + \quad \lambda\{I + GOV - p_T T - p_X X\}$$

$$(5b) \qquad F = fT$$

$$(5c) \qquad p_T = (p_F + t_F)f + k(f) + \bar{p}_T$$

T denotes goods whose production and distribution involves a given amount of shipping by trucks, where units are normalized so that T is also truck miles. X is a general good whose production and consumption involves minimal transportation. E_F and E_T are externalities that vary in proportion to diesel fuel consumption and truck mileage respectively, where fuel

[4] We also lump together different types of trucks, rather than considering them separately, even though external costs per vehicle mile will differ across truck classes. For example, external costs per mile on a given road class will be greater for heavy-duty trucks as opposed to light-duty commercial vehicles (the share of these truck types in truck fuel consumption in Chile is currently 65 and 35 percent respectively, according to SII 2008). However, our approach is reasonable if the proportionate reduction in mileage in response to higher diesel taxes is approximately the same for different truck classes. This seems plausible, given that fuel consumption per mile should be roughly proportional to truck weight.

consumption is the product of mileage and fuel per mile, f. Households choose T and X taking externalities as given, subject to the budget constraint and respective product prices p_T and p_X.

In (5c) the unit price of the trucked good consists of fuel costs per mile, where p_F is the pre-tax price of diesel and t_F if the diesel tax. The price also consists of vehicle capital costs expressed on a per mile basis, $k(f)$, where k is increasing with respect to reductions in f due to the incorporation of fuel-saving technologies. $\bar{p}_T$ is non-transportation, unit production costs. Firms choose f to trade off fuel costs per mile with capital costs. As a result, an increase in the diesel tax will increase fuel economy (reduce f), as well as reduce truck mileage, as the tax is passed forward into p_T and hence causes households to substitute away from freight-intensive goods towards non-freight-intensive goods.

The corrective diesel fuel tax, denoted t_F^C, is (see Appendix B):

(6a) $$t_F^C = e_F + \alpha \cdot e_T / f$$

(6b) $$e_F = -u_{E_F} E_F' / \lambda \, , e_T = -u_{E_T} E_T' / \lambda \, , \alpha = f \frac{dT / dt_F}{dF / dt_F}$$

These expressions are exactly analogous to those in (2a) and (2b) with e_F and e_T the marginal external cost of diesel and truck miles respectively, and α is the fraction of the incremental reduction in fuel use that comes from reduced truck mileage, as opposed to better fuel economy. Vehicle noise and roadway wear and tear are included in mileage-related externalities. For trucks, which are also subject to emissions per mile standards in Chile, we again start by assuming that one-third of local emissions are proportional to fuel combustion and two-thirds to miles driven. Functional forms for truck mileage and fuel per mile, and welfare gains from tax reform, are analogous to the previous expressions.

3. Parameter Compilation

This section discusses how parameter values might be obtained for a middle- or lower-income country where many relevant data may be lacking, and using Chile as our case study. This involves pooling local data sources with extrapolations from U.S. evidence and using judgment where data is unavailable. A later sensitivity analysis demonstrates that the valuation of health risks and global warming are the major sources of uncertainty, while in other cases alternative plausible assumptions (e.g., concerning fuel economy or emission rates) have relatively modest implications for corrective fuel taxes. Parameter values are for year 2006 or thereabouts and are summarized in Table 1. All parameters are expressed in U.S. currency.[5]

Fuel Use, Prices, and Mileage Data

Data is, for countries we would have in mind for such a study, typically available for fuel use in the transportation sector, fuel prices, and fuel taxes but not necessarily for vehicle miles of travel or fuel economy. However, if a plausible assumption about fuel economy can be made, mileage is easily inferred. We assume that the on-road fuel economy of automobiles in Chile is roughly comparable to that in European countries like the United Kingdom a few years ago, 30 miles per gallon (e.g., Parry and Small 2005).[6] For heavy trucks, we assume fuel economy is 8 miles per gallon, based on U.S. figures for single-unit trucks in Parry (2008), Table 2. For 2007, total gasoline and diesel fuel consumption in Chile was 819 and 898 million gallons respectively, with Santiago accounting for 46.7 and 39.7 percent of these totals, respectively (SII 2008).

Initial retail fuel prices for 2006 are taken to be $4.27/gallon for gasoline and $3.17/gallon for diesel, and the respective excise taxes are $1.46 and $0.37/gallon (SII 2008).

External Damages from Local Tailpipe Emissions

For regions outside of Santiago, there is no local data on local pollution damages from automobiles. However, we believe it is reasonable for a first pass to extrapolate local pollution damages from the United States, after adjusting for differences in the value of statistical life (VSL)—given that damages are heavily dominated by mortality effects—and in vehicle emission rates. This procedure is described in Appendix C. The end result is damages of $0.01/mile and $0.02/mile, based on two plausible values for the Chilean VSL of $1.12 or $2.15 million, extrapolated from U.S. VSL estimates. The lower VSL value, our preferred estimate, is

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[5] They and can be converted into local currency using a market exchange rate of CLP 550 per U.S. $1. This is the average exchange rate that applied during the 2006-2008 period. See www.latin-focus.com/latinfocus/countries/chile/chlexchg.htm.

[6] Automobile fuel economy in the United States is currently about 22 miles/gallon (BTS 2009), but this reflects a large share of light-duty trucks (minivans, sport utility vehicles, pickups) in the fleet which have lower fuel economy than cars.

consistent with (updated) results from a stated preference study by Cifuentes et al. (2000) that uses Chilean data.[7]

For Santiago, we might expect much larger damages given its high population density and that meteorological and topographical conditions are especially favorable to pollution formation. Rizzi (2008a) provides detailed local evidence on pollution-health impacts for Santiago. Using that study, we compute damage estimates of $0.04/mile or $0.07/mile, under our different VSL assumptions (see Appendix C).[8] Weighting damages for Santiago and the rest of the country by the respective mileage shares (assumed to be the same as the fuel consumption shares) gives a nationwide pollution cost of $0.02/mile or $0.04/mile for Chile. As noted above, we apportion two-thirds of this cost to mileage and one-third to fuel use, to obtain the figures in Table 1.

We assume pollution damage costs for trucks, on a per mile basis, are 3.4 times those for cars. This is based on our own calculations for Santiago (see Appendix C) and it is also consistent with estimates of relative car/truck damage estimates for the United States in FHWA (2000), Table 13.

Global Pollution

Combusting a gallon of gasoline and diesel fuel produces 0.009 and 0.010 tons of CO_2 respectively.[9] Worldwide damages from the future global warming potential of these emissions (e.g., from agricultural impacts, defense against sea level rise, health effects from the possible spread of tropical disease, damage risks from more extreme climate scenarios) remain highly contentious. Most studies use market discount rates and estimate damages in the order of $5-$20/ton of CO_2, while studies that use below market rates put damages in the order of $80/ton of

[7] Personal communication with Luis Cifuentes, December 2008.

[8] The study year was 2001. However, we adjust the health impact estimates downwards by one-third, based on a personal communication with Luis Cifuentes (December, 2008). This reflects more recent U.S. evidence suggesting that the relationship between health impacts and pollution concentrations is better represented by a concave (log-linear) rather than linear function (Pope et al. 2004, 2006).

[9] See http://bioenergy.ornl.gov/papers/misc/energy_conv.html.

CO_2 (see the review in Tol 2008).[10] Even more controversial is the treatment of extreme catastrophic risks (for example from an unstable feedback mechanism leading to a runway warming effect) which may, or may not, imply damages per ton that are arbitrarily large in expectation (Weitzman 2008). However, this consideration does not provide specific guidance on an appropriate value for the social cost of CO_2. To be conservative, we start with a value of $10/ton of CO_2, and consider a value eight times as large in sensitivity analysis.

Congestion

Marginal congestion costs depend on the marginal delay (i.e., the increase in delay to other road users due to the added congestion caused by one extra vehicle mile) and the value of travel time (VOT).

An approximation for the marginal delay (averaged across a region) can be inferred from data on average delay, and an assumption about the functional relation between the two implied by speed/traffic flow curves (for some discussion see Lindsay and Verhoef 2000, Small and Verhoef 2007, Ch. 3). For Santiago, we obtain an estimate of average delay at peak and off-peak periods, by comparing observed travels speeds with speed under free-flow conditions. And we obtain marginal delay from average delay using the "Bureau of Public Roads" formula, which is widely used in traffic engineering models. As detailed in Appendix C, this procedure yields a marginal delay for Santiago of 0.035 hours per auto mile (averaged across time of day).

As for the rest of Chile, we assume no congestion in rural areas. For other urban centers we assume travel speeds are comparable to those outside of the (congested) downtown core in Santiago. Reasonable information on these speeds is available from a local transportation model for Santiago, and based on this data, marginal delays in other cities are calculated at 32 percent of those for Santiago as a whole. Weighting regional marginal delays by respective mileage shares yields a nationwide marginal delay of 0.022 hours per mile. (Again, see Appendix C for details).

[10] The ethical argument for using below market rates (essentially, a zero rate of pure time preference) is that it does not discriminate against future generations, just because they are born in the future (Stern 2007). Critics of this approach view market discounting as essential for meaningful policy analysis and to avoid perverse implications if applied in other policy contexts (Nordhaus 2008, Ch. 9).

As for the VOT, we use a preferred value of $2.7 per hour and a value of $1.5 per hour for sensitivity analysis. The first figure is obtained by extrapolating evidence on the VOT for the United States (and is in line with limited evidence available from Chilean data), while the second figure reflects current government practice in Chile (see Appendix C).

Combining our preferred VOT and marginal delay yields a marginal external congestion cost of $0.055 per mile. One further complication is that driving on relatively congested roads (which are heavily used by commuters) is typically less sensitive to gasoline prices than driving on relatively uncongested roads. Thus, the congestion benefits from a given reduction in nationwide mileage are smaller than they would be if driving on congested and uncongested roads were equally price sensitive. Based on typical estimates of the relative sensitivity of driving under congested and uncongested conditions, Parry and Small (2005) scaled back nationwide marginal congestion costs by 30 percent. We follow the same procedure to obtain a preferred marginal external congestion cost of $0.04 per mile.

Finally, based on standard estimates from the literature (e.g., Santos and Fraser 2006, Santos 2008) we assume that a vehicle mile by a heavy truck contributes 2.5 times as much to congestion as an extra automobile mile. These estimates take into account the extra road space used by trucks, their slower driving speeds, and their greater propensity for off-peak travel.

Accidents

Local data on traffic injuries is critical for gauging accident externalities, not least because the incidence of pedestrian/cyclist injuries—a major determinant of externalities—varies dramatically across countries (Kopits and Cropper 2008). As discussed in Appendix C, we start with Chilean accident data for various non-fatal injury classifications, for 2006. We make assumptions about what portion of personal injury, medical costs and property damages associated with these injuries are external (e.g., occupant injury risk in single vehicle collisions is assumed internal). The external components are then monetized using a mixture of local evidence and U.S. extrapolations, and an assumption that the VSL for an instantaneous fatality (in an auto accident) is about a fifth greater than for a fatality occurring with a lag in response to pollution exposure.

The end result is external cost for a car of $0.06 per mile or $0.10 per mile, under alternative values for the VSL. Pedestrian/cyclist fatalities alone account for about three-quarters of this figure, therefore alternative assumptions about the extent to which medical costs, property damages, and injuries in multi-vehicle collisions are external versus internal have a relatively modest impact on the external cost estimate.

As for trucks, we follow de Palma et al. (2008), Parry (2008), and FHWA (2000), in assuming that external accident costs are 25 percent greater than for cars, implying an externality of \$0.07 or \$0.12 per mile.[11]

Road Damage and Noise

Road damage costs for trucks are estimated at \$0.08 per mile and noise costs a much smaller \$0.01 per mile. Appendix C provides details on these calculations. Road damage is inferred from government expenditures on road maintenance, after attributing a portion of these costs to other vehicles and other factors, while noise costs are obtained from U.S. estimates (after making an adjustment for income and the share of urban versus rural driving).

Elasticities

According to reviews by Goodwin et al. (2004) and Glaister and Graham (2002) the long run gasoline demand elasticity for countries like the United States is around –0.6, though a recent, widely cited, study by Small and Van Dender (2006) suggests a somewhat smaller size elasticity of –0.4. About 40 or 50 percent of the elasticity is attributed to reduced mileage, as opposed to long run vehicle fuel economy improvements. Given the wider availability of transit alternatives, we might expect mileage to be moderately more price-responsive in Chile than the United States.[12] We choose a value of –0.5 for the gasoline price elasticity, with the assumed response split equally between improved fuel economy and reduced driving.

The limited evidence available on diesel fuel elasticities for heavy trucks for high-income countries suggests that they are roughly comparable in magnitude to gasoline demand elasticities (e.g., Dahl 1993, pp. 122-123). It seems plausible that the mileage component of the elasticity is somewhat larger for diesel than for gasoline, as technological opportunities for improving fuel

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[11] Due to their much greater weight, we would expect heavy-duty trucks to pose far greater risks than autos to other vehicles and their occupants in a collision (for given travel speeds). However, a counteracting factor is that trucks are driven by professionals, typically at lower speeds, and more frequently at night, than cars, and therefore crash less often.

[12] The only estimate we are aware of that uses local data is Rogat and Sterner (1998), who put the gasoline demand elasticity for Chile at –0.43.

economy are more limited for trucks than for cars given the high power requirements necessary to move freight. We use a diesel fuel price elasticity of –0.5, with 60 percent of the response from changes in mileage, and 40 percent from changes in fuel economy.

4. Corrective Fuel Tax Calculations

Benchmark Results

The top half of Table 2 presents the corrective tax calculations under our benchmark parameter assumptions (Case 1).

(i) Gasoline tax. The corrective gasoline tax is $1.82 per gallon, which is 25 percent larger than the rate prevailing in 2006. Traffic accidents account for 45 percent of the tax, congestion 32 percent, local tailpipe emissions 20 percent, and global warming only 4 percent.

This corrective tax estimate is higher than comparable estimates for the United States (e.g., Parry and Small 2005). At first glance, this seems surprising given the lower valuation of health risks and travel time in Chile. However, one offsetting factor is that accident externalities are much larger in Chile, due to the much higher incidence of pedestrian/cyclist fatalities. In addition, despite the lower VOT in Chile, our nationwide figure for marginal congestion costs is comparable to that in U.S. studies, because a larger share of nationwide driving occurs under highly congested conditions (in Santiago). Similarly, although the assumed VSL for Chile is lower, the (nationwide) pollution-mortality rate is greater, given the large share of the population residing in Santiago and therefore exposed to elevated risks. Yet another factor is that the assumed miles per gallon is about 30 percent larger in Chile than the United States. This implies a greater reduction in mileage per gallon of fuel saved, which in turn magnifies the mileage-related externality benefits, particularly congestion and accidents (through lowering g in equation (2a).

(ii) Diesel tax. The corrective diesel fuel tax in the benchmark case is $1.69 gallon. This is smaller than the corrective gasoline tax, but only moderately so—external cost considerations do not warrant the current, and strikingly large, tax preference for diesel over gasoline.

Local and global pollution contribute essentially the same to the corrective tax for either fuel. However, unlike for gasoline, road damage contributes a significant amount ($0.39 per gallon) to the diesel tax (the contribution from noise is small). On the other hand, an offsetting factor is that trucks travel a shorter distance on a gallon of fuel than cars, which substantially reduces the mileage-related externalities per gallon of diesel fuel reduction. This is particularly the case for accidents, which contribute 34 cents to the corrective diesel tax compared with 81 cents for the corrective gasoline tax. Congestion also contributes less, but only moderately so (49 cents to the diesel tax and 58 cents to the gasoline tax), given our assumption that a truck mile contributes two and a half times the congestion as a car mile. Again, this corrective tax estimate is higher than for comparable estimates for the United States (e.g., Parry 2008), for similar reasons to those for the gasoline tax.

(iii) Impacts of tax reform. Also indicated in Table 2 is the impact of tax reform. Raising taxes from their 2006 levels to their corrective levels in the benchmark case would reduce (long-run) gasoline and diesel use by an estimated 4.0 and 15.9 percent respectively (the latter reduction is much larger due to the much larger difference between corrective and initial tax rates). The fuel economy increase is small for cars (2.1 percent) though a more significant 7.2 percent for trucks. Under corrective taxes, gasoline tax revenue increases 22 percent above 2006 levels while diesel tax revenues are more than three times as large. Annual welfare gains from raising taxes on gasoline and diesel to their corrective levels are \$5.9 million and \$64.1 million, respectively.

If initial tax rates were zero (and initial fuel consumption were proportionately larger according to equation (4)), fuel reductions from implementing the corrective tax would be in the order of 20 percent for either fuel. Estimated welfare gains (from the corrective fuel tax relative to no tax) would be substantially larger at \$158 million and \$165 million, respectively.

Sensitivity Analysis

Also shown in Table 2 are corrective taxes under different assumptions about global warming damages and the VSL. These are the two largest sources of uncertainty in the corrective tax assessment.

Using a higher value for global warming damages—\$80 per ton of CO_2 instead of \$10 per ton—increases the corrective gasoline tax and diesel tax by \$0.69 and \$0.81 per gallon, respectively (Case 2). These increases are moderately larger than the increase in CO_2 damages per gallon of gasoline (\$0.62 per gallon) and per gallon of diesel (\$0.70 per gallon), as higher taxes increase fuel economy, which in turn magnifies the contribution of mile-related externalities (again, though lowering g in (2a) and f in (6a)).

Using the higher VSL for Chile (\$2.15 million instead of \$1.12 million for pollution, and \$2.58 million for accident fatalities) increases both local pollution and accident externalities by around 70-80 percent (Case 3 in Table 2). As a result, the corrective gasoline and diesel taxes increase to \$2.97 per gallon and \$2.31 per gallon respectively. The tax increase is substantially larger for gasoline (\$1.15 per gallon) than for diesel (\$0.62), given the greater importance of accident externalities in the corrective gasoline tax.

Table 3 indicates the implications for corrective fuel taxes from changing a variety of other assumptions used in the parameter compilation, one at a time. In most cases the perturbations have a noticeable, but not dramatic impact on corrective fuel taxes.

We vary the initial fuel economy between 24 and 36 miles per gallon for cars and between 6.4 and 9.6 miles per gallon for trucks. This causes the corrective fuel taxes to vary by up to + and – 17 percent as higher (lower) fuel economy magnifies (dampens) the contribution of mileage-related externalities.

Increasing and decreasing local pollution damages by up to 50 percent causes the corrective fuel taxes to vary by up to +14 and –12 percent, while increasing and decreasing marginal travel delay by up to 50 percent causes corrective taxes to vary by up to +18 and –18 percent. Using the smaller value for the VOT (\$1.50 instead of \$2.70 per hour) decreases both corrective taxes by about 12 percent. Varying accident externalities by + and –50 percent causes the corrective gasoline tax to vary by + and –24 percent and the corrective diesel tax to vary between + and –11 percent. Varying road damage + and –50 percent causes the corrective diesel tax to vary between + and –12 percent. The results are fairly insensitive to varying own-price fuel elasticities, with mileage and fuel economy elasticities changing in the same proportion. More significant is, for a given overall fuel price elasticity, the relative price responsiveness of mileage and fuel economy (which determines β and α in equation (2) and (6)). As indicated in the last row of Table 3, varying the fraction of the gasoline elasticity that is due to reduced mileage from 0.35 to 0.65 causes the corrective gasoline tax to vary between + and –29 percent. And varying the fraction of the diesel fuel price elasticity due to mileage between 0.45 and 0.75 causes the corrective diesel tax to vary between +21 and –23 percent.

5. Conclusion

This paper presents a methodology for compiling estimates of parameters needed to assess corrective motor fuel taxes for a middle-income country. We use Chile as an illustration, though we believe the paper provides a useful template for approximately gauging corrective fuel taxes in other countries at similar levels of development (at least those with comparable data sources). To our knowledge, this is the first comprehensive study of optimal motor fuel taxes for a country outside of the OECD.

For Chile, the corrective gasoline and diesel taxes are $1.82 and $1.69 per gallon in the benchmark case—higher than typical tax rates prevailing in Western Hemisphere countries, but lower than typical rates in Western Europe. Despite lower valuations of health risks and travel delays, the corrective fuel tax estimates for Chile are larger than comparable estimates for the United States, due to a mix of factors, including the higher incidence of pedestrian fatalities in Chile as well as the high proportion of its population residing and driving in the metropolitan Santiago region, where conditions are conducive to pollution formation and roads are clogged.

Again, we emphasize that the analysis is only meant to provide a first-pass assessment. There is plenty of scope for parameter estimates to improve with better data though, aside from the valuation of mortality risk and global warming, we conjecture that, in most cases, refinements will be likely to have a non-substantial impact on corrective fuel tax estimates.

Another caveat is that there are far more efficient instruments than fuel taxes for addressing some of the key externalities. For example traffic congestion is better addressed through peak-period road pricing (Santos 2004) and accident externalities by altering auto insurance so it varies directly in proportion mileage (Bordhoff and Noel 2008).[13] However, until these externalities are comprehensively internalized through other instruments, in the interim it is entirely appropriate to include them in fuel tax assessment.

Furthermore, our analysis abstracts from linkages between fuel taxes and the broader fiscal system, particularly tax distortions in the labor market which depress the level of work effort below economically efficient levels. These interactions take two forms (e.g., Goulder 1995). First is the potential efficiency gain from using fuel tax revenues to reduce distortionary taxes, or fund socially productive public projects. Second is an efficiency loss to the extent that higher transportation prices cause a (slight) contraction in economic activity and hence labor supply. West and Williams (2007) estimate how these adjustments might alter the optimal gasoline tax for the United States. In fact, they estimate that on net the optimal (revenue-neutral) tax is about 50 percent higher than the corrective tax because gasoline is a relative complement to leisure (due to the high portion of passenger trips that are not work related). However, reliable evidence on behavioral responses (i.e., labor supply responses to income and fuel taxes) needed to make a similar adjustment for Chile is not available at present.

[13] Road tolling is beginning to emerge in Chile, for example the major north-south toll route in Santiago (the Autopista Central) was opened in 2004. However, such tolls affect a small portion of roads nationwide at present.

Finally, the distributional argument against higher fuel taxes in Chile seems open to question given that, according to CASEN (2006), in 2006 only 9.4 percent of households in the bottom income decile owned a car, compared with 72.7 percent for the top-income decile. Thus, Jorratt (2008) estimated that gasoline taxes impose a progressively larger burden-to-income ratio across higher income households. However, one exception is that the bottom income decile suffers a disproportionately large burden-to-income ratio, perhaps due the preponderance for old, fuel-inefficient vehicles among the poor. Nonetheless, a common view among economists is that distributional concerns are better addressed through adjustments to the broader tax and benefit system (accounting for higher energy prices), rather than holding down fuel taxes.

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Appendix A. Further Details on the System of Highway Fuel Taxation in Chile

Gasoline and diesel excise taxes in Chile are related to the so-called UTM (Unidad Tributaria Mensual), an official unit of account which is continuously adjusted for general price inflation, and which was CLP 36,000, as of September 2008. For gasoline, the tax was 6 UTM/1000 liters until April 2008, when it was temporarily reduced to 4.5 UTM/1000 liters, and further reduced to 3.5 UTM/1000 liters in September 2008. The gasoline tax was in July 2009 again increased to 4.5 UTM/1000 liters. For diesel the tax is 1.5 UTM/1000 liters. Fuel taxes are also subject to value added taxes (VAT), currently 19 percent, applied to the refinery price and gross margin. However, VAT does not count towards the optimal fuel tax as it raises the price of goods in general rather than just fuels.

Fuel taxes in Chile are further complicated by a stabilization fund that counteracts volatility in refinery prices (due to variable world oil prices) by establishing price ceilings and floors 5 percent above and 5 percent below a reference refinery price, equal the average refinery price over the previous year. Payments are made out of, or into, the stabilization fund when refinery prices hit the ceiling or floor prices. Over the long haul, payments into and out of the stabilization fund should roughly balance out. However, in the short term, during periods of steadily rising prices, the fund could be depleted. This happened during the price spike of 2008, when the Chilean government replenished the fund directly, in an amount of about US$1 billion.[14]

For diesel, the tax structure has been further complicated by tax refunds to trucking companies, initially equal to 25 percent of the diesel fuel tax in 2001, and temporarily raised to 80 percent in July 2008. This rebate is set to expire at the end of 2009..

[14] Presumably, these funds could be paid back to the government, now the price is at its floor level, requiring payments into the fund.

Appendix B

Deriving Equation (2): The corrective gasoline tax. The optimal tax is derived using a standard two-step procedure. First, we solve the household optimization problem in (1), where externalities, and government variables, are taken as given. This yields the first order conditions:

(B1) $$\frac{u_m}{v} = \lambda(p_G + t_G)g\ , u_v = \lambda\left[(p_G + t_G)gm + c\right], -c'(g) = (p_G + t_G)m\ , \quad u_X = \lambda p_X$$

The second step is to totally differentiate the household's indirect utility function, which is simply equivalent to the expression in (1), with respect to the gasoline tax. In this step, economy-wide changes in externalities and the government transfer are taken into account. Using the first order conditions in (B1) to eliminate terms in dm/dt_G, dv/dt_G, dg/dt_G, and dX/dt_G, the total differential is given by:

(B2) $$u_{E_G}E'_G\frac{dG}{dt_G} + u_{E_M}E'_M\frac{dM}{dt_G} + \lambda\left\{\frac{dGOV}{dt_G} - G\right\}$$

The government budget constraint, equating spending with fuel tax revenue, is $GOV = t_G G$. Totally differentiating gives:

(B3) $$\frac{dGOV}{dt_G} = G + t_G\frac{dG}{dt_G}$$

Equating (B2) to zero, to obtain the corrective tax, and substituting (B3), gives:

(B4) $$t_G^C = -\frac{u_{E_G}}{\lambda}E'_G - \frac{u_{E_M}}{\lambda}E'_M\frac{dM/dt_G}{dG/dt_G}$$

From differentiating the expression for gasoline use in (1b):

(B5) $$\frac{dG}{dt_G} = g\frac{dM}{dt_G} + M\frac{dg}{dt_G}$$

Thus, the fraction of the reduction in gasoline use that is due to reduced mileage is

(B6) $$\beta = \frac{gdM/dt_G}{dG/dt_G}$$

Substituting (B6) and expressions in (2b) in (B4), gives the corrective tax formula in (2a).

Deriving Equation (4): Welfare gains from tax reform. Expression (B2) gives the welfare gain from an incremental increase in the gasoline tax. Dividing by λ to express in monetary terms, and substituting from (B3) and (2b), gives:

(B7) $$-e_G \frac{dG}{dt_G} - e_M \frac{dM}{dt_G} + t_G \frac{dG}{dt_G}$$

Using the definitions of t_G^C and β in (2) gives

(B8) $$-(t_G^c - t_G)\frac{dG}{dt_G}$$

Integrating over the tax rise gives the total welfare gain in (4).

Deriving Equation (6): The corrective diesel tax.

The household optimization in equation (5) yields the first order conditions:

(B9) $$u_T = \lambda p_T, u_X = \lambda p_X$$

And the optimization over fuel intensity by producers (i.e., the minimization of per unit trucking costs in (5c), yields:

(B10) $$t_F + p_F = -k'(f)$$

Differentiating the household's indirect utility function (equivalent to the expression in (5a)), accounting for changes in externalities, and using (B9) to eliminate terms in dT / dt_F and dX / dt_F gives:

(B11) $$u_{E_F} E_F' \frac{dF}{dt_F} + u_{E_T} E_T' \frac{dT}{dt_F} + \lambda \left\{ \frac{dGOV}{dt_F} - T \frac{dp_T}{dt_F} \right\}$$

Differentiating the government budget constraint, $GOV = t_F F$, gives

(B12) $$\frac{dGOV}{dt_F} = F + t_F \frac{dF}{dt_F}$$

The impact of the fuel tax on the price of the trucked good is, from differentiating (5c) and substituting (B10):

(B13) $$\frac{dp_T}{dt_F} = f$$

Substituting (B12), (B13) and (5b) in (B11), and equating to zero, gives the corrective diesel tax formula defined in (6a) and (6b).

Appendix C. Additional Details on External Cost Assessment

Pollution

For regions outside of Santiago: extrapolating from U.S. estimates. There is reasonable consensus in the U.S. literature on the overall size of (local) pollution damages from automobiles. Summarizing this literature, Small and Verhoef (2007), pp. 104-5, put damages at $0.011/mile nationwide for 2005. Mortality effects for sensitive groups (seniors and people with pre-existing health conditions) account for about three-quarters of these estimates (other effects include morbidity, reduced visibility, ecosystem impacts, building corrosion, etc.).[15] Small and Verhoef (2007) assume the value of a statistical life (VSL) is $4.15 million, after accounting for discounting of the lag between exposure and premature mortality, and the lower VSL for seniors (compared with the average age individual). To extrapolate the damage figure to Chile (outside of Santiago) we need to consider differences in the VSL and vehicle emission rates.

To extrapolate VSL estimates to Chile we use the following, commonly used formula (e.g., Cifuentes et al. 2005, pp. 40-41):

$$\text{(C1)} \qquad VSL_{Chile} = VSL_{US} \cdot \left(\frac{I_{Chile}}{I_{US}} \right)^{\eta_{VSL}}$$

where I_Y denotes real per capita income in county Y and η_{VSL} is the elasticity of VSL with respect to income. From World Bank (2008) I_{Chile} / I_{US} is ($13,000/$48,150=) 0.27.[16] We consider two values that roughly span the range of estimates for η_{VSL}: 0.5 and 1.0.[17] We thus obtain VSL values for Chile of $1.12 million or $2.15 million.

[15] Damages are also easily dominated by particulate matter (rather than ozone), some emitted directly, and some formed in the atmosphere from nitrogen oxides and hydrocarbons.

[16] This is based on purchasing power parity rather than market exchange rates to account for the greater spending power of income in Chile due to lower (non-tradable) goods prices.

[17] Viscusi and Aldy (2003) and Miller (2000) estimate η_{VSL} at about 0.5 and unity respectively. Alan Krupnick, an expert on this issue, also recommended we use the above values (personal communication, November, 2008).

Based on a personal communication with Luis Cifuentes (November, 2008) we assume current auto emission rates in Chile are the same as those applying in the United States in 1992, or three times current U.S. rates (BTS 2008, Table 4.38).[18]

For Santiago. We begin with Rizzi (2008a)'s estimated incidences of mortality and morbidity (for year 2001) in Santiago that are attributed to trucks and automobiles, as shown in the first two columns of the upper part of Table B1. The data only allows an assessment of short-term or acute mortality effects. Long-term mortality effects occurring with a lag in the lifecycle, following an extensive period of pollution intake, are inferred based on the ratio of long-term to short-term mortality from U.S. literature. The figures in Table C1 account for a downward adjustment of one-third recommended by Luis Cifuentes (personal communication, December 2008) to account for more recent evidence on the functional relation between health impacts and pollution concentrations (Pope et al. 2004, 2006).

In Table C1, we monetize these effects with our two values for the VSL. For acute mortality, we assume the VSL is 22 percent larger, to account for the greater number of life years lost (Small and Verhoef 2007, pp. 104). Morbidity effects, for example, instances of asthma and bronchitis, are valued by the respective unit costs in Rizzi (2008a). Overall pollution damages are not very sensitive to alternative assumptions for valuing morbidity.

Multiplying instances of health impacts by the cost per impact, and aggregating gives total annual health costs of $0.49 or $0.84 billion for automobiles and $0.42 billion or $0.72 billion for trucks. In Table C1 we also include corrosion to buildings and other objects from pollution, based on Rizzi (2008a), Table 6.[19] These effects amount to 7-14 percent of health damages.

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[18] Although vehicles imported into Chile are now subject to approximately equivalent emissions standards as new vehicles in the United States, emissions standards were introduced, and ramped up, far later in Chile than the United States. Consequently, there is a significantly greater share of older, highly emissions-intensive vehicles, in the current automobile fleet in Chile.

[19] The estimates have been increased by 30 percent to reflect the approximate increase in valuation of such damages up to 2006.

Dividing the total pollution damage figures in Table C1 by distance travelled by automobiles and trucks in Santiago gives damages of \$0.04 and \$0.07 per mile for automobiles and \$0.15 or \$0.25 per mile for trucks.

Congestion

Average delay for Santiago. We obtain travel speeds for Santiago from the ESTRAUS model.[20] Based on our own simulations of this model, the average automobile travel speeds under peak, off-peak, and free-flow traffic conditions in the Santiago metropolitan area are 21.2, 24.5 and 28.5 miles per hour, respectively. Inverting these figures, and comparing actual and free-flow travel times, we obtain average delays due to congestion of 0.012 hours per mile and 0.006 hours per mile, for peak and off-peak travel respectively. From the ESTRAUS model, 50 percent of auto travel occurs during the peak period and 50 percent at off-peak (including weekends), hence delay averaged over time of day is 0.009 hours per mile.

Ratio of marginal to average delay. The most commonly used functional form relating travel time per mile (the inverse of speed), denoted T, to traffic volume (vehicles per lane mile per hour), denoted V, is:

(C2) $$T = T_f\{1+\alpha V^{\theta}\}$$

α and θ are parameters and T_f is time per mile when traffic is free flowing. A typical value for the exponent θ is 2.5–5.0 (Small 1992, pp. 70–71). With $\alpha = 0.15$ and $\theta = 4.0$, equation (C2) is the Bureau of Public Roads formula, which is widely used in traffic engineering models. Subtracting T_f from (C2) and dividing by V gives the delay per vehicle mile due to congestion, $T_f \alpha V^{\theta-1}$. And subtracting T_f from (C2), and differentiating, the marginal delay per vehicle mile is $\theta T_f \alpha V^{\theta-1}$. Hence the ratio of the marginal to average delay is θ, or 4 with the Bureau of Public Roads formula. Quadrupling average delay gives a marginal delay of 0.035 hours per mile.

[20] This model provides a detailed and carefully calibrated representation of the Santiago road transportation network (see de Cea Ch. et al. 2003 for a description of the model).

Nationwide delay. Santiago accounts for about half of nationwide car mileage, other urban areas a further 40 percent, and rural areas 10 percent (Sii 2008). We assume no congestion in rural areas. In other urban areas we assume travel speeds are comparable to those in Santiago, outside of the congested downtown core. Based on our simulations of the ESTRAUS model, average (and hence marginal) delays in other cities are 32 percent of those for Santiago as a whole. Thus, weighting marginal delays in Santiago, other urban areas, and rural areas by their respective mileage shares gives a nationwide marginal delay of 0.022 hours per mile.

Value of travel time. Reviews of empirical literature for the United States and some European countries recommend a VOT for peak-period auto travel of about half the market wage (e.g., Waters 1996, DOT 1997, Mackie et al. 2003). Based on average urban wage rates in BLS (2006), Table 1, this implies a U.S. VOT of $10/hour.

To extrapolate to Chile, we multiply by the ratio of the Chilean to U.S. income (0.27) raised to the power of the VOT/income elasticity. Estimates of this elasticity for high-income countries are typically around unity (e.g., Wardman 2001, Mackie et al. 2003), which gives our preferred VOT for Chile of $2.7/hour. We also consider a VOT of $1.5/hour, which is consistent with current government practice in Chile (e.g., Ministerio de Planificación 2008).[21]

Accidents

According to police-reported data, in 2006 there were 1,652 road deaths in Chile, with pedestrians/cyclists and car/truck occupants, accounting for 55 percent and 41 percent of these deaths respectively.[22] We make the common assumption that all pedestrian/cyclist deaths are external. Of the vehicle occupant deaths, we assume, as in the United States, that half of these are in single vehicle accidents, and represent internalized risks. To what extent injuries in multi-vehicle collisions are external is unsettled. All else constant, the presence of an extra vehicle on the road raises the likelihood that other vehicles will be involved in a collision, but a given collision will be less severe if people drive slower or more carefully in heavier traffic. Following

[21] Jara-Díaz et al. (2008) estimate the value of time (in general, rather than specifically for travel) at $2.9/hour using Chilean data. According to Luis Rizzi (personal communication, December 2008) some other unpublished estimates put the VOT for automobile travel in Chile at over $4.4/hour, which reflects the heavy concentration of car ownership and use among high-income groups. To the extent that these larger estimates are plausible, our preferred value should be viewed as conservative.

[22] Figures are from www.conaset.cl.

Parry (2004) (medium scenario), we assume that half of the remaining deaths in multi-vehicle collisions represent an external cost.

Fatalities are valued using the VSLs for an immediate death, assumed to be 22 percent larger than the VSL for a fatality occurring with a lag (see above). This gives a total cost of $1.5 billion or $2.7 billion.

There are various other dimensions to accident costs that we include but, at least for Chile, these costs are small relative to those from pedestrian/cyclist fatalities (given the large share of these fatalities in total fatalities). Therefore, the precise assumptions made below are not that important.

There were 6,515, 4,400 and 36,020 serious, less-serious, and light injuries in police-reported road accidents in 2006.[23] These injuries are not broken out according to pedestrian/cyclists and vehicle occupants, though we would expect pedestrians to account for a much smaller share of these nonfatal injuries (than their share in fatalities), given that a car/pedestrian collision is far more likely to cause a fatality than a car/car collision. We assume that 32 percent of non-fatal injuries are external (compared with 65 percent for fatalities).

We value the personal suffering costs from nonfatal injuries using two sources. First, we take the personal cost of suffering from a serious, less-serious, and light injury from the corresponding figure for disabling, evident, and possible injuries in Parry (2004), Table 2, scaled by the Chile/US VSL in our preferred case (0.27). These costs are $0.023 million, $0.005 million and $0.004 million respectively. Adding up, and monetizing, external non-fatal injuries produces an additional external cost of $0.10 billion. Second, Rizzi (2008b) values serious, less-serious, and light accident injuries at $0.074 million, $0.018 million and $0.004 million respectively. These values combine medical costs and personal injury costs, though they are not decomposed in the data. Based on Parry (2004), Table 2, we assume that medical costs and personal injury costs account for 20 percent and 80 percent respectively of these figures. Adding up, and monetizing, external non-fatal injuries with these alternative personal cost assumptions gives an additional external cost of $0.18 billion. Splitting the difference between the two estimates gives our preferred external cost of $0.14 billion.

[23] Again, see www.conaset.cl. These figures are conservative as they exclude traffic accidents that are not reported to the police. In fact, non-fatal traffic injury data may not be very reliable, even in the United States (e.g., Miller 1997).

We assume that 85 percent of medical costs for all non-fatal injuries (including injuries in single-vehicle collisions, etc.) are external (they are largely borne by third parties, particularly government medical services).[24] Again, we obtain the total external cost from valuing 85 percent of non-fatal injuries using the medical costs implied by Parry (2004) and by Rizzi (2008b) (in each case medical costs per injury are one-quarter of personal injury costs) and split the difference. This produces an additional external cost of $0.09 billion.

Finally, we assume that 50 percent of property damage costs (from all accidents) are external, that is, borne by insurance companies, rather than individuals (through deductibles, non-insured accidents, elevated premiums following a claim, etc.). Data on traffic accidents involving property damage only (and no injuries) is unavailable: based on Parry (2004), Table 2, we assume the number of these accidents is the same as those involving light injuries. Property damages per accident class are also obtained from Parry (2004), Table 2, scaled by 0.27. Overall, we compute external costs from property damage at $0.04 billion.

Adding up the above components gives a total external cost of $1.74 billion or $2.96 billion. Dividing by total distance travelled by cars and trucks (from Table 1) gives an average external cost (across all vehicles) of $0.056 or $0.095 per mile. The external cost for a car is obtained by dividing this figure by the share of cars in total vehicle miles plus the share of trucks in total vehicle miles multiplied by 1.25 (which is the assumed ratio of external costs per truck mile relative to that for a car mile). Thus, we obtain the external cost for a car of $0.053 or $0.090 per mile.[25]

[24] Medical costs per fatality are tiny relative to the VSL, and are ignored.

[25] Edlin and Karaca-Mandic (2006) develop an alternative methodology for quantifying accident externalities, based on a statistical analysis of how extra driving in the United States raises the risk of property damage costs for other drivers and insurance companies. Their estimates of accident externalities are substantially greater than those based on U.S. studies that use an approach similar to that above. In this regard, our accident externality assumptions might be conservative.

Road Damage and Noise

We measure road damage costs by central and local government spending on road maintenance in Chile, which totaled $0.85 billion in 2006.[26] We assume that all road maintenance expenditures in Santiago (21 percent of the total), and two-thirds in the rest of Chile, are due to vehicle driving (and that the remainder is due to weather, erosion, falling rocks etc.). After allocating a portion of these costs to buses and cars, we are left with $0.08 per truck mile.[27]

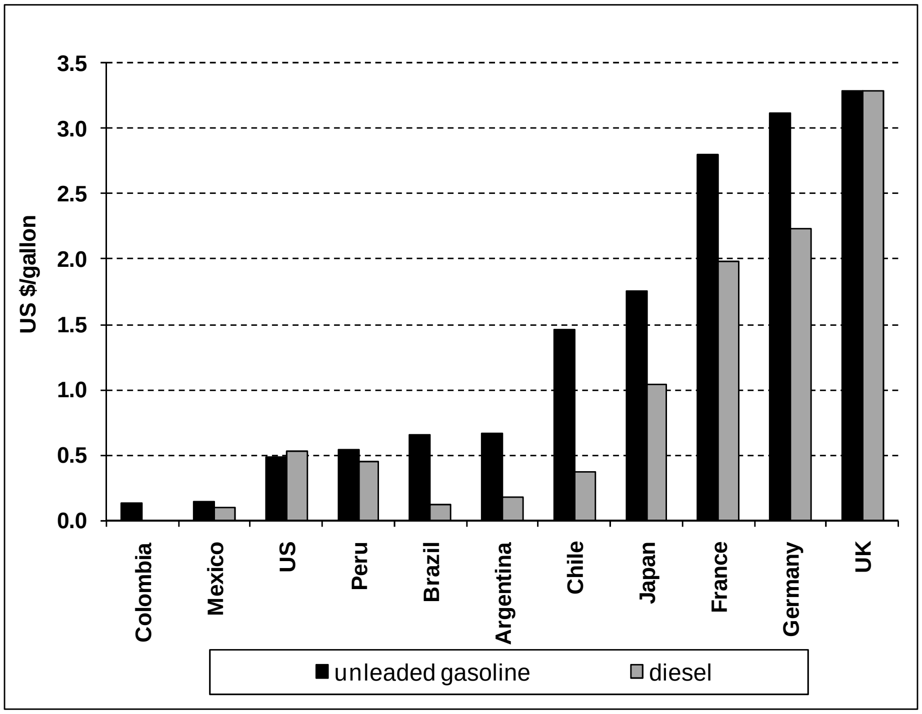
Vehicle noise costs have been estimated by examining how proximity to traffic affects local property values. For heavy trucks FHWA (2000), Table 13, puts the (average) costs for urban and rural truck driving at $0.027 and $0.002 per mile, respectively. We multiply by the Chile/US real income ratio (0.27) to transfer these values to Chile and weight by the share of mileage in urban and rural areas (0.87 and 0.13 respectively) to give a nationwide external cost of $0.006/mile).

[26] These figures were provided by David Noe and Rodrigo Terc from the Chilean Ministry of Finance. Implicitly, we assume that spending on road maintenance is optimal. If spending were sub-optimal our calculation would understate road damage externalities, and vice versa if spending were excessive. However, there is little basis on which to adjust for this.

[27] We assume the damage per truck mile is 1000 times the damage from a car or twice the damage from a bus mile (Porter 1999). The damage per truck mile is given by solving for x, where $x(s_T + s_B/2 + s_C/1000)$ = (total damage cost)/(total vehicle miles), and s_T , s_B and s_C are the shares of truck, bus and car miles in total vehicle miles (bus miles were 3.0 billion in 2006).

Figures and Tables

Figure 1. Excise Taxes on Gasoline and Diesel in Selected Countries in Year 2006



Sources: SII (2008), IEA (2008) and other sources compiled by Javier Beverinotti.

Table 1. Benchmark Data and Parameter Assumptions
(for year 2006 or thereabouts)

Data and parameter values	Automobiles	Trucks
Initial fuel consumption, million gallons	819	898
Initial fuel economy, miles/gallon	30.0	8.0
Vehicle miles, billion	24.6	7.2
Initial retail fuel price, $/gallon	4.27	3.17
Initial fuel tax, $/gallon	1.46	0.37
Fuel tax revenue, $billion	1.19	0.33
Externalities from fuel combustion, $/gallon		
local tailpipe emissions (varying with fuel use)		
VSL = $1.12 mn	0.103	0.063
VSL = $2.15 mn	0.182	0.110
Carbon	0.070	0.084
Externalities from driving, $/vehicle mile		
local tailpipe emissions (varying with mileage)		
VSL = $1.1 mn	0.016	0.056
VSL = $2.2 mn	0.029	0.098
congestion		
value of time = $2.7/hour	0.038	0.095
value of time = $1.5/hour	0.021	0.053
accidents		
VSL = $1.4 mn	0.053	0.066
VSL = $2.6 million	0.097	0.121
noise	0	0.006
road damage	0	0.076
Fuel demand elasticity	-0.50	-0.50
Milage to fuel price elasticity	0.50	0.60
Fuel economy elasticity	0.25	0.20

Sources. See text and Appendix C for documentation.

Table 2. Corrective Tax Computations

	Gasoline	Diesel
Case 1: Benchmark parameters		
Corrective fuel tax, $/gal.	**1.82**	**1.69**
Contribution of:		
local tailpipe emissions	0.35	0.35
carbon	0.07	0.08
congestion	0.58	0.49
accidents	0.81	0.34
noise	0	0.03
road damage	0	0.39
Impact of corrective tax:		
Relative to year 2006 tax rate		
Percent reduction in fuel use	4.0	15.9
Percent increase in fuel economy	2.1	7.2
Percent increase in tax revenue	17.6	298.4
Welfare gain, $ million	5.9	94.1
Relative to zero tax rate		
Percent reduction in fuel use	18.0	20.50
Welfare gain, $ million	157.7	164.8
Case 2: High global warming damages		
Corrective fuel tax, $/gal.	**2.51**	**2.50**
Case 3: High VSL		
Corrective fuel tax, $/gal.	**2.97**	**2.31**
Contribution of:		
local tailpipe emissions	0.65	0.63
accidents	1.63	0.66

Source: See text for corrective tax formulas and parameter assumptions.

Table 3. Further Sensitivity Analysis of Corrective Taxes

	Gasoline tax, $/gallon	Diesel tax, $/gallon
Benchmark case	1.82	1.69
Initial fuel economy		
Increased 20 percent	2.14	1.96
Decreased 20 percent	1.50	1.48
Local pollution damages		
Increased 50 percent	2.01	1.93
Decreased 50 percent	1.62	1.49
Travel delay		
Increased 50 percent	2.14	1.95
Decreased 50 percent	1.50	1.43
Value of travel time		
Decreased from $2.7 to $1.5/hour	1.61	1.48
Accident externalities		
Increased 50 percent	2.27	1.87
Decreased 50 percent	1.38	1.51
Road damage		
Increased 50 percent	1.82	1.90
Decreased 50 percent	1.82	1.48
Magnitude of fuel price elastcity		
Increased 50 percent	1.84	1.75
Decreased 50 percent	1.80	1.63
Fraction of fuel price elasticity due to reduced mileage		
Gasoline 0.65, diesel 0.75	2.34	2.04
Gasoline 0.35, diesel 0.45	1.29	1.31

Table C1. Pollution Damage Calculations for Santiago

Health effect	Instances of health effect: Automobiles	Instances of health effect: Trucks	cost per effect $ thousands
Acute mortality	83	70	1,432 or 2,752
Long-term mortality	240	200	1,129 or 2,151
Hospital admissions	332	277	1.45
Emergency room admissions	3,377	2,814	0.18
Chronic bronchitis	515	429	52.7
Acute bronchitis	876	730	0.03
Asthma attacks	18,693	15,578	0.03
Work days lost	157,450	131,320	0.03
Restricted activity days and symptom days	538,010	448,230	0.01
Total health cost, $ million	400	351	
Materials damage, $million	85	73	
Total pollution cost, $million	570	511	
Fraction of cost due to mortality	0.79	0.75	
Pollution cost, US$/mile	0.04	0.15	

Source. Rizzi (2008a) and personal communication, Luis Cifuentes, December 2008.

Note: Mortality effects are monetized using our lower VSL of $1.12 million.