

International Trade in Used Vehicles: The Environmental Consequences of NAFTA[†]

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Since trade restrictions were eliminated in 2005, Mexico has imported over 2.5 million used vehicles from the United States. Using a unique, vehicle-level dataset, we find that traded vehicles are dirtier than the stock of vehicles in the United States and cleaner than the stock in Mexico, so when a vehicle is traded from the United States to Mexico average vehicle emissions per mile tend to decrease in both countries. Overall, however, the evidence suggests that trade has increased total lifetime emissions, primarily because of low vehicle retirement rates in Mexico. (JEL F13, F14, L62, O13, O19, Q53, Q56)

Over the last two decades an unprecedented increase in private vehicle ownership has taken place in the developing world. The total number of registered vehicles in non-Organisation for Economic Co-operation Development (OECD) countries increased from 110 million to 210 million between 1990 and 2005, and, by some estimates, is forecast to increase to 1.2 billion by 2030.¹ Rising income explains a large share of this growth. Another important, but rarely discussed, factor is international trade in used vehicles. High-income countries export large quantities of used vehicles to low-income countries. The scope for continued expansion of trade is enormous. For example, in 2007 there were 768 total vehicles per 1,000 people in the United States compared to 30 per 1,000 in China and only 12 per 1,000 in India.

In this paper, we examine the environmental consequences of international trade in used vehicles. Vehicles play a central role in the production of local and global pollutants. Perhaps most importantly, vehicles are a major source of carbon dioxide, the principal greenhouse gas associated with climate change. Trade in used vehicles raises policy issues at the intersection of international free trade and global efforts to mitigate the production of greenhouse gas emissions. For example, between July and August 2009, consumers in the United States were able to trade in their old,

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[†] To comment on this article in the online discussion forum, or to view additional materials, visit the articles page at <http://www.aeaweb.org/articles.php?doi=10.1257/pol.2.4.58>.

¹ Ward's Automotive Group "Ward's World Motor Vehicle Data" (1992–2008), Joyce Dargay, Dermot Gately, and Martin Sommer (2007).

gas-guzzling vehicles and receive vouchers worth up to \$4,500 to help pay for new, more fuel efficient cars and trucks.² The cost effectiveness of this program hinges on what would have become of these vehicles in the absence of this purchase program.

We document that international trade between rich and poor countries has acted as a substitute for an explicit “cash for clunkers” program. Differences in operating costs, and willingness to pay for quality, imply that used vehicles will tend to be traded from high-income countries to low-income countries. Because retirement rates are lower in low-income countries, this leads vehicles to be used for many more years than they would have otherwise. In addition to this scale effect, trade affects the composition of vehicles in all countries. Older vehicles tend to emit substantially higher levels of pollutants, so trade may have a large impact on environmental quality in both importing and exporting countries.

Our study focuses on the deregulation of US-Mexico trade in used cars and trucks following the North American Free Trade Agreement (NAFTA). In accordance with the conditions of NAFTA, in August 2005 Mexico issued a decree allowing vehicles 10–15 years old to be imported from the United States and Canada. This represented a dramatic break from the previous policy that prohibited entry for all used vehicles except for certain vehicles used in agriculture. Virtually overnight a vigorous trade flow emerged and we document that between 2005 and 2008 over 2.5 million used vehicles were exported from the United States to Mexico.

To evaluate the environmental consequences of this trade pattern, we assemble the most comprehensive dataset ever compiled on North American trade in used vehicles and vehicle emissions. Our dataset allows us to identify, at the vehicle level (using the vehicle identification number (VIN)), which vehicles were traded. The results show that traded vehicles are higher-emitting per mile than the stock of vehicles in the United States, but lower-emitting per mile than the stock of vehicles in Mexico. As a result, when a vehicle is traded, average vehicle emissions per mile tend to decrease in both countries. We also show that vehicles that are exported to Mexico are more likely to have failed emissions testing. This provides evidence for the pollution havens hypothesis, the idea that trade liberalization causes pollution to move to countries with lax environmental standards.

The paper then goes on to examine vehicle retirement in both countries and new vehicle sales in Mexico. Measuring changes in vehicle retirement and purchase behavior is challenging because one must construct a credible counterfactual to describe what would have happened in the absence of trade. Here we rely heavily on before and after comparisons. The results indicate that the number of vehicles in circulation in the United States changed little after 2005, suggesting that most of the vehicles exported to Mexico were vehicles that would have been scrapped otherwise. In addition, there is no evidence that the increased availability of used vehicles has decreased sales of new vehicles in Mexico. These findings seem reasonable, but it is important to be upfront about the limitations of these before and after comparisons. Although we can and do control for covariates that are changing over time,

² http://energycommerce.house.gov/Press_111/20090505/cashforclunkers.pdf.

these results will be biased if there are unobservable time-varying factors that affect vehicle retirement and purchase behavior.

Overall, the analysis suggests that trade has led to an increase in total emissions. While trade decreases emissions in the United States, this is not enough to offset the increase in emissions in Mexico. Moreover, emissions increases are highly persistent because of low vehicle retirement rates in Mexico. We document that vehicle retirement rates in Mexico are much lower than vehicle retirement rates in the United States and illustrate how this can have a large impact on lifetime vehicle emissions. These results highlight the importance for policy makers of recognizing the synergies between environmental legislation and free trade legislation. For example, our findings suggest that unilateral policies in the United States aimed at reducing carbon emissions will increase exports of fuel-inefficient vehicles to Mexico, consistent with an emerging literature on carbon leakage.³ If the goal of US carbon policy is to minimize global emissions, then such trade effects must be anticipated.

Our study is germane to a substantial literature on trade and the environment. Whereas most previous studies have focused on how trade affects where goods are produced, this study focuses on how trade affects where goods are *consumed*. Several theoretical contributions have recognized the role of consumption-based pollution (Brian R. Copeland and M. Scott Taylor 1995; Carol McAusland 2008; Scott Holladay 2008), but empirical studies in this area have typically been limited by the lack of available data. Holladay (2008) explains that, “high quality measures of emissions from consumption rarely exist, making empirical work difficult.” Our focus on vehicles is valuable because vehicle emissions are well understood and vehicles have VIN numbers that allow them to be tracked consistently across countries. Similar methods could be used to examine emissions from other forms of transportation equipment, as well as a broad class of residential and commercial durable goods.

I. Related Literature

Previous studies of trade and the environment have emphasized how trade affects where goods are produced. See, e.g., Gene M. Grossman and Alan B. Krueger (1993); Copeland and Taylor (1994); Werner Antweiler, Copeland and Taylor (2001); Copeland and Taylor (2003); and Arik Levinson and Taylor (2008). In contrast, our study focuses on where goods are consumed. Trade affects prices and choice sets and thus changes the type and quality of goods in use, potentially with serious implications for the environment. With vehicles, how and where they are consumed is potentially even more important than how and where they are produced.

³ This literature explores the idea that with incomplete regulation carbon reductions in regulated areas may be offset by increases in unregulated areas. For example, Meredith L. Fowlie (2009) examines the effect of a source-based carbon cap and trade program on the California electricity sector, finding substantial scope for leakage to unregulated states. See also, Lawrence H. Goulder, Mark R. Jacobsen, and Arthur A. van Benthem (2009) that uses simulations to evaluate interactions between state and federal-level average vehicle fuel economy standards, showing that emission reductions in states with stringent requirements are largely offset by increases elsewhere.

For example, only 7 percent of the total lifetime carbon emissions for vehicles come from production and assembly, whereas 93 percent come from fuel usage.⁴

Another important feature of our analysis which distinguishes it from much previous work is our focus on both local and global pollutants. The leading empirical studies in the trade and environment literature have emphasized effects on local pollutants such as sulfur dioxide in judging the consequences of trade (see, e.g., Antweiler, Copeland, and Taylor 2001 and Copeland and Taylor 2003). We agree that local pollutants are important, but given the paramount importance of the issue of climate change it is also important to investigate how free trade affects this global environmental criterion. With global pollutants the location of consumption is irrelevant, but the magnitude of lifetime consumption is not. As a result, policies aimed at reducing greenhouse gas emissions may not achieve aggregate gains when fuel inefficient durable goods can be traded.

There are also a small number of empirical studies that focus specifically on the environmental impact of trade within North America. Working prior to NAFTA, Grossman and Krueger (1993) use a cross-country regression to show that ambient levels of sulfur dioxide and particulates increase with per capita gross domestic product (GDP) at low levels of GDP, suggesting that NAFTA would improve environmental quality via an overall increase in income. William T. Harbaugh, Levinson, and David Molloy Wilson (2002) argue that these results are fragile. Levinson and Taylor (2008) examine the effect of US environmental regulations on trade with Canada and Mexico, finding a robust relationship between abatement costs and import levels. For the average industry, a 1 percent increase in abatement costs is associated with a 0.2 percent increase in net imports from Mexico.

Our study is also relevant to a small existing literature on trade in used durables. Previous studies provide two complementary explanations for the observed pattern of trade in which used vehicles tend to be traded from high-income countries to low-income countries. Amartya Kumar Sen (1962) argues that older durable goods require larger labor inputs, making them relatively more desirable in countries where wage rates are low. Francisco E. Thoumi (1975), Eric W. Bond (1983), and Giorgio Barba Navaretti, Isidro Soloaga, and Wendy Takacs (2000) extend this argument to incorporate transportation costs, heterogeneous buyers and skill constraints. In this operating cost framework, high-income countries consume capital-intensive new goods. As these goods grow older they become labor-intensive and thus less desirable in high-income countries. The trade pattern is sensitive to wage levels, but also to energy prices, availability of replacement parts, access to specialized repair equipment, and supply of experienced repair technicians. In addition, environmental regulations affect operating costs by, for example, requiring costly emissions testing.

An alternative and complementary explanation for trade is non-homothetic preferences. If demand for quality is increasing in income then free trade will cause used vehicles to be exported from high-income countries to low-income countries. A

⁴ This estimate is from Malcolm A. Weiss et al. (2000) based on a total lifetime driving distance of 300,000 kilometers. Vehicles are one of the central sources of consumption-based pollution. In the United States 20.7 percent of carbon dioxide emissions are derived from motor gasoline. United States Department of Energy, "Annual Energy Review 2007," DOE/EIA-0384 (2008), Table 12.3, Carbon Dioxide Emissions from Energy Consumption by Sector by Energy Source, 2006.

growing literature in trade has recognized the importance of income effects in explaining trade patterns. See, e.g., Harry Flam and Elhanan Helpman (1987); Nancy L. Stokey (1991); Kevin M. Murphy and Andrei Shleifer (1997); Kiminori Matsuyama (2000); Ana Cecilia Fieler (forthcoming); and Pablo D. Fajgelbaum, Grossman, and Helpman (2009). A straightforward implication of non-homothetic preferences is that low-quality goods are relatively more desirable in low-income countries. High-income countries satisfy their demand for high-quality by purchasing new goods. As these goods depreciate they are traded to low-income countries that prefer lower quality.

The operating cost and non-homothetic preference models have similar testable implications. When trade restrictions are eliminated for used durable goods, these goods are traded from high-income countries to low-income countries. Which particular durable goods are traded depends on the labor-intensity of different types on durable goods, and on preferences in both countries. In addition, trade changes demand for new durable goods in both countries. Faced with increasing prices for used durable goods, high-income countries increase their purchases of new goods. Low-income countries do the opposite, substituting away from new durable goods as used durable goods become increasingly available. In equilibrium, high-income countries use a high proportion of new durable goods. Low-income countries use a high proportion of old durable goods, purchasing them from high-income countries where they are relatively less desirable. Trade continues indefinitely, as durable goods depreciate in both countries and need to be replaced.

II. Background: The North American Free Trade Agreement

NAFTA came into effect January 1, 1994, immediately eliminating tariffs on many goods and establishing a timetable for tariff reductions on many other goods. Restrictions for used vehicles imports were immediately eliminated in Canada and the United States. Mexico did not initially eliminate restrictions but agreed to a timetable under which restrictions would be eliminated in five phases beginning January 1, 2009 and ending, with complete liberalization, January 1, 2019.⁵

Gearing up to meet these changes, Mexican President Vicente Fox surprised many industry insiders by accelerating the deregulation process, eliminating trade restrictions for a large class of used vehicles beginning August 22, 2005. Under the new rules, 10–15-year-old vehicles produced in the United States or Canada could be imported to Mexico virtually tax free. Trade restrictions remained in place for vehicles less than 10 years old and more than 15 years old. The decision to allow this particular set of vintages was a political compromise. While recognizing the potentially large gains from trade, vehicles over 15 years old were perceived to be too high-emitting to warrant importation. At the same time, by continuing to restrict the importation of used vehicles less than 10 years old, the Mexican government

⁵ Our study is germane to a small literature that examines the determinants of trade restrictions for used vehicles. Danilo Pelletiere and Kenneth A. Reinert (2004) find that among 132 countries for which data are available, 74 have some kind of restrictions on used vehicle imports. Using cross-country regressions, Pelletiere and Reinert (2002, 2004) find that the most significant factor determining used automobile protection is the presence of domestic automobile production.

hoped to appease the powerful Mexican Association of Automobile Distributors and other political factions within Mexico with a vested interest in new vehicle sales.⁶

This removal of restrictions marked a substantial change from previous Mexican policies, which allowed used vehicles to be imported only for agricultural use. During the following three years, over 2.5 million used vehicles were exported from the United States to Mexico. This represents a small fraction of the vehicle stock in the United States (232 million in 2005 according to R. L. Polk & Company), but represents a substantial fraction of the vehicle stock in Mexico (22 million in 2005 according to The Mexican National Statistics Institute (INEGI)). The used car import market that has evolved in response to this policy change is highly decentralized, with thousands of car dealers and private citizens bringing vehicles into Mexico.⁷

This pattern of trade was foreshadowed by Steven Berry, Vittorio Grilli, and Florencio López-de-Silanes (1993).

If free trade in used cars is permitted, the relatively poor Mexican consumers would become a major source of demand for used cars from the United States and Canada. This would substantially drive up the price of used cars and lead wealthier consumers (in all countries) to trade in their old cars more frequently. In this case a more complicated trading pattern might emerge, with the increase in North American demand for new cars coming largely from US and Canadian consumers, while a large portion of Mexican demand is satisfied by used cars.

While these changes were occurring in the used-car market, trade policy for new vehicles did not change.⁸ Since 1994, NAFTA has allowed duty-free trade of new vehicles and new vehicle parts within North America as long as certain content restrictions are met. In 2005, the most recent year for which data are available, Mexico exported 506,000 new vehicles to the United States and 49,000 vehicles to Canada.⁹ Since 1994, all new vehicles sold in Mexico must meet US emissions standards.

In March 2008, Mexico's trade policy changed again, when trade restrictions were reinstated for all 11–15-year-old vehicles. Thus, after the change the only used vehicles that could be imported were vehicles that were exactly 10 years old. At the same time, the government increased the tariff on used vehicles entering Mexico from 3 percent to 15 percent. This return to trade restrictions was a political response to pressure from the Mexican Association of Automobile Distributors who pointed to alleged decreased sales of new vehicles and argued vigorously for trade

⁶ Vehicles exceeding 4,500 kilograms (e.g., buses and semi trucks) are not eligible. Diesel vehicles are eligible, but less than one-fifth of 1 percent of all imports during this period were diesel vehicles.

⁷ Although Central America is a large market for used vehicles from the United States, very few of these vehicles were likely re-exported to Central America. Vehicles headed from the United States to Central America can bypass the expense of legalizing the vehicle in Mexico by shipping the vehicle by boat, or by driving through Mexico with a temporary permit.

⁸ In the short-run there is limited scope for producers of new durable goods to respond to competition from used goods. For example, trade in used durable goods may change incentives for producers by altering the market structure. As first articulated by Ronald H. Coase (1972) and more recently analyzed by Susanna Esteban and Matthew Shum (2007), the market for used durable goods limits market power for producers. A trade pattern in which used durable goods are traded from high-income to low-income countries will increase the ability of producers in the high-income country to exercise market power, and decrease the ability of producers in the low-income country to exercise market power.

⁹ See INEGI, *Industria Automotriz en México, 2007*, table 3.3.2, *Volumen de Las Exportaciones de Automóviles y Camiones por Continente y País de Destino*.

restrictions, claiming that the change in policy was needed to, “stop the accelerated conversion of our country into the world’s biggest automotive garbage dump.”¹⁰

It is worth noting that there is much precedent for high-income countries exporting used vehicles to lower-income trading partners. Japan exports vehicles to over 100 different countries, South Korea exports vehicles to Vietnam and Russia, and the United Kingdom exports vehicles to Ireland.¹¹ Another prominent example of a vehicle importing country is Peru, where over 80 percent of the vehicles in circulation were imported as used vehicles from the United States and Japan.¹² Although these accounts suggest that the total volume of international trade in used vehicles is large, we are not aware of any comprehensive measures of global trade. For example, World Trade Organization (2007) tracks “automobile products” but does not distinguish between new and used vehicles.

III. Empirical Analysis: Scale and Composition

In this section, we examine the environmental consequences of used-vehicle trade between the United States and Mexico during the period 2005–2008. Following the existing trade and environment literature, we distinguish between scale and composition effects. Whereas these effects have typically been used to describe production, we recast these mechanisms to describe consumption. In Section IIIA, we focus on scale. The scale effect of trade is the change in pollution due to the overall change in economic activity, or in our case, the total number of vehicles on the road. In Section IIIB, we characterize composition. The composition effect of trade is the change in pollution due to adjustments in the mix of goods. In our case, composition will be assessed by comparing the average emissions of traded vehicles to the average emissions of the stock of vehicles in both countries. In Section IIIC we further refine our characterization of composition, testing for differences in emissions levels at the vehicle-level. Our dataset allows us to identify, at the vehicle level (using VIN numbers), which vehicles were traded. This degree of detail is crucial because, for example, it allows us to test for whether traded vehicles are more likely to have failed emissions testing.

A. Descriptive Evidence on Trade Flows

Central to our analysis is a dataset collected by the Mexican Customs Agency that describes the universe of vehicles that were imported into Mexico between November 2005 and July 2008. These vehicles were legally exported from the

¹⁰ *Associated Press*, “Mexico Bans Imports of Most Used Cars” (March 2, 2008) reports that this policy change has caused a surge in prices for vehicles that are exactly 10 years old. In 2008 dealers in South Texas reported \$500–\$800 premiums for 1998 model vehicles.

¹¹ According to the *Wall Street Journal*, “Driving Change: How Japan’s Second-Hand Cars Make Their Way to Third World” (January 8, 2004), Japan exports one million used vehicles annually to countries all over Asia, Africa, and the Middle East. According to *The Korea Herald*, “Exports of Used Cars Hit Record in 2007” (April 17, 2008), South Korea exported over 220,000 used cars and trucks in 2007. See also *The Irish Times*, “Used Car Imports from UK Hit 50,000 a Year” (July 4, 2007).

¹² See *Centro de Investigación y de Asesoría del Transporte Terrestre del Perú*, “Cuarto Informe de Observación Pública: Externalidades Negativas Generadas por la Importación de Vehículos Usados Sobre la Salud y la Vida de la Población en Perú,” April 2005, for details.

TABLE 1—DESCRIPTIVE STATISTICS

	Vehicles that entered Mexico 2005–2008	Stock of vehicles in the United States in 2005	Stock of vehicles in Mexico in 2008
	(1)	(2)	(3)
Total number of vehicles (millions)	2.45	232.0	24.8
Mean vehicle age (in years)	11.4	8.8	13.7
Vehicle manufacturer (proportion)			
Ford	0.33	0.18	0.22
Chevrolet	0.17	0.17	0.06
Dodge	0.10	0.07	0.03
Nissan	0.07	0.04	0.16
Jeep	0.06	0.02	0.00
Plymouth	0.05	0.01	0.00
Mercury	0.04	0.02	0.01
GMC	0.03	0.03	0.09
Chrysler	0.03	0.02	0.06
Pontiac	0.02	0.04	0.01
Other	0.10	0.40	0.36

Notes: Column 1 describes used vehicles that were imported by Mexico from the United States or Canada between August 2005 and July 2008. These data were collected by the Mexican Customs Agency, a branch of the Mexican Ministry of Finance. For vehicle age in column 1 this is the mean vehicle age when the vehicle enters Mexico.

United States to Mexico and received Mexican license plates; vehicles that entered Mexico temporarily (i.e., with a tourist permit) do not appear in these data.¹³

Table 1 provides descriptive statistics. Column 1 describes the vehicles that entered Mexico between 2005 and 2008. Columns 2 and 3 describe the stock of vehicles in the United States in 2005, and in Mexico in 2008. For the stock in the United States, we obtained data from R. L. Polk & Company that describe the universe of registered vehicles in the United States as of 2005 by manufacturer and vintage. For the stock in Mexico, we filed the equivalent of a Freedom of Information Act request with the Mexican Ministry of Public Safety, and received data that describe the distribution of vehicles in Mexico as of 2008 by manufacturer and vintage.¹⁴

Mean vehicle age differs considerably across columns. Among traded vehicles the average age is 11.4 years. The stock in the United States is newer and the stock in Mexico is older. Interestingly, whereas 10–15-year-old vehicles were eligible for trade, it turns out that 10-, 11-, and 12-year-old vehicles were much more often traded than 13-, 14-, and 15-year-old vehicles.¹⁵ Only vehicles produced in the

¹³ To cross-check these data, we purchased CARFAX vehicle history reports for a random sample of 50 vehicles. All 50 VIN numbers corresponded to actual vehicles that had been registered in the United States. Moreover, the date of the last available record in the CARFAX data corresponded well with the importation dates in the Mexican Customs data. In no case was a record available in the CARFAX data *after* the importation date in the Mexican Customs data, and in 46 of 50 cases the last record in the CARFAX data was within 12 months prior to the importation date.

¹⁴ No comparable data are available for Mexico for 2005; the Mexican Ministry of Public Safety compiled this national database for the first time in 2008. Although vehicle registration is required in all parts of Mexico, registries are maintained at the state level. INEGI compiles total vehicle counts by state and year, but not by vintage or manufacturer. Moreover, since 2006 INEGI has measured vehicle counts by adding vehicle sales to the totals for 2005 rather than through direct measurement of vehicle registries, making these data inappropriate for examining vehicle retirement patterns.

¹⁵ This may reflect the travel and administrative costs associated with importing a vehicle. The Alchian-Allen, or “Shipping the Good Apples Out” theorem points out that fixed transportation costs decrease the relative price of

TABLE 2—TOP TEN MOST TRADED VEHICLE MODELS

Rank	Manufacturer	Model	Vehicles that entered	Stock of vehicles
			Mexico 2005–2008	in the United States in 2005
			(1)	(2)
1	Ford	Explorer (SUV)	0.08	0.02
2	Chevrolet	S-10 (truck)	0.06	0.01
3	Dodge	Caravan (minivan)	0.05	0.01
4	Ford	Ranger (truck)	0.05	0.02
5	Ford	Windstar (minivan)	0.05	0.01
6	Chevrolet	Silverado (truck)	0.04	0.02
7	Ford	F-150 (truck)	0.04	0.03
8	Plymouth	Voyager (minivan)	0.03	0.01
9	Jeep	Cherokee (SUV)	0.03	0.02
10	Ford	Taurus (car)	0.03	0.02

United States and Canada were eligible for trade. This is apparent in Table 1 with Ford, Chevrolet, and Dodge representing 60 percent of all traded vehicles but only 42 percent of the stock in the United States.

Table 2, column 1 describes the top 10 most traded models.¹⁶ For comparison, column 2 reports model shares for the stock of vehicles in the United States in 2005. A striking feature of this list is the prevalence of trucks and other large vehicles. There are several explanations for this pattern. First, this reflects the fact that only US and Canadian-produced vehicles were eligible to be imported. Second, gasoline prices in the United States were high during the period 2005–2008, making these fuel-inefficient vehicles relatively desirable in Mexico where gasoline prices are set by *Petróleos Mexicanos* (PEMEX), the national petroleum company, at less than \$2.50 per gallon.¹⁷ Third, larger vehicles are valued in rural areas in Mexico because they can be used on rough roads.

Figure 1 describes the monthly trade flows of used vehicles into Mexico. The first vertical line indicates the policy change in August 2005 that removed restrictions for 10–15-year-old vehicles. The second vertical line in March 2008 indicates the second policy change when trade restrictions were reinstated for all 11–15 year old vehicles. Trade spikes at the end of 2005, reaching 225,000 vehicles in December 2005. Similar smaller spikes occur at the end of 2006 and 2007. After March 2008 trade continues but at a considerably slower pace.

high-quality goods in importing countries, causing consumption to shift toward these goods. See Armen A. Alchian and William R. Allen (1964) and Thomas E. Borcherding and Eugene Silberberg (1978) for details.

¹⁶ The most commonly traded vehicle model is the Ford Explorer, a vehicle that fell somewhat out of favor with US consumers after a highly-publicized recall of Firestone tires in August 2000 and claims that the large number of tread separations observed with these tires might be related to vehicle design. See Krueger and Alexandre Mas (2004) for details.

¹⁷ According to the Mexican Energy Information System, the average price per gallon of regular unleaded gasoline in Mexico was \$2.11 in 2005, \$2.39 in 2006, \$2.40 in 2007, and \$2.49 in 2008 compared to \$2.31, \$2.62, \$2.84, and \$3.30 for the United States according to the Department of Energy, Energy Information Administration.

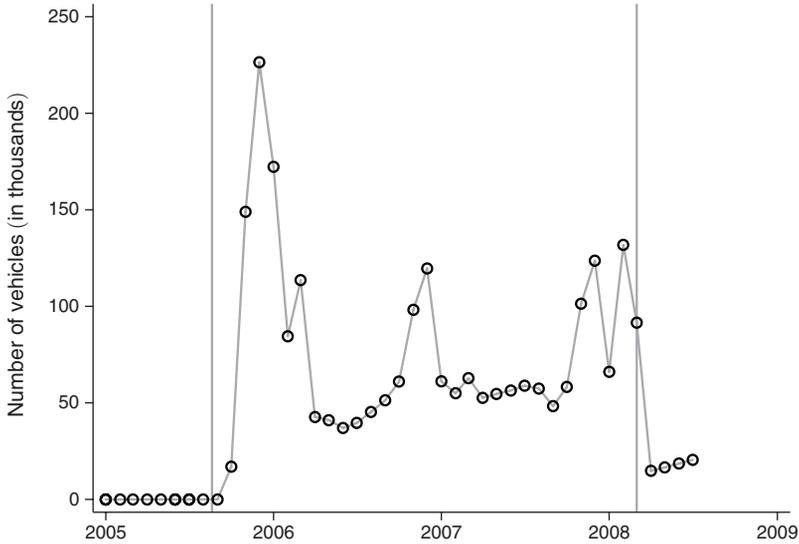


FIGURE 1. MONTHLY TRADE FLOWS OF USED VEHICLES INTO MEXICO

B. Comparison of Traded Vehicles with Vehicle Stocks

Although scale is clearly important, the environmental impact of trade also depends on the characteristics of vehicles that are traded. In this subsection, we compare the emissions characteristics of traded vehicles with the emissions characteristics of the stock of vehicles in the United States and Mexico.

Vehicle level data on emissions and vehicle attributes come from data describing 7.2 million vehicles that were tested in 2005 under California's Smog Check program. We use these records to estimate average emissions levels for vehicles of different manufacturers and vintages. For vehicles which were tested multiple times, we use data on the first test for each vehicle. In Section IIIC, we return to these multiple tests to examine whether traded vehicles are more likely to have failed emissions testing.

Let α_{jt} denote the average emissions level among all vehicles from manufacturer j and vintage t . Vehicles produced in 1976 or before are grouped together, and vehicles produced after 2005 are grouped together, so the set of all vintages, T , includes 1976–2005. We focus on all manufacturers for which there were more than 1 million total registered vehicles in the United States as of 2005. Other vehicle manufacturers are included in an “other” category.¹⁸ Average emissions

¹⁸ Our manufacturers include Acura, BMW, Buick, Cadillac, Chevrolet, Chrysler, Dodge, Ford, GMC, Honda, Hyundai, Infiniti, Isuzu, Jeep, Kia, Lexus, Lincoln, Mazda, Mercedes-Benz, Mercury, Mitsubishi, Nissan/Datsun, Oldsmobile, Plymouth, Pontiac, Saturn, Toyota, Volkswagen, and Volvo. In the United States in 2005, these 29 manufacturers represented 97.5 percent of the vehicle stock.

TABLE 3—COMPARING TRADED VEHICLES TO THE STOCK IN THE UNITED STATES AND MEXICO

	Stock of vehicles in the United States in 2005	Vehicles that entered Mexico 2005–2008	Stock of vehicles in Mexico in 2008	<i>p</i> -value (1) vs. (2)	<i>p</i> -value (2) vs. (3)
	(1)	(2)	(3)	(4)	(5)
Local pollutants					
Hydrocarbons (parts per million)	39.9	44.4	50.7	.00	.00
Carbon monoxide (percent)	0.147	0.153	0.215	.00	.00
Nitrogen oxide (parts per million)	248	309	321	.00	.00
Global pollutants					
Miles per gallon	23.8	23.5	22.3	.00	.00
Vehicle weight (pounds)	3,516	3,708	3,460	.00	.00
Engine size (liters)	3.47	3.70	3.45	.00	.00

Notes: This table reports means of the variables listed in the row headings. Columns 4 and 5 report *p*-values from tests that the means are equal. See Section IVB for details.

are calculated by multiplying emissions factors by the proportion of vehicles of each type,

$$\text{Average Emissions of Traded Vehicles} = \sum_{j \in J, t \in T} \alpha_{jt} \mu_{jt}^T,$$

$$\text{Average Vehicle Emissions in US} = \sum_{j \in J, t \in T} \alpha_{jt} \mu_{jt}^{US},$$

$$\text{Average Vehicle Emissions in Mexico} = \sum_{j \in J, t \in T} \alpha_{jt} \mu_{jt}^M,$$

where μ_{jt}^T denotes the proportion of traded vehicles of each manufacturer and vintage, and μ_{jt}^{US} and μ_{jt}^M denote the proportion of the vehicle fleet of each manufacturer and vintage in the United States and Mexico.

Table 3 presents mean emission levels for hydrocarbons, carbon monoxide, and nitrogen oxide. Compared to the stock of vehicles in the United States, traded vehicles emit higher levels of all three local pollutants. The differences are substantial, ranging from 4 percent for carbon monoxide to 22 percent for nitrogen oxide. Compared to the stock of vehicles in Mexico, traded vehicles emit lower levels of all three local pollutants. Again the differences are substantial, ranging from 4 percent for nitrogen oxide to 34 percent for carbon monoxide. Columns 4 and 5 report *p*-values from tests that the means are equal. In all six cases, the differences are strongly statistically significant.

Table 3 also reports results for miles per gallon (MPG), vehicle weight, and engine size.¹⁹ These measures directly or indirectly measure vehicle fuel efficiency

¹⁹ We imputed MPG for each vehicle using vintage, vehicle weight, and engine size using data from the Department of Transportation, National Highway Traffic Safety Administration (NHTSA). For each vintage 1978–2005, we estimated a separate regression of MPG on weight and engine size, then used the estimated coefficients to predict MPG for each vehicle.

and, therefore, carbon dioxide emissions which are proportional to total gasoline consumption. Traded vehicles are heavier and have larger engines on average than the stock of vehicles in both countries. However, the differences are relatively small in magnitude. Whereas local emissions vary across columns by as much as 20–30 percent, the differences in MPG vary by less than 5 percent.

C. Exported Vehicles Are High Emitting

The previous subsection illustrates that the vehicles exported from the United States to Mexico were higher-emitting on average than the stock of vehicles in the United States and lower-emitting than the stock in Mexico. Our data, however, allow us to refine the analysis further. For each vehicle that was emissions tested in California in 2005, we know the VIN. By merging these records with the customs records of traded vehicles, we were able to identify the subset of vehicles that were subsequently exported to Mexico.²⁰

In this section, we test hypotheses concerning differential emission levels between vehicles that were exported to Mexico and vehicles that were not. In particular, we run regressions controlling for vintage, manufacturer, and model fixed effects,

$$y_i = \beta_0 + \beta_1[\text{Exported to Mexico}]_i + \delta_i + \omega_{jt} + \sigma_{mt} + \varepsilon_i.$$

We estimate a variety of specifications using as the dependent variable the same measures of emissions and vehicle characteristics used in the previous subsection. In all specifications, the coefficient of interest β_1 corresponds to an indicator variable for whether the vehicle was subsequently exported to Mexico. We report results from specifications that control for vintage indicators, δ_i , as well as specifications that control for manufacturer/vintage interactions, ω_{jt} , and even model/vintage interactions, σ_{mt} . In this fully interacted specification β_1 describes how the dependent variable differs compared to other vehicles of the same model and vintage.

Table 4 reports coefficients and standard errors from 28 separate least squares regressions. The sample used in all specifications is the 7.2 million vehicles that were tested in 2005 under California's Smog Check program. First examining the estimates for local pollutants, across specifications we find evidence that the vehicles exported to Mexico have higher emissions levels. Column 1 reports results without controls. Compared to the stock of vehicles in California in 2005, traded vehicles have significantly higher levels of hydrocarbon and nitrogen oxide emissions. Columns 2–4 add vintage fixed effects, manufacturer/vintage

²⁰ Out of 7.2 million total vehicles in the California Smog Check data, 143,222 vehicles were subsequently exported between 2005 and 2008. This represents only 5.8 percent of the vehicles exported from the United States to Mexico, while nearly 15 percent of vehicles registered in the United States are from California. This would seem low given the proximity to Mexico. However, it is important to bear in mind that emissions testing in California is required only every other year. Moreover, 24 out of 58 counties in California do not require emissions testing, and an additional six counties require emissions testing only within certain zip codes. Finally, there may be some vehicles that were intended to be exported and thus not emissions tested in 2005.

TABLE 4—COMPARING TRADED VEHICLES TO THE STOCK IN CALIFORNIA

	No controls	With vintage fixed effects	With manufacturer vintage interactions	With model vintage interactions	With model vintage interactions and quartic in mileage
	(1)	(2)	(3)	(4)	(5)
Local pollutants					
Hydrocarbons (in logs)	0.132	0.089	0.102	0.081	0.039
[mean = 3.27]	(0.052)	(0.036)	(0.014)	(0.005)	(0.005)
Carbon monoxide (in logs)	0.044	0.109	0.088	0.072	0.030
[mean = -2.41]	(0.058)	(0.032)	(0.025)	(0.008)	(0.008)
Nitrogen oxide (in logs)	0.211	0.143	0.085	0.094	0.036
[mean = 4.95]	(0.051)	(0.028)	(0.022)	(0.011)	(0.009)
Miles on odometer (1,000s)	20.6	10.8	11.4	9.8	—
[mean = 113.3]	(2.62)	(2.21)	(1.16)	(0.44)	
Global pollutants					
Miles per gallon	-1.24	-1.51	-0.26	—	—
[mean = 24.9]	(0.301)	(0.281)	(0.218)		
Vehicle weight (pounds)	253.8	222.9	50.8	—	—
[mean = 3,458]	(44.4)	(41.2)	(32.5)		
Engine size (liters)	0.31	0.38	-0.06	—	—
[mean = 3.22]	(0.083)	(0.079)	(0.057)		

Notes: This table reports coefficients corresponding to 1(*Exported to Mexico*) from 28 separate least squares regressions. The row headings list the dependent variable used in each regression. The data used for these regressions is set of all vehicles that were tested in 2005 under California's Smog Check program, 7.2 million total vehicles. Of these, 143,000 were subsequently exported to Mexico between 2005 and 2008. Standard errors (in parentheses) are robust to heteroskedasticity and arbitrary correlation within vehicle models.

interactions, and model/vintage interactions.²¹ The point estimates tend to decrease as these additional controls are added, but all nine estimates are positive and statistically significant at the 1 percent level. The positive coefficient estimates remain in column 5 after controlling for a quartic in mileage, indicating higher emissions for exported vehicles even within vehicles of the same vintage, manufacturer, model, and mileage. We also examine odometer readings as a separate dependent variable. Controlling for model/vintage interactions, vehicles exported to Mexico have on average almost 10,000 more miles than other vehicles.

The table also reports coefficients corresponding to MPG, vehicle weight, and engine size. Whether or not one controls for vintage, traded vehicles are less fuel efficient, heavier, and with larger engines than the stock of vehicles in California. This is consistent with the pattern observed in Table 2 that minivans, SUVs, and trucks are heavily represented among traded vehicles. However, after controlling for manufacturer/vintage the coefficients become much smaller. These smaller coefficients likely reflect the fact that only US and Canadian-produced

²¹ Model is measured using the 5th and 6th digits of the VIN number as assigned by each individual manufacturer. This classification not only distinguishes between, for example, the Ford Windstar (a minivan) and the Ford F-Series (a truck), but also distinguishes, for example, between the Ford F-150 and the Ford F-250.

TABLE 5—ARE TRADED VEHICLES MORE LIKELY TO BE SUPER-EMITTERS?

	California sample with model vintage interactions
1(Failed emissions test once) [mean = 0.1483]	0.0267 (0.0019)
1(Failed emissions test twice) [mean = 0.0310]	0.0104 (0.0009)
1(Failed emissions test three or more times) [mean = 0.0085]	0.0023 (0.0003)
1(Gross polluter once) [mean = 0.0357]	0.0050 (0.0005)
1(Gross polluter twice) [mean = 0.0059]	0.0015 (0.0002)
1(Gross polluter three or more times) [mean = 0.0013]	0.0003 (0.0001)

Notes: This table reports coefficients corresponding to 1(*Exported to Mexico*) from 6 separate least squares regressions. The row headings list the dependent variable used in each regression. The data used for these regressions is set of all vehicles that were tested in 2005 under California's Smog Check program, 7.2 million total vehicles. Standard errors (in parentheses) are robust to heteroskedasticity and arbitrary correlation within vehicle models. A "gross polluter" is a vehicle that exceeds twice the allowable emissions for at least one pollutant.

vehicles were eligible to be imported. We do not report coefficients controlling for model/vintage because there is essentially no variation within vehicle model in these characteristics.

Table 5 presents coefficient estimates from additional regressions using as the dependent variable whether or not the vehicle has failed emissions testing. Vehicles that emit extremely high levels of pollutants are particularly important for the environment because it has been shown that these vehicles contribute a large proportion of total emissions. In these regressions, the dependent variable is an indicator variable for whether the vehicle failed emissions once, twice, and three or more times, as well as whether the vehicle was a "gross polluter" once, twice, and three or more times. According to California law, a "gross polluter" is a vehicle that exceeds twice the allowable emissions for at least one pollutant. The results indicate that exported vehicles are significantly more likely to be super-emitters. For example, after controlling for model/vintage fixed effects, exported vehicles are 27 percent more likely to have failed emissions testing three times.

Overall the results of these vehicle-level regressions imply that exports are significantly "brownier" than the average stock in California. This effect remains after controlling for a rich set of control variables. We have performed similar analyses using emissions testing data from the state of Illinois and the pattern is the same. Similar data are not available for Texas or most other states so we are unable to make strong statements generalizing our results beyond California and Illinois. Nonetheless, these results provide suggestive evidence of sorting with regard to vehicle quality. This pattern is consistent with the models of trade in used durable goods described in Section I, in which low-quality durable goods are disproportionately valuable in low-income countries.

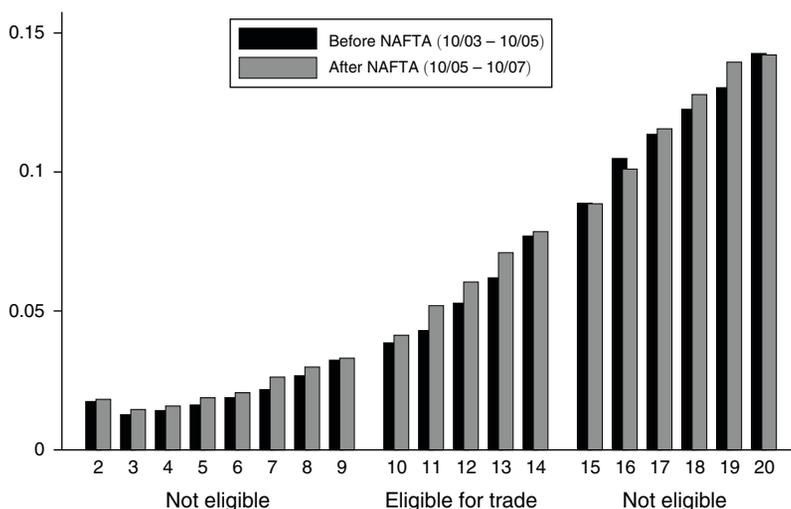


FIGURE 2. EXIT RATES BY VEHICLE AGE IN THE UNITED STATES

Source: R. L. Polk & Company.

IV. The Behavioral Response: Vehicle Retirement and New Vehicle Sales

A. Vehicle Retirement in the United States

Mexico imported 2.5 million used vehicles between 2005 and 2008. Does this imply that the stock of vehicles in the United States has decreased by the same amount? In order to address this question, we turn to data from R. L. Polk & Company that describe the number of registered vehicles in the United States by vintage and year. We test for a change in the number of registered vehicles after NAFTA among vehicles 10–15 years old. Adjustments in retirement behavior are important because they may mitigate the direct environmental impact of trade.

Figure 2 plots vehicle exit rates by age in the United States before and after NAFTA. Annual exit rates increase with vehicle age, from less than 2 percent for vehicles that are 4–5 years old to more than 10 percent for vehicles over 15 years old. The figure reveals modest increases in exit rates after NAFTA for vehicles that are 10–15 years old. However, there also appears to be an increase for many other ages. This across-the-board increase is not predicted by the models described in Section I. If anything, one would have expected decreases in vehicle retirement for non-eligible vehicles as drivers in the United States substitute to these vehicles. This suggests that the general increase in the after NAFTA period may be due to other factors. We now turn to a regression framework in order to control explicitly for year fixed effects.

Table 6 reports estimated coefficients and standard errors from two separate regressions. In each regression the dependent variable is the exit rate (in percent). Column 1 reports that, controlling for vehicle age after NAFTA, vehicles that are 10–15 years old exhibit higher exit rates. For example, after NAFTA, 11-year-old

TABLE 6—THE EFFECT OF NAFTA ON VEHICLE EXIT RATES IN THE UNITED STATES

	(1)	(2)
(After NAFTA)* (10 years old)	0.28 (0.39)	0.05 (0.17)
(After NAFTA)* (11 years old)	0.90 (0.47)	0.67 (0.17)
(After NAFTA)* (12 years old)	0.76 (0.42)	0.54 (0.19)
(After NAFTA)* (13 years old)	0.90 (0.61)	0.68 (0.25)
(After NAFTA)* (14 years old)	0.16 (0.81)	-0.07 (0.42)
(After NAFTA)* (15 years old)	-0.02 (0.78)	-0.25 (0.40)
Vehicle age indicators	Yes	Yes
Calendar year indicators	No	Yes
Observations	76	76
R ²	0.98	0.99

Notes: This table reports estimated coefficients from two separate regressions, each estimated using least squares. There are four calendar years (2004, 2005, 2006, and 2007) and 19 vehicle ages (2–20) for 76 total observations. In each regression the dependent variable is the exit rate (in percent) between the current and previous year. The mean exit rate in the sample is 6.2 percent. Standard errors (in parentheses) are robust to heteroskedasticity.

vehicles are 0.9 percentage points more likely to exit the R.L. Polk data annually. The increases range from essentially zero (for 15-year-old vehicles) to above 0.75 percentage points for 11-, 12-, and 13-year-old vehicles. As a point of comparison, the mean exit rate in the sample is 6.1 percent. Column 2 adds calendar year fixed effects. The point estimates fall, consistent with the overall increase in exit rates post-NAFTA observed in Figure 2. At the same time, the standard errors become considerably smaller, with three out of the six coefficients statistically significant at the 1 percent level.

The changes in exit rates tend to be in the expected direction. However, the implied number of total exits is considerably smaller than the 1 million vehicles per year that were exported annually to Mexico during this period. The coefficients in column 2 imply only 105,000 additional exits annually among 10–15-year-old vehicles. The null that the number of additional exits exceeds 250,000 can be rejected at the 2 percent significance level. The results indicate, therefore, that less than one in four traded vehicles represent a net exit from the stock in the United States. This suggests that most of the vehicles that were exported to Mexico were either vehicles that would have been retired otherwise, or vehicles that were already retired.²²

²² Michael Wilson, Executive Vice President of the Automotive Recyclers Association, confirmed that since 2005 fewer vehicles are reaching scrapyards in the United States for recycling. There has been a “significant impact” on their members with the largest effects on facilities in the Southwest. With over 8,000 vehicle recycling facilities in the United States, it is difficult to obtain comprehensive information about the decrease in volume of vehicles processed. We examined and did not find evidence of increases in scrap steel prices from the Bureau of

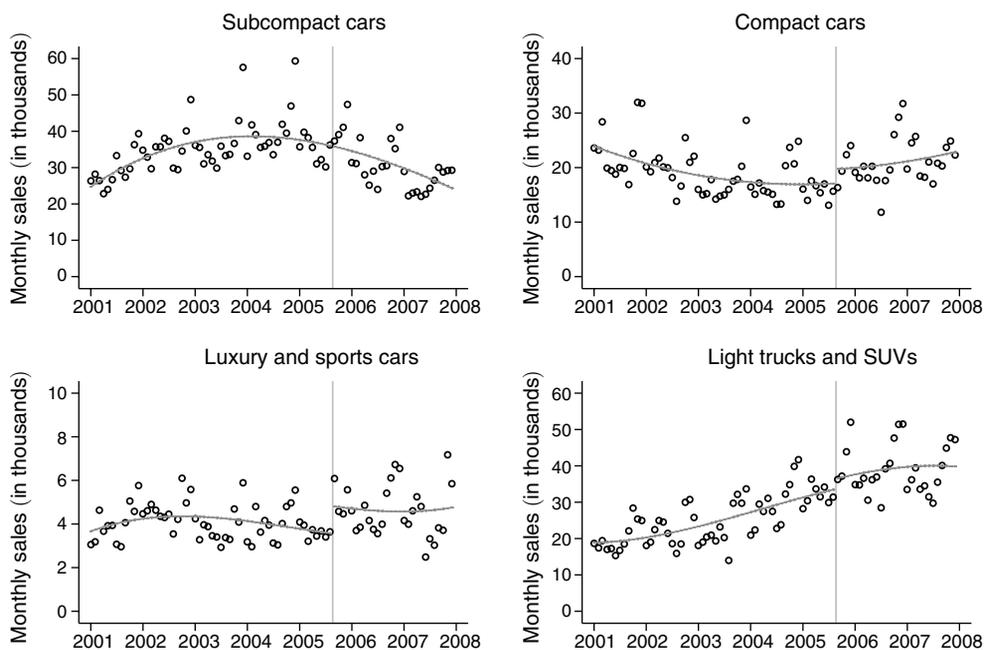


FIGURE 3. MONTHLY SALES OF NEW VEHICLES IN MEXICO BY VEHICLE CATEGORY

Source: INEGI, *La Industria Automotriz en México, 2002–2008*.

The fact that NAFTA appears to have had little effect on the number of registered vehicles in the United States is perhaps not surprising. The stock of used vehicles in the United States is large, so increased demand for used vehicles is unlikely to have raised used vehicle prices more than a few hundred dollars per vehicle. Moreover, capital costs are only one part of the costs of operating a vehicle (e.g., maintenance, insurance, gasoline, etc.), and in the United States the elasticity of vehicle ownership with respect to these costs is likely very low. In short, it is hard to imagine trade leading a large number of households in the United States to reduce the number of vehicles they own.

These results highlight the immense size of the used vehicle market in the United States. During the period 2003–2007, 5.9 million vehicles exited vehicle registries annually in the United States—2.1 million of those vehicles were 10–15 years old. This provides an enormous potential stock of vehicles for export. A relatively small fraction of these castoffs can represent a large number of vehicles for a smaller country like Mexico.

B. Vehicle Sales in Mexico

After trade restrictions were eliminated, millions of relatively high-quality used vehicles were exported from the United States to Mexico. Did the increased

Labor Statistics, but this is perhaps not surprising because, according to the Steel Recycling Institute, vehicles represent only 14 million tons of recycled steel annually compared to a market of 83 million tons.

TABLE 7—THE EFFECT OF NAFTA ON NEW VEHICLE SALES IN MEXICO

Total vehicles (1)	Subcompact cars (2)	Compact cars (3)	Luxury and sports cars (4)	Trucks and SUVs (5)
-0.015 (0.033)	-0.045 (0.055)	0.053 (0.064)	0.197 (0.082)	-0.054 (0.054)

Notes: This table reports estimates that correspond to 5 separate least squares regressions. In column 1 the dependent variable is total monthly sales of new vehicles in Mexico (in logs). In columns 2–5 the dependent variable is monthly sales of new vehicles (in logs) for individual vehicle segments. The table reports coefficients and standard errors for an indicator variable for the period after trade restrictions were eliminated in August 2005. The data come from from INEGI, *La Industria Automotriz en México, 2002–2008* and include January 2001–December 2007, 84 total observations. Specifications include a cubic polynomial time trend, month-of-the-year indicators, and the growth rate of GDP. In accordance with findings from standard diagnostic tests of serial correlation, reported standard errors are estimated following Whitney K. Newey and Kenneth D. West (1987) with a 1-month lag.

availability of used vehicles cause vehicle buyers in Mexico to substitute away from new vehicles? The Mexican Association of Automobile Distributors has been a vocal opponent to liberalization, and claims that NAFTA has reduced sales considerably.²³ In this subsection, we examine new vehicle sales in Mexico. The impact of trade on new vehicle sales is important because changes in new vehicle sales may offset the direct environmental impact of trade. If vehicle sales have indeed increased, this would imply fewer vehicles on the road and a more modest overall impact on carbon emissions.

Figure 3 plots monthly sales of new vehicles in Mexico by vehicle category during the period January 2001–December 2007, as well as fitted cubic polynomials in time with intercepts at August 2005. Based on these plots, it is difficult to make strong statements about the impact of trade deregulation on sales. The one vehicle segment where there appears to possibly be a decrease in sales is subcompact cars. However, the negative trend in subcompact sales appears to begin prior to trade deregulation. In addition, the decrease seems to be somewhat offset by mild increases in the other vehicle segments.

Table 7 reports coefficients and standard errors from an analogous regression analysis. The dependent variable is indicated in the column headings. In column 1, the dependent variable is monthly sales (in logs) of total vehicles. Columns 2–6 report results for individual vehicle segments. The table reports coefficients and standard errors for an indicator variable for the period after trade restrictions were eliminated in August 2005. Controls include month-of-the-year indicator variables and cubic polynomial time trends. Based on our graphical analysis, we determined that the third-order polynomial was the most parsimonious specification that captured the shape of the underlying data. We have also examined second and fourth-order polynomials and the results are similar. To control for aggregate changes in demand, we also include the growth rate of GDP (available quarterly) from the Mexican National Statistics Institute, National System of Accounts.

²³ Recent publications from the Mexican Association of Automobile Distributors describe trade in used vehicles as an environmental and commercial threat. See, e.g., *El Comercio de Autos Usados de Gran Antigüedad: Un Reto a la Calidad del Aire en las Cuencas Atmosféricas de la Frontera de EUA y México*, August 2007. Our study is the first full-scale attempt to measure empirically the impact of NAFTA on new vehicle sales.

The estimates in Table 7 provide no evidence of a decrease in new vehicle sales. For total vehicles, the point estimate is -1.5 percent, but is not statistically significant. Point estimates for subcompact cars and trucks are also negative, but again not statistically significant. The null hypothesis of a 20 percent drop in vehicle sales can be rejected at the 1 percent level in all columns. In evaluating these results, it is important to keep in mind the overall size of the new vehicle market in Mexico. From 2001 to 2004, total new vehicle sales in Mexico averaged 83,000 vehicles per month, about one million vehicles per year. This is similar to the volume of used vehicles imported annually during the period 2005–2008, so to completely offset the influx of used vehicles one would need to see a decrease in sales close to 100 percent.

Overall, these results suggest that the 10–15-year-old used vehicles may not have been an attractive alternative for most buyers of new vehicles. Still, it is important not to overstate these results. The regression-discontinuity approach adopted here is appropriate only to the extent that one would have expected a discontinuous change in new vehicle purchase behavior when trade restrictions were eliminated. Although the policy change was unanticipated, one might have expected a more gradual response between 2005 and 2008 as potential buyers learned about the availability and characteristics of used vehicles from the United States. Moreover, broader comparisons of, for example, 2001–2004 versus 2005–2008 are difficult because it is not clear that the earlier period is a credible counterfactual for new vehicle sales in the absence of trade. Just as there appears to be an increase in sales of luxury/sports cars after 2005, there may be other time-varying factors that have affected new vehicle sales during this period, so it is very difficult to predict what sales would have been in the absence of trade.

V. Total Vehicle Emissions

Up until this point, we have examined the flow of used vehicles, compared these vehicles to the stock of vehicles in the United States and Mexico, and considered the impact of trade on vehicle retirement in the United States and new vehicle purchases in Mexico. These results provide much of the information required to calculate the change in total vehicle emissions. Nonetheless, these estimates require us to make a number of additional assumptions. Although where possible, we explore the robustness of these estimates by presenting results from alternative specifications, these results should be interpreted with caution.

We consider what happens to both annual and lifetime emissions. Annual emissions are the product of the number of vehicles, number of miles driven annually, and emissions per mile. Thus the change in total annual emissions is equal to:

$$\sum_{a=10}^{15} [(V_{MEX,a})(VMT_{MEX,a})(E) + (V_{US,a})(VMT_{US,a})(E)],$$

where $V_{i,a}$ is the net change in the number of vehicles in country i with vehicle age a . Consistent with the results in Section IVB, for Mexico we assume that there was no change in new vehicle purchases so that the total change in the number of vehicles

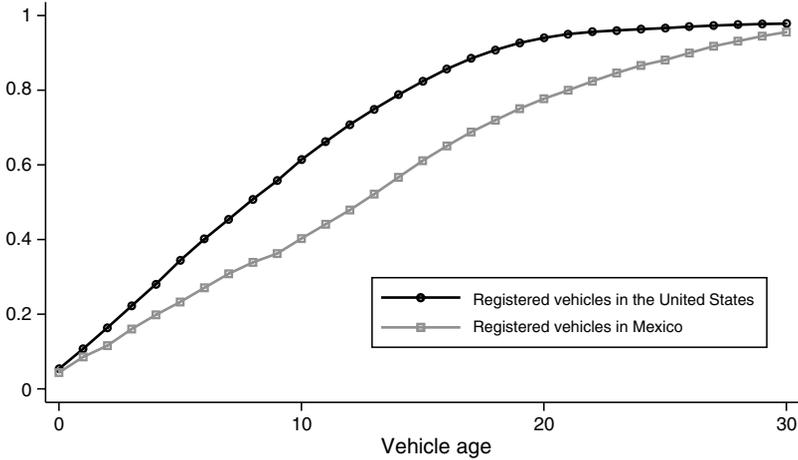


FIGURE 4. THE CUMULATIVE DISTRIBUTION OF VEHICLE AGE BY COUNTRY

Sources: R. L. Polk & Company and Mexican Ministry of Public Safety.

$\sum_{10}^{15} (V_{MEX,a})$ is 2.5 million. The calculation takes into account the substantial increase in the number of vehicles in Mexico, but also allows for the possibility of a mild decrease in the vehicle stock in the United States. Consistent with the results in Section IVA, the baseline specification assumes that 1 in 10 traded vehicles represents a net exit from the US stock. VMT denotes annual vehicle miles traveled and E is emissions per mile.

The change in lifetime emissions is then equal to:

$$\sum_{y=2008}^{2037} \sum_{a=10}^{45} [(V_{MEX,y,a})(VMT_{MEX,a})(E) + (V_{US,y,a})(VMT_{US,a})(E)],$$

where the summation is over both vehicle age a and calendar year y . Whereas the change in annual emissions above is calculated for the calendar year 2008, the change in lifetime emissions is calculated for a thirty-year period covering 2008–2037.

Lifetime emissions depend critically on retirement rates. We calculate the number of vehicles $V_{i,y,a}$ using vehicle retirement rates inferred from the cross-sectional age distribution of vehicles following S. Lu (2006). Figure 4 plots the cumulative distribution of vehicle age in the United States and Mexico. In Mexico, used vehicles are relatively expensive and vehicle repairs are relatively inexpensive, so vehicle owners tend to hold on to vehicles longer. In the United States, used vehicles are relatively inexpensive and vehicle repairs are relatively expensive, so when faced with repair costs vehicle owners tend to replace rather than repair. In calculating $V_{i,y,a}$ we allow retirement rates to vary both by country and vehicle age. The implied retirement rates increase with vehicle age in both countries, but tend to be considerably higher overall in Mexico. Overall, the implied mean annual retirement rate for 10–30-year-old vehicles is 12.2 percent in the United States, compared to only 3.8 percent in Mexico. Another key component of these calculations is vehicle miles

TABLE 8—CHANGE IN TOTAL EMISSIONS

	Baseline assumptions	Alternative specifications		
	(1)	Mexican vehicle retirement rate doubles (2)	Vehicle exits in the United States tripled (3)	Mexican drivers substituting away from minibuses (4)
<i>Panel A. Annual emissions</i>				
Carbon dioxide (millions of tons)	5.6	5.6	3.4	2.9
Hydrocarbons (thousands of tons)	3.4	3.4	2.1	1.8
Carbon monoxide (thousands of tons)	41.3	41.3	25.1	21.4
Nitrogen oxide (thousands of tons)	7.9	7.9	4.8	4.1
<i>Panel B. Lifetime emissions</i>				
Carbon dioxide (millions of tons)	83.9	72.4	68.2	47.2
Hydrocarbons (thousands of tons)	50.9	44.0	41.4	28.7
Carbon monoxide (thousands of tons)	618.7	533.9	502.9	348.1
Nitrogen oxide (thousands of tons)	118.9	102.6	96.7	66.9

traveled (VMT). For the United States, we use average VMT by vehicle age from Lu (2006, table 5). For Mexico, no similar data are available, so we assume that VMT by vehicle age is proportional to VMT by vehicle age for the United States, scaled to match the average fleet-wide VMT for Mexico.²⁴

Table 8 reports the results. In the baseline specification, annual carbon dioxide emissions increase by 5.6 million tons annually, and lifetime emissions increase by 83.9 million tons. So while trade lowers emissions in the United States, the decrease is too small to offset the increase in emissions in Mexico. The increase is highly persistent because of the low retirement rates in Mexico. Using \$35 per ton of carbon (\$9.9 per ton of carbon dioxide) and a 1.5 percent annual discount rate following William D. Nordhaus (2007), this implies social external costs of \$55 million and \$760 million, respectively.

Table 8 also reports results for local pollutants. The increases in local pollutants are proportional to the results for carbon dioxide, but imply far fewer tons of total emissions.²⁵ Nonetheless, there is reason to believe that the social cost from

²⁴ In the United States in 2006 the average annual vehicle miles traveled (VMT) is 12,400. U.S. Department of Transportation, Federal Highway Administration, "Highway Statistics 2006," Section V: Roadway Extent, Characteristics, and Performance, Table VM-1. No analogous survey-based statistic is available for Mexico. However, annual gasoline consumption indicates that vehicles tend to be used less intensively. Gasoline consumption in Mexico in 2007 totaled 8.6 billion gallons (SIE 2008). Using average miles per gallon from Table 3, this implies that the average vehicle in Mexico travels 6,100 miles annually. Vehicles are used less intensively in Mexico for many reasons including lower income levels, lower quality roads and highways, and differences in commuting patterns.

²⁵ We calculated emissions factors for hydrocarbons, carbon monoxide, and nitrogen oxide using our data with conversion formulas from Donald H. Stedman, "FEAT Equations for CO, HC, and NO," available online at <http://www.feat.biochem.du.edu/assets/reports/ftmath.pdf>.

these increases could be large. For example, Mexico Air Quality Management Team (2002) finds that the annual benefits of a 10 percent reduction in ozone and particulates in Mexico City would be approximately \$882 million (in 2006 US dollars). A more comprehensive analysis of the social costs of trade in used vehicles would track vehicles after they enter Mexico, model the relationship between emissions and ambient pollution levels, and calculate the social costs of the resulting increases.²⁶

Table 8 also reports results for three alternative specifications. The estimates in column 2 adopt Mexican vehicle retirement rates that are twice the rates used in the baseline specification. This may be important because the influx of relatively inexpensive used vehicles from the United States may increase vehicle retirement rates. Under this alternative specification, lifetime emissions are somewhat lower, but the net effect is still large and positive. The estimates in column 3 allow for a larger decrease in the US stock. Whereas the baseline specification assumes that only 1 in 10 traded vehicles represents a true exit from the US stock, these results use 3 in 10, consistent with the very high end of the confidence interval estimated in Section IVA. Under this assumption both annual and lifetime emissions are lower, but still large and positive. Finally, column 4 reports results that take into account that Mexican drivers may be substituting away from other forms of transportation that generate emissions. The baseline specification implicitly assumes that, prior to driving an imported used vehicle, Mexicans were generating no emissions from transportation. For households substituting from high-occupancy public transportation, this is a reasonably accurate approximation. However, for households substituting away from low-occupancy public transportation, or from shared private vehicles, there will be an offsetting decrease in vehicle emissions. In particular, we assume that prior to driving an imported vehicle, Mexican drivers were riding in a minibus with average occupancy of eight riders (compared to 1.6 for private vehicles) and emissions twice that for private vehicles.²⁷ Emissions are lower in this specification, but again still large and positive.

VI. Conclusion

Wealthy nations demand a range of high-quality transportation equipment (cars, trucks, trains, buses, boats, and planes), as well as residential durable goods (air conditioners, clothes washers), commercial durables (computers, lighting, heating and cooling equipment) and industrial durables (power generating equipment, metalworking equipment, construction machinery). These durable goods depreciate in quality over time. Poorer nations want to purchase similar durable goods, but due to operating cost differences and income effects, desire lower quality. From a societal perspective, there are gains to trade from shipping used durable goods from rich countries to poorer countries.

In this paper, we argued that this pattern has important implications for the environment. As we discuss in the paper, the effect of trade on emissions depends on the

²⁶ In such an analysis, the magnitude of social costs would depend not only on the level of emissions, but also on the location of emissions. One of the important themes in a recent literature in the atmospheric sciences is that marginal damages from emissions can vary dramatically across locations. See, e.g., Denise L. Mauzerall et al. (2005).

²⁷ Average occupancy and fuel economy for minibuses come from International Association of Public Transport, "Millenium Cities Database for Sustainable Transport" (2007).

relative magnitude of scale and composition effects. Trade provides rich countries with an outlet for older durable goods. Because older durables are typically high-emitting, this tends to decrease average and total emissions in rich countries. In poor countries, trade increases the number of durable goods, but may also improve the quality of the stock. Whether or not this change in composition is large enough to offset the scale effect, depends on the characteristics of the initial stock of durable goods and other factors.

Whereas several theoretical contributions have recognized the role of consumption-based pollution, the deregulation of the market for used cars and trucks following NAFTA provides a valuable opportunity to empirically assess the magnitude of these different effects. We find that scale effects are immediate and large in magnitude, with millions of vehicles exported from the United States to Mexico during the first years of trade. Composition effects are also large. For local pollutants, we find that traded vehicles have significantly higher emissions per mile than the stock in the United States, and significantly lower emissions per mile than the stock in Mexico. Overall, however, the evidence suggests that trade has increased total lifetime emissions, primarily because of low vehicle retirement rates in Mexico.

The broader conclusion of our paper is that policymakers, in conducting economic analysis of environmental policies, ought to take careful account of the implications of their policies for trade in used durables. This is particularly important for regional and global pollutants, where domestic policies designed to reduce emissions can be easily undermined by emissions increases abroad. As a result, unilateral policies aimed at reducing emissions may not achieve aggregate gains when durable goods can be traded. For example, policies that increase the cost of gasoline in the United States will increase exports of used vehicles, leading to increased emissions in importing countries. In contrast, increasing fuel economy standards for new vehicles, or offering “cash for clunkers” (Alan S. Blinder 2008), increases the price of used vehicles in the United States, decreasing trade.²⁸ Thus, the broader conclusion of our analysis is that the composition of trade can change sharply as US policy incentives change.

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²⁸ As articulated by Howard K. Gruenspecht (1982), new vehicle regulations such as fuel economy standards increase the cost of new vehicles, causing households to delay new car purchases. This would increase demand for used cars in the United States, bidding up the price, and leading fewer used cars to be shipped to Mexico.

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