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**International Trade in Used Durable Goods:
The Environmental Consequences of NAFTA**

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Abstract

Previous studies of trade and the environment overwhelmingly focus on how trade affects where goods are produced. However, trade also affects where goods are consumed. In this paper we describe a model of trade with durable goods and non-homothetic preferences. In autarky, low-quality (used) goods are relatively inexpensive in high-income countries and free trade causes these goods to be exported to low-income countries. We then evaluate the environmental consequences of this pattern of trade using evidence from the North American Free Trade Agreement. Since trade restrictions were eliminated for used cars in 2005, over 2.5 million used cars have been exported from the United States to Mexico. 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 trade leads average vehicle emissions to decrease in both countries. Total greenhouse gas emissions increase, primarily because trade gives new life to vehicles that otherwise would have been scrapped.

Key Words: Durable Goods, Non-Homothetic Preferences, NAFTA, Climate Change
JEL: F18, H23, Q54, Q56

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1. Introduction

Policy makers and environmentalists have been concerned that free trade between rich and poor nations encourages dirty factories to locate in the poorer “pollution haven”. The public health issue is that industrial migration will create local pollution hot spots in the poor country and that this will exacerbate environmental justice and equity challenges as ambient air quality improves in the rich importing country and is degraded in the poor exporting country.

Today, as climate change has become the pre-eminent environmental policy issue, there is now a new set of policy concerns revolving around the issue of trade and “carbon leakage”. If a rich nation signs a carbon reduction treaty (i.e some version of the Kyoto Protocol) while its poorer trading partner does not, then shifts in production of carbon intensive goods from the rich country to the poor country would allow the rich country to meet its carbon obligations but the globe’s aggregate emissions would not decline and might rise. Anticipating this issue, policy makers are proposing complex “border adjustments” to reflect the expected carbon content of imports and exports (Orzag 2008).

In both of these trade and the environment policy discussions, the focus has been on how trade affects where goods are produced and the environmental consequences of this trade. But, trade also affects where goods are *consumed*. Trade affects prices and consumer choice sets and thus changes the type and quality of goods that are consumed, potentially with serious implications both for local ambient pollution levels and for aggregate greenhouse gas emissions.

In this paper we use theory and empirical evidence to evaluate the environmental implications of free trade in used durable goods between a rich nation and a poorer trading partner. In our model preferences are non-homothetic such that demand for good quality is increasing in income. In autarky, low-quality (used) goods are relatively inexpensive in high-income countries and free trade causes these goods to be exported to low-income countries. This result is consistent with a widely-recognized

but seldom studied pattern that high-income countries export large quantities of used durable goods to low-income countries.

Both countries enjoy large gains from trade. However, our model also highlights several mechanisms by which trade impacts the environment. These external costs are potentially very important because of the central role of energy-using durable goods in producing local and global emissions. The model implies that the direct effect of trade is to increase the number of used goods in low-income countries and decrease the number of used goods in high-income countries. Trade also affects the composition, or mix of goods that is consumed in each country. How average emissions change in both countries depends on how the environmental characteristics of traded goods compare to the existing stock.

We apply this framework to the deregulation of the North American market for used cars and trucks following the North American Free Trade Agreement (NAFTA). In 2005, Mexico eliminated trade restrictions on all 10-15 year-old vehicles. This represented a dramatic break from the previous policy that prohibited entry for all used vehicles except for certain vehicles used in agriculture. Consistent with the predictions of our model, we document that between 2005 and 2008 over 2.5 million used cars and trucks 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 VIN numbers), which vehicles were traded as a result of trade liberalization. The results show that traded vehicles are higher-emitting than the stock of vehicles in the United States, but lower-emitting than the stock of vehicles in Mexico. As a result, trade has led to a decrease in average emissions in both countries.¹

Total greenhouse gas emissions increase, primarily because trade gives new life to vehicles that otherwise would have been scrapped. Although trade led to no

¹ This is similar to a result from Feenstra and Hanson (1997) that capital flows from North to South can increase the average capital intensity in both countries.

discernible decrease in the number of vehicles in circulation in the United States, it led to a large increase in the number of vehicles in Mexico. Over the long-run this scale effect is exacerbated by differences in vehicle retirement rates between the two countries. As predicted by our model, we document that vehicle retirement rates are substantially lower in Mexico and we show that this can have a large impact on lifetime carbon emissions from vehicles.

Previous studies of trade and the environment have not emphasized the role of durable goods. Grossman and Krueger (1993), Antweiler, Copeland and Taylor (2001), Copeland and Taylor (2003), and Levinson and Taylor (2008) focus on the effect of trade on the location of production. For example, Copeland and Taylor (2003) find that trade concentrates the production of dirty capital-intensive goods in high-income countries where goods are produced more cleanly, potentially leading to lower overall emissions levels. With durable goods, how and where goods are consumed is potentially even more important than how and where they are produced. For example, only 7% of the total lifetime carbon emissions for vehicles come from vehicle materials production and assembly. The remaining 93% of carbon emissions come from fuel usage.²

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.

² These estimates are from Massachusetts Institute of Technology Energy Laboratory (2000) based on a total lifetime driving distance of 300,000 kilometers.

2 The Environmental Consequences of Trade in Used Durable Goods

This section describes a model of trade in used durable goods. In section 2.1, we demonstrate that if demand for good quality is increasing in income then free trade will lead old durable goods to be exported from high-income countries to low-income countries. Section 2.2 shows how trade affects the choice set in each country, and argues that the effect of trade on average quality in each county is ambiguous. Finally in section 2.3, we examine the environmental consequences of this trade pattern. Older goods tend to emit higher levels of local and global pollutants. As a result, trade in used durables may have a large impact on environmental quality in both importing and exporting countries.

2.1 Non-Homothetic Preferences and Gains to Trade

Suppose preferences are non-homothetic such that demand for good quality is increasing in income.³ For constant prices, countries consume an increasing fraction of high-quality (new) goods as income increases. Figure 1b shows that in the relevant case, the income expansion path bends toward new goods and away from old goods.

Figure 1a: Homothetic Preferences

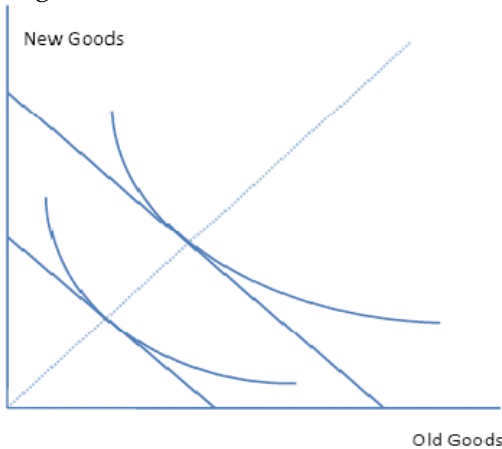


Figure 1b: Non-Homothetic Preferences

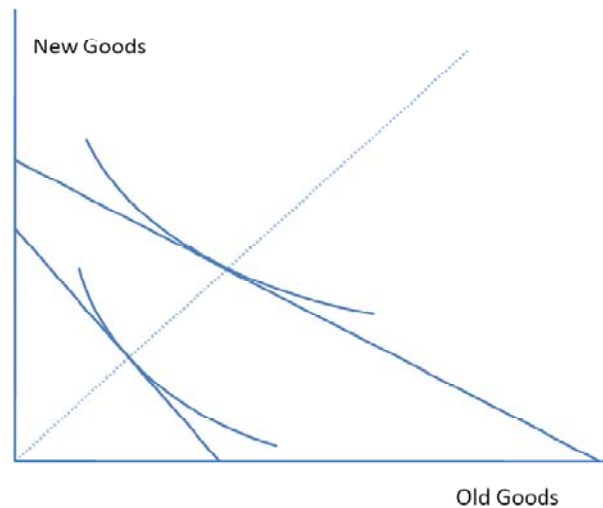


³ Previous studies of trade with non-homothetic preferences have not focused on durable goods. Flam and Helpman (1987), Stokey (1991), and Matsuyama (2000) adopt non-homothetic preferences in the context of the Ricardian trade model, with low-income countries having a comparative advantage in producing low-quality goods. It is difficult to incorporate durable goods into this framework because used goods are not produced directly so a country cannot, e.g., have a comparative advantage in producing used durable goods.

This framework implicitly assumes a vertical model of quality. Durable goods are differentiated products described by a vector of different utility-bearing attributes (Rosen, 1974). We are assuming, however, that these attributes can be mapped into a single measure of quality that is consistent across countries. The vertical model provides an important starting point for describing the trade pattern between rich and poor countries.

Consider the case in which durable goods have a lifespan of two periods. Goods are new in the first period and then old in the second period. If new goods are purchased at a constant rate, there will be a fixed proportion of new and old goods. In autarky old goods will be relatively inexpensive in the high-income country and relatively expensive in the low-income country. This can be seen graphically in figure 2, with the fixed proportion of new and old goods represented by a 45-degree line.

Figure 2: Equilibrium Prices in Autarky



With non-homothetic preferences a country would like to consume relatively more new goods as income increases.⁴ When the proportion of new and old goods is fixed, however, relative prices must change to clear the market. In particular, as income

⁴ Urban economists have noted a “filtering” pattern with respect to long-lived houses. New houses tend to be owned by high-income households but over time neighborhoods with an older housing stock tend to attract lower-income households. See Brueckner and Rosenthal (2008) for details.

increases, old goods must become relatively less expensive in order to maintain equal demand for both quality levels.

When the market is opened to trade in new goods, prices of new goods equalize but the prices of old goods continue to adjust to maintain equal demand for both quality levels in both countries. As durable goods age, they decrease in price more quickly in the high-income country. When, in addition, the market is opened to trade in old goods, old goods are exported from the high-income country to the low-income country. Trade expands until the price of old goods equalizes as in the original figure 1b.

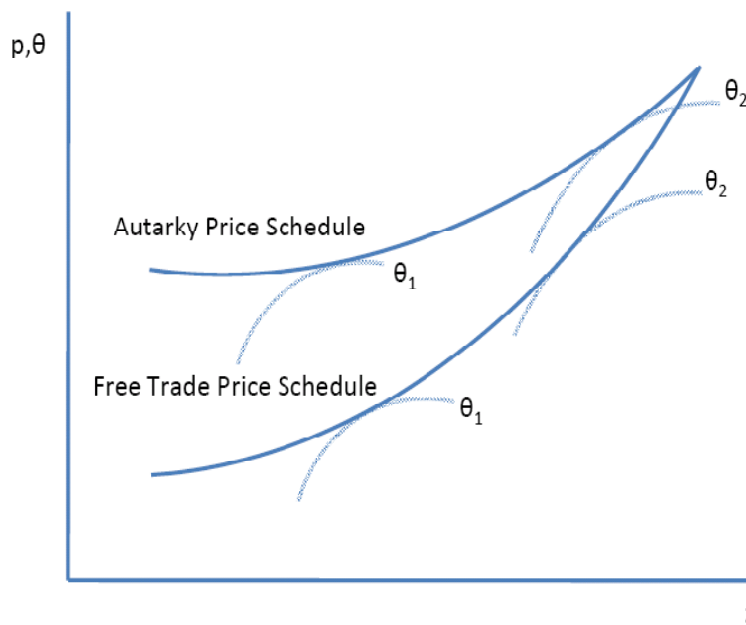
Both countries gain from trade. The high-income country, with its high willingness-to-pay for quality, is able to consume a high proportion of new goods. As these goods depreciate in quality, trade provides an outlet for the high-income country to sell their old goods. The low-income country uses a high proportion of old goods, purchasing them from the high-income country where they are relatively less desirable. Trade continues indefinitely, as goods depreciate in both countries and need to be replaced.

Results are similar allowing for endogenous retirement of old goods. In the baseline model described above, durable goods have a two period lifespan and then are retired exogenously. However, in autarky the low-income country has more incentive than the high-income country to delay retirement. Old goods are relatively expensive in the low-income country, and so when faced with repair costs, agents in the low-income country are less likely to retire the good. In the high-income country, old goods are relatively cheap, and so when faced with repair costs, the agents are more likely to retire the good. This differential retirement mitigates the compositional mismatch across countries, increasing the relative share of old goods in the low-income country and the relative share of new goods in the high-income country.

2.2 Extending the Model to Allow for a Continuum of Quality Levels

With two quality levels (new and old) the effect of trade on quality in each country is unambiguous – raising average quality in the rich country and lowering average quality in the low-income country. However, when one extends the model to allow for a continuum of quality levels, the effect of trade on quality is ambiguous. Consider first what happens in the low-income country. As in Rosen (1974), the relationship between price (p) and quality (z) is determined by equilibrium interactions between buyers and sellers. Figure 3 demonstrates how this hedonic price schedule might shift in response to international trade in used durable goods.

Figure 3: An Illustration of How Trade in Old Goods Shifts the Hedonic Price Schedule in the Low-Income Country



International trade shifts the hedonic price schedule downward, decreasing the equilibrium prices of older, lower-quality goods, with the largest price decreases for very old, very low-quality goods. Buyers locate at different points along the price schedule depending on their willingness-to-pay for quality. Different buyers within the low-income country have different willingness-to-pay for quality because of differences

in income or other factors. Preferences for quality are described by the buyer's bid function, denoted θ , an indifference curve in (p,z) space.

The figure demonstrates how two different types of buyers respond to the shift in the hedonic price schedule. Type 1 buyers substitute to higher-quality goods, walking up the "quality ladder" in response to the lower price of quality. Type 2 buyers, in contrast, substitute to lower-quality goods, responding to the considerably lower prices for somewhat lower-quality goods than they were consuming in autarky.

In the high-income country the hedonic price schedule shifts in the opposite direction. Owners of durable goods in the high-income country recognize that they have a tradeoff between using their current good, trading it to the low-income country, or scrapping it. Trade increases the price of low-quality goods, leading some buyers to substitute toward higher quality and others to substitute toward lower-quality.

Trade may also change the number of buyers in the market. In the Rosen framework there are a fixed number of buyers who are assumed to demand a single good inelastically. However, by shifting the hedonic price schedule, trade may cause changes along the extensive margin. In the low-income country, trade decreases the price of low-quality goods, potentially making them accessible to buyers who had been previously priced out of the market. In the high-income country, trade increases the price of low-quality goods, potentially forcing some buyers out of the market. We revisit these possibilities in the following subsection because they have particular relevance in the empirical application which follows.

Overall, the impact of international trade on average quality is ambiguous. In the low-income country if there are large changes in the extensive margin, or widespread substitution away from new durables, then average quality will fall. In contrast, if enough buyers respond to the decrease in the price of quality by upgrading to higher-quality goods, then average quality will rise. Similarly, in the high-income country, if there are large changes along the extensive margin or widespread substitution toward new durables then average quality will rise. However, if enough buyers respond to the increase in quality by downgrading to lower quality, then average quality will fall.

Implicitly in this section we are assuming that there is limited scope for producers of new durable goods to respond to competition from old goods.⁵ We recognize, however, that changes in the prices of old durable goods will affect pricing for new durable goods that are close substitutes. This is reflected in the smooth price gradient after trade in figure 3. We assume, however, that as one moves toward the high-end of the quality gradient, this effect attenuates to zero. This is likely to be a reasonable approximation in the short-run, where only prices can change. In the long-run, however, producers of new durable goods will want to, for example, increase the quality of new goods in order to differentiate them from old goods available through trade. Our analysis does not capture these long-run responses.

2.3 The Environmental Consequences of this Pattern of Trade

This pattern of trade has important environmental implications because energy-using durable goods are a major source of local and global pollutants. This section discusses the different mechanisms by which trade affects the overall level of emissions. Following the existing literature on trade and the environment (e.g., Grossman and Krueger 1993, Copeland and Taylor 2003) we distinguish between scale and composition, recasting these mechanisms to our framework which emphasizes consumption rather than production.⁶

⁵ For example, trade in used durable goods changes the incentives for forward-looking firms. As first articulated by Coase (1972) and more recently analyzed by Esteban and 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. These dynamic effects are mitigated, however, when there are a relatively large number of firms because each producer does not internalize the effect current production will have on future profits for other firms. Trade will also affect the market for new durable goods by changing resale prices, increasing resale prices in high-income countries and decreasing resale prices in low-income countries.

⁶ A similar distinction between consumption and production is made by McAusland (2008) which examines theoretically how opposition to environmental regulations varies with whether pollution is generated by producers or consumers.

The model implies that the direct effect of trade is to increase the number of old goods in the low-income country and decrease the number of old goods in the high-income country. Changes in relative prices also engender changes in purchases of new goods, decreasing consumption of new goods in the low-income country, and increasing consumption of new goods in the high-income country. The scale effect is the total change in the overall number of durable goods in each country.

In addition, trade affects the composition, or mix of durables in each country. The model implies that old durable goods will be exported from the high-income country to the low-income country. Because older, low-quality durable goods also tend to be high-emitting, this pattern of trade potentially has important implications for the environment. How average emissions change in both countries depends on how the environmental characteristics of traded goods compare to the existing stock.

Scale and composition effects also depend on changes in the number of agents in the market. As discussed earlier, trade equalizes the price of quality across countries, increasing the number of buyers in the low-income country and decreasing the number of buyers in the high-income country. These changes along the extensive margin will affect composition if these buyers demand a different level of quality than the average buyer in the market. For example, new entrants in the low-income country will tend to demand very low-quality durable goods. If these goods are also very high-emitting this can have large environmental effects.

Another important factor is intensity of use. Emissions are a function of the number of durable goods, their emissions levels, and the intensity with which they are used. If intensity of use varies across countries, trade will affect the total level of emissions even if the total number of durable goods in use does not change. Income effects imply that intensity of use will tend to be higher in high-income countries. If this is the case, then total intensity of use will decline as durable goods are traded from high-income countries to low-income countries.

For local pollutants, the magnitude of social costs depends 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., Mauzerall, et al., 2005. One of the most important factors is the number of people nearby who are exposed to the increase in ambient pollution levels. Thus, a comprehensive analysis of the social costs from local pollution would need to measure not only the change in total emissions, but also model the relationship between emissions and ambient pollution levels, and examine changes in levels across particular locations.

We have highlighted the key mechanisms by which trade in used durable goods will affect the environment. We now turn to a specific empirical application to quantify the size of these separate effects.

3 Background: The North American Free Trade Agreement

NAFTA is a good candidate for an empirical study of the environmental consequences of trade in durable goods for several reasons. First, the volume of trade within North America is large. Total merchandise trade between the United States and Mexico in 2006 was \$335 billion (WTO, 2007, p.17). This represents a large proportion of total trade, particularly for Mexico where 84.8% of all exports in 2006 went to the United States (WTO, 2007, p. 23). Second, the stark difference in income levels between Mexico and the U.S. make this a particularly good case for testing the implications of a model based on non-homothetic preferences. Third, NAFTA marked a sharp change from previous policies, allowing us to observe market behavior both with and without trade restrictions. Fourth, a substantial literature already exists about the environmental consequences of NAFTA, providing a point of comparison for our analysis.⁷

⁷ Previous empirical studies of the effect of NAFTA on the environment have found mixed results. 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 GDP at low levels of GDP, suggesting that NAFTA would improve environmental quality via an overall

We restrict the analysis to cars and trucks. Vehicles are the single largest category of internationally traded used durable goods, and the most important in terms of environmental considerations. In the United States, for example, 33.8% of carbon dioxide emissions are derived from the transportation sector.⁸ Using a midpoint estimate of the marginal damage per ton of carbon dioxide (\$15, Metcalf 2008), this implies external costs of approximately \$30 billion annually. In addition, in many cities, vehicles are responsible for a substantial proportion of emissions of local pollutants.⁹ Moreover, restricting our analysis to a single class of durable goods allows us to assess environmental quality using a consistent set of measures.

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, 2019.¹⁰ 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

increase in income. Harbaugh, Levinson, and Wilson (2002) argue that these results are fragile. Grossman and Krueger use cross-industry evidence to examine the impact of U.S. tariff rates and pollution abatement costs on U.S. imports from Mexico, finding no significant effect. Levinson and Taylor (2008) examine the effect of U.S. environmental regulations on trade with Canada and Mexico, finding a robust relationship between abatement costs and import levels. For the average industry, a 1% increase in abatement costs is associated with a .2% increase in net imports from Mexico.

⁸ United States Department of Energy, "Energy Outlook 2008", DOE/EIA-0383(2008), Table A18, Carbon Dioxide Emissions by Sector and Source, 2006 and 2030.

⁹ A large literature documents the social cost of local air pollution (see, e.g., Dockery, et al. 1993, Pope 1995, Chay and Greenstone 2003, Currie and Neidell 2005, and Chay and Greenstone 2005). Airborne pollutants have been linked to respiratory infections, chronic respiratory illness and aggravation of existing cardiovascular disease.

¹⁰ Our study is germane to a small literature that examines the determinants of trade restrictions for used vehicles. Pelletiere and 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) and Pelletiere and Reinert (2004) find that the most significant factor determining used automobile protection is the presence of domestic automobile production.

used vehicles beginning August 22, 2005. Under the new rules, 10-15 year old vehicles 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. In continuing to restrict the importation of relatively new vehicles the Mexican government hoped to appease the powerful Mexican Association of Automobile Distributors (MAAD) and other political factions within Mexico with a vested interest in new vehicle sales.¹¹

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 vehicles were imported by Mexico from the United States. This represents a small fraction of the vehicle stock in the United States (232 million in 2005 according to R.L. Polk), but represents a substantial fraction of the vehicle stock in Mexico (22 million in 2005 according to *INEGI*). The used car import market that has evolved in response to this policy change is highly decentralized, with thousands of car dealers and hundreds of thousands of citizens bringing vehicles into Mexico. An account in the *Los Angeles Times* describes how Ciudad Juarez, a border city just south of El Paso, Texas, has become a major point of trade for used vehicles entering Mexico.¹²

This pattern of trade was foreshadowed by Berry, Grilli and 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 US 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.”

¹¹ Only vehicles produced in the United States and Canada are eligible to be imported. Vehicles exceeding 4,500 kilograms (e.g. buses and semi trucks) are not eligible. Diesel vehicles are eligible, but less than 1/5th of 1 percent of all imports during this period were diesel vehicles.

¹² *Los Angeles Times*, “In Mexico, old U.S. Cars Find New Homes” (February 16, 2008).

While these changes were occurring in the North American used car market, trade policy for new vehicles did not change. Since 1994, NAFTA has allowed duty-free trade of new vehicles and new vehicle parts as long as 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.¹³ Since 1994, all new vehicles sold in Mexico must meet U.S. emissions standards so emissions characteristics of new vehicles are similar in both countries.

President Fox's policy remained in place until March 18, 2008, when restrictions were reinstated for all 11-15 year old vehicles. Thus, after the change only 10 year old vehicles could be imported. In addition, the government increased the excise tax on used vehicles entering Mexico from 3% to 15%. This return to trade restrictions was a political response to pressure from MAAD, who pointed to alleged decreased sales of new vehicles, and argued vigorously for trade 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."¹⁴

Although this pattern of trade between the United States and Mexico is unusual because of the high volume of trade, 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.¹⁵ Another prominent example of a vehicle importing country is Peru, where over 80% of the vehicles in circulation were imported

¹³ 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*.

¹⁴ *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.

¹⁵ According to the *New Zealand Herald*, "Import Age Limit Plan: Car Prices To Soar" (October 16, 2006), over 100 countries "compete" with New Zealand to purchase used cars from Japan. 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).

as used vehicles from the United States and Japan.¹⁶ 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, WTO (2007) tracks “automobile products” but does not distinguish between new and used goods.

4 Empirical Analysis: Scale and Composition

In section 4.1, we describe the vehicles that were exported from the United States to Mexico during the first two years after trade deregulation. This provides our measure of scale, the total number of vehicles on the road. In section 4.2, we compare the traded vehicles to the stock of vehicles in both countries, characterizing composition. We compare the vehicle emissions of traded vehicles to the stock of vehicles in both countries. In section 4.3 we look within vehicle model-vintage groups. Our dataset allows us to identify, at the vehicle level (using VIN numbers), which vehicles were traded as a result of trade liberalization. This degree of detail is crucial because there is rich heterogeneity across vehicles in emissions levels even among vehicles of the same model and vintage.

Our approach emphasizes documenting changes in quantities rather than changes in prices. Our model implies that free trade will cause prices for used cars to increase in the United States and decrease in Mexico. Examining prices would be a valuable test of the model, and would provide indirect evidence about trade flows. Nonetheless, for several reasons we chose not to pursue this approach. First, the U.S. used car market is very large, so we did not expect to find large price effects. Moreover, identification of price changes would be based primarily on changes in prices over time for vehicles of different vintages, and thus could be difficult to separate from other time-varying factors that affect prices. Second, no publicly-available data exist for used car prices in Mexico. In a different context, Davis (2008) examines used car prices in

¹⁶ See (in Spanish) *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.

newspaper advertisements. However, this analysis is only for Mexico City and relies on advertised prices which may be a poor proxy for transaction prices. Third, our objective is to document changes in the quantity of local and global pollutants brought about by international trade. Given our focus, it is crucial to track the scale and composition of trade flows.

4.1 The Effect of Trade Deregulation on Scale

Tables 1 and 2 describe the vehicles exported from the United States to Mexico between November 2005 and July 2008. These data were collected by the Mexican Customs Agency a branch of the Mexican Ministry of Finance and represent the universe of vehicles that were exported during this period. Table 1 describes vehicles by year traded, vintage and vehicle manufacturer. Table 2 describes the top 10 most traded models.¹⁷ The customs records describe in detail the substantial flow of used vehicles from the United States to Mexico during this period. Overnight the flow of used vehicles from the United States to Mexico changed from virtually zero to over 75,000 vehicles per month. Overall, 2.45 million vehicles were traded during the almost three year period.¹⁸

Newer vehicles are heavily represented among traded vehicles. Vehicles 10-15 years old were eligible to be traded but 10-11 year old vehicles were much more often traded than 14-15 year old vehicles. Our model predicts the largest price differentials for very old, very low-quality vehicles. Trade may be limited, however, by transaction costs. Even a huge relative price differential on a very old car may not be enough to cover the travel and administrative costs associated with importing a vehicle.¹⁹

¹⁷ The most commonly traded vehicle model is the Ford Explorer, a vehicle that fell largely out of favor with U.S. 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 Mas (2004) for details.

¹⁸ 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.

¹⁹ The Alchian-Allen, or “Shipping the Good Apples Out” theorem points out that fixed

The fact that relatively newer vehicles are heavily represented provides suggestive evidence about what trade in vehicles would look like under different trade policies. According to NAFTA, the North American market for used vehicles will be completely deregulated in 2019. Without a household-level model, it is impossible to predict what vehicles would tend to be traded under such a policy change. However, the observed pattern suggests that the policy might lead to substantial trade in vehicles less than 10 years old.

Another striking feature of these data is the prevalence of trucks and other large vehicles. There are several explanations for this pattern. First, this reflects the fact that only U.S. and Canadian-produced vehicles were eligible to be imported. In addition, oil 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 PEMEX, the national petroleum company at less than \$2.50 per gallon.²⁰

4.2 The Effect of Trade Deregulation on Composition

Although scale is clearly important, the environmental impact of trade also depends critically on the type of vehicles that are traded. The model implies that trade will cause the price of used goods to equalize, with an ambiguous effect on average vehicle quality in both countries. In order to examine the emissions characteristics of traded vehicles we contacted the California and the Illinois Environmental Protection Agencies to collect vehicle level data on emissions and vehicle attributes. These large states provided us with data from their used vehicle emissions programs in 2005. For California, we were provided with emissions records for 7.2 million vehicles that were tested in 2005 under California's Smog Check program using an ASM emissions test. For

transportation costs decrease the relative price of high-quality goods in importing countries, causing consumption to shift toward these goods. See Alchian and Allen (1964) and Borchering and Silberberg (1978) for details.

²⁰ 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 \$2.20 in 2008. As a point of comparison the average price in the United States in July 2008, according to the Department of Energy, Energy Information Administration, was \$3.95.

Illinois we were provided with a sample of 835,000 vehicles that were tested in 2005 using an IM240 test. 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 vehicle emissions test for each vehicle. In Section 4.3 we return to these multiple tests and are able to test directly if 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 1,000,000 total registered vehicles in the United States as of 2005. Other vehicle manufacturers are included in an “other” category.²¹ Let J denote this set of 30 manufacturers. For the results reported below, we calculated the α_{jt} vector using the emissions data from California, the largest and arguably the most reliable set of emissions measures. We have also examined results based on emissions factors calculated using data from the Mexico City Emissions Testing Program and results are qualitatively similar, providing evidence that our results are not driven by selection of a particular set of emission factors.

Composition is measured by comparing the emissions characteristics of traded vehicles with the emissions characteristics of the stock of vehicles in the United States and Mexico,

$$\begin{aligned} \text{Average Emissions of Traded Vehicles} &= \sum_{j \in J, t \in T} \alpha_{jt} \mu_{jt}^T \\ \text{Average Vehicle Emissions in U. S.} &= \sum_{j \in J, t \in T} \alpha_{jt} \mu_{jt}^{US} \end{aligned}$$

²¹ 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.

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

Here 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. We measure the empirical distribution of vehicles in the United States and Mexico using ancillary datasets. For the United States, we obtained data from R.L. Polk that describe the distribution of registered vehicles in the United States as of 2005 by manufacturer and vintage. For Mexico, describing the distribution of vehicles was more challenging.²² We filed the equivalent of a Freedom of Information Act request with the Mexican Ministry of Public Safety via the Mexican Federal Institute for Access to Public Information. In response to our request, we were provided with a document describing the distribution of vehicles in Mexico by state, vintage, and manufacturer as of 2008. Similar data for 2005 are not available.

Table 3 presents the composition results. The table reports mean emission levels for hydrocarbons, carbon monoxide and nitrogen oxide, as well as vehicle vintage. The results imply that NAFTA led to a decrease in average emissions of local pollutants in both the United States and Mexico. 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 6% for carbon monoxide to 20% 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 approximately 3% for nitrogen oxide to 38% for carbon monoxide.²³

²² Although vehicle registration is required in all parts of Mexico, registries are maintained at the state level and the Mexican National Statistics Institute compiles total vehicle counts by state and year, but not by vintage or manufacturer. Another possibility would be to use commercially-available data. R. L. Polk maintains data about registered vehicles in Mexico by vehicle manufacturer, but not by vintage.

²³ The table indicates a clear ordering of vehicles by age. The stock in the United States is considerably newer than the stock of vehicles in Mexico, with traded vehicles in between. Older vehicles tend to emit higher levels of emissions because of both vintage effects and age effects, though engineering studies (e.g. Bishop and Stedman, 2008) have tended to find that vintage effects are more important. This suggests that these differences in local emission levels are likely

The table also reports results for miles-per-gallon, vehicle weight, number of cylinders, and engine size.²⁴ Carbon dioxide emissions are proportional to total gasoline consumption and these measures directly or indirectly measure vehicle fuel-efficiency. Traded vehicles are marginally less fuel efficient on average than the stock of vehicles in both countries. As a result, trade increases fuel efficiency in the United States, and decreases fuel efficiency in Mexico City. The differences are small. Whereas local emissions vary across columns by as much as 30-40%, the differences in miles-per-gallon vary by less than 3%, indicating that composition effects are likely to play a much smaller role for global pollutants.

4.3 Vehicle-Level Heterogeneity in Emission Levels

The previous subsection illustrated 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 and Illinois in the year 2005, we know the vehicle identification number (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. This information is crucial for examining changes in composition because even within vehicles of the same model and vintage there is large heterogeneity in emissions levels.

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

to be persistent over time.

²⁴ We imputed miles-per-gallon for each vehicle using vintage, vehicle weight, cylinders, and engine size. Using data from the Department of Transportation, National Highway Traffic Safety Administration, for each vintage 1978-2005 we estimated a separate regression of miles-per-gallon on weight, cylinders and engine size and then used the estimated coefficients to predict miles-per-gallon for each vehicle in the emissions testing data.

$$y_i = \beta_0 + \beta_1 1[\textit{Exported to Mexico}] + \delta_t + \omega_{jt} + \sigma_{mt} + \varepsilon_i.$$

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. A positive coefficient indicates that vehicles exported to Mexico have higher levels of y . We report results from specifications that control for vintage indicators, δ_t , as well as specifications that control for manufacturer/vintage interactions, ω_{jt} , and even model/vintage interactions, σ_{mt} .²⁵ In this fully interacted specification β_1 describes how y varies compared to other vehicles of the same model and vintage.

Table 4 reports coefficients and standard errors corresponding to 36 separate OLS regressions. Across pollutants and specifications we find evidence that the vehicles exported to Mexico have higher local emission levels. Columns (3) and (7) report results with the full set of model/vintage interactions. Compared to other vehicles of the same model and vintage, traded vehicles have emissions levels that are significantly higher than vehicles not sent to Mexico. The effect remains in column (4) after controlling for a quadratic in mileage, indicating higher emissions for exported vehicles even within vehicles of the same make, vintage, 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. Consistent with our model, these results provide evidence that low-quality vehicles are disproportionately desirable in Mexico.

The table also reports coefficients corresponding to miles-per-gallon and other vehicle characteristics predictive of carbon dioxide emissions. Controlling for vintage, traded vehicles are less fuel efficient, heavier, with more cylinders, and larger engines than the stock of vehicles in California. This is consistent with the pattern observed in

²⁵ Model is measured using the 5th digit of the VIN number as assigned by each individual manufacturer. This classification of model distinguishes between, for example, the Ford Windstar (a minivan) and the Ford F-Series (a truck), but does not distinguish, for example, between the Ford F-150 and the Ford F-250.

table 2 that minivans, SUVs, and trucks are heavily represented among traded vehicles. After controlling for manufacturer/vintage or model/vintage interactions the coefficients become much smaller.

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 overall 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 more likely to be super-emitters. The magnitude of the differences is large. For example, after controlling for model/vintage fixed effects, exported vehicles are over four times more likely to have failed emissions testing three times, and over five times more likely to have been declared a gross polluter three or more times. This pattern is consistent with vehicles being exported to Mexico after they become too expensive to maintain according to emissions standards. This could also be evidence of differential asymmetric information, with Mexican buyers less able to identify high-emitting “lemons”.

Overall the results imply that exports are “brownier” than the average stock in the United States. We conclude based on the California and Illinois samples that exported vehicles tend to be significantly higher-emitting than other vehicles. This effect remains after controlling for vintage, manufacturer, and model. Our model implies that low-quality vehicles are disproportionately desirable in Mexico, and the trade pattern reflects this.

5 The Behavioral Response: New Vehicle Sales and Vehicle Retirement

According to our model, trade liberalization causes prices of low-quality (used) goods to increase in the high-income country and decrease in the low-income country. In the high-income country, high-quality goods (new) goods become relatively less expensive, and consumption of these goods increases. In addition, because low-quality goods have become relatively more expensive, households hold on to them longer, and one would expect vehicle retirement rates to decrease. See, e.g. Gruenspecht (1982). In the low-income country, the results are exactly the opposite. High-quality (new) goods become relatively more expensive, and consumption of these goods decreases. Low-quality (used) goods become less expensive, and vehicle retirement rates increase. These changes in behavior are potentially important because they may mitigate the environmental impact of trade.

In this section we examine vehicle purchase and retirement behavior using detailed data from both countries. The section has three main results. First, NAFTA did not meaningfully affect the number of registered vehicles in the United States. Second, vehicle retirement rates are substantially lower in Mexico than the United States. Third, there is little evidence that trade decreased sales of new vehicles in Mexico.

5.1 Vehicle Retirement in the United States

In this subsection we examine changes in the stock of registered vehicles in the United States during the period 2003 to 2007. We observe increased exit rates among 10-15 year old vehicles during the post-NAFTA period, but the increase is much smaller than the flow of vehicles to Mexico. We conclude that most of the vehicles exported to Mexico during this period were either vehicles that would have been retired otherwise or vehicles that were already retired (i.e. not registered). This is consistent with our evidence from Section 4.3 that very low-quality vehicles are more likely than other vehicles to be traded.

As a result, the elimination of trade restrictions in Mexico led to little or no impact on the number of registered vehicles in the United States. This “zero effect” for scale in the United States is 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, the capital cost of used vehicles is 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.

Figure 4: Exit Rates by Vehicle Age in the United States

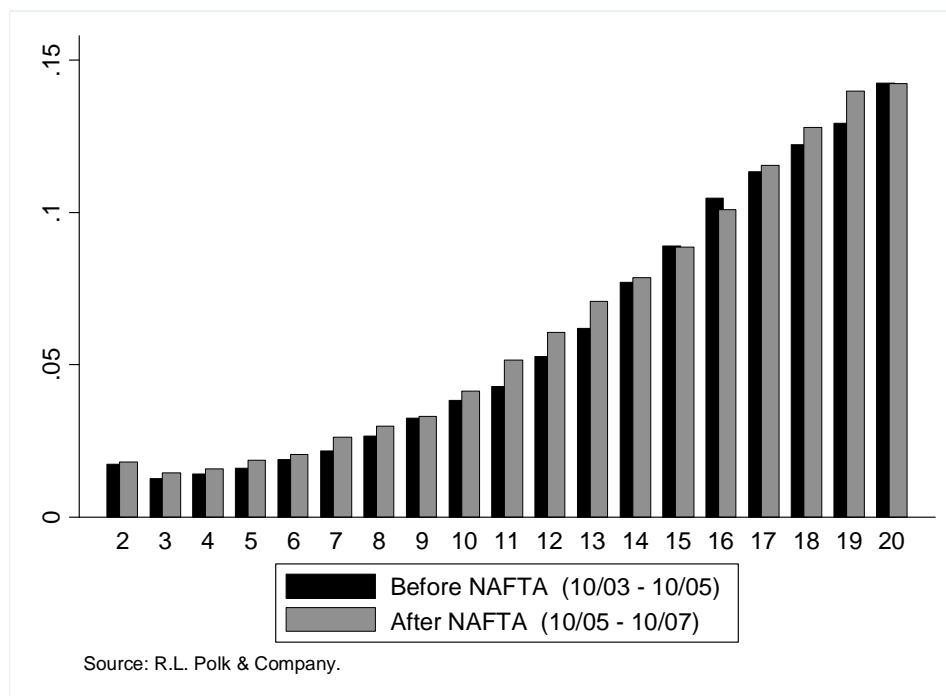


Figure 4 plots exit rates by vehicle age in the United States before and after NAFTA.²⁶ The overall pattern is consistent with previous studies of vehicle retirement

²⁶ These data were obtained from R.L. Polk & Company in April 2008. Exit rates were calculated by calendar year and vehicle age as follows. Let v denote vehicle vintage (e.g. 1991) and let t denote calendar year. We calculated the exit rate for vehicles age $t-v$ for year t , as the percentage change in the number of vehicles of vintage v between year $t-1$ and t .

patterns. Annual exit rates increase with vehicle age from less than 2% for vehicles that are 4-5 years old to more than 10% for vehicles over 15 years old. The figure reveals higher exit rates after NAFTA for vehicles 10-15 years old. Five out of the six differences are statistically significant at the 1% level. Across vehicle ages, retirement rates tend to be higher during the post-NAFTA period, perhaps due to the gasoline price increases during this period. However, we take the disproportionately large increases among 10-15 year old vehicles as evidence of trade with Mexico.

However, the increase in exit rates for vehicles 10-15 years old implies only a small overall decrease in the number of vehicles in the United States. Even without controlling for the apparent overall increase in exit rates during the post-NAFTA period, these results imply only approximately 180,000 additional exits annually among 10-15 year old vehicles relative to the earlier period. The number of exits is considerably smaller than the 1,000,000 vehicles per year that were exported annually to Mexico during this period, suggesting that most of the vehicles that were exported to Mexico would have been retired otherwise or were drawn from the stock of already retired vehicles.

These data underestimate the total number of exits because there is a lag between when a vehicle exits and when it is removed from the R.L. Polk database.²⁷ Results are similar, however, when we instead define the post-NAFTA period as October 2006 to October 2007, a later period which includes exits both from the October 2006 to October 2007 period and delayed exits from October 2005 to October 2006. Using this specification the results imply 315,000 additional exits annually among 10-15 year old vehicles relative to the earlier period.

²⁷ The R. L. Polk data are based on vehicle registrations, and vehicles are registered only once a year. Thus, for example, if a vehicle is registered in January and then exported in February it will not disappear from the vehicle registry until the following January. In addition, R.L. Polk allows for another 6 months past the due date of registration before dropping a vehicle from its database. As a result, in some cases a vehicle that is exported will not be reflected as “missing” until 18 months later. Assuming that exports are uniformly distributed across years and months and assuming that vehicle registrations are uniformly distributed throughout the year (consistent with our conversations with R. L. Polk), exits October 2005 to October 2006 will include only 25% of actual exports, whereas exits October 2006 to October 2007 will include 96%.

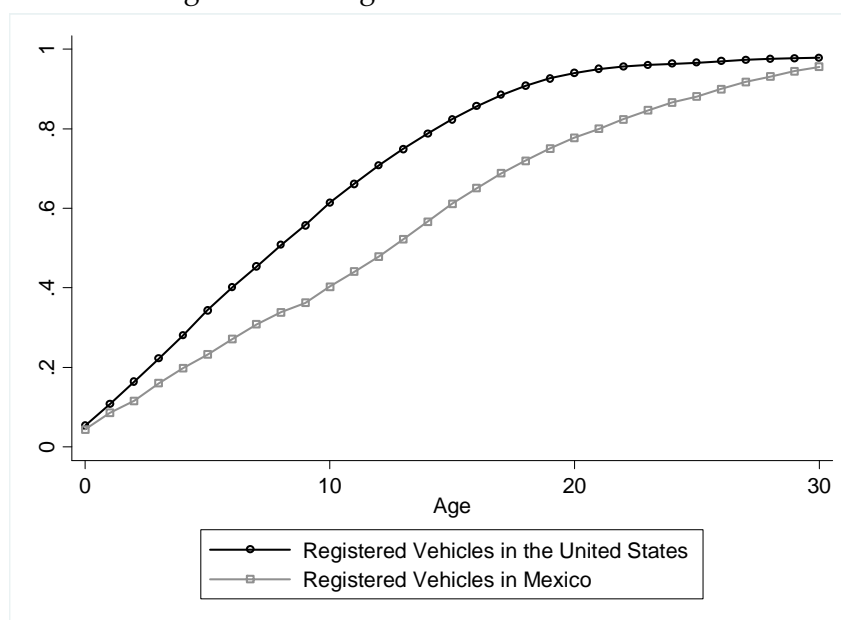
These results highlight the immense size of the used vehicle market in the United States. During the period 2003-2007, 5.9 million vehicles were retired annually in the United States, 2.1 million vehicles 10-15 years old. This provides a large potential stock of vehicles for export, even without dipping into the stock of registered vehicles. A relatively small fraction of these castoffs can represent a large number of vehicles for a smaller country like Mexico.

5.2 Differential Vehicle Retirement Rates in the United States and Mexico

The model implies that retirement rates will be higher in the United States than Mexico. In autarky, old durable goods are relatively inexpensive in the high-income country, so when faced with repair costs, agents are more likely to retire the good. In the low-income country, old durable goods are relative expensive, so when faced with repair costs, agents are less likely to retire the good.

Figure 5 describes the age distribution of vehicles in both countries. Consistent with the predictions of the model, vehicles in Mexico tend to be much older. The average age of vehicles in the United States is 9.4 years compared to 13.5 years in Mexico. The distribution implies dramatically different vehicle retirement behavior in the two countries. The implied mean annual exit rate for 10-30 year old vehicles is 12.2% in the United States and only 3.8% in Mexico.

Figure 5: The Age Distribution of Vehicles



5.3 Vehicle Sales in Mexico

Our model implies that the influx of relatively high-quality used vehicles will cause households in Mexico to substitute away from new vehicles. Indeed, MAAD has been a vocal opponent to liberalization, and claims that NAFTA has reduced sales considerably.²⁸ In this subsection we examine the evidence from new vehicle sales, finding no evidence of decreased sales. The one possible exception is subcompact car sales, which indeed drop during the post-NAFTA period, though sales appeared to be in decline even prior to trade deregulation. Overall, the evidence from new vehicle sales suggests that the 10-15 year old used vehicles were not an attractive alternative for most buyers of new vehicles.

²⁸ Recent publications from the Mexican Association of Automobile Distributors describe in detail the environmental and commercial threats from free trade in used vehicles. See, e.g., “Trade in Very Old Used Cars: A Challenge for Air Quality” (“*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.

Figure 6. Monthly Sales of New Vehicles in Mexico

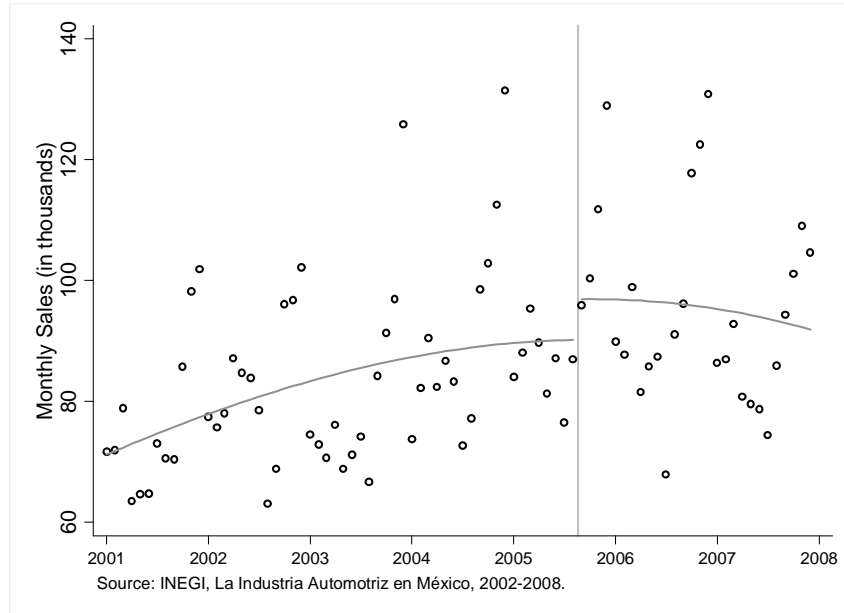


Figure 6 plots monthly sales of new vehicles in Mexico during the period January 2001 to December 2007, as well as a fitted cubic polynomial in time with intercept at August 2005 when the market for used vehicles was liberalized. Based on the plot it is difficult to make strong statements about the impact of trade deregulation on sales. Overall, vehicle sales post-NAFTA are similar to sales pre-NAFTA. There is a pronounced season pattern to sales, which will be taken into account in the regression analysis which follows.

Figure 7 plots monthly sales of new vehicles in Mexico by vehicle category. Whereas sales of subcompacts decrease steadily after August 2005, sales for subcompacts, luxury cars, and light trucks and SUVs increase. With their relatively low quality design and few features, subcompacts are likely the closest substitute to the used vehicles from the United States, and thus it is not surprising that this category would have been most affected. Still, we are hesitant to make definitive statements about causality particularly because the decline in subcompact sales appears to begin even prior to trade deregulation.

Figure 7. Monthly Sales of New Vehicles in Mexico by Vehicle Category

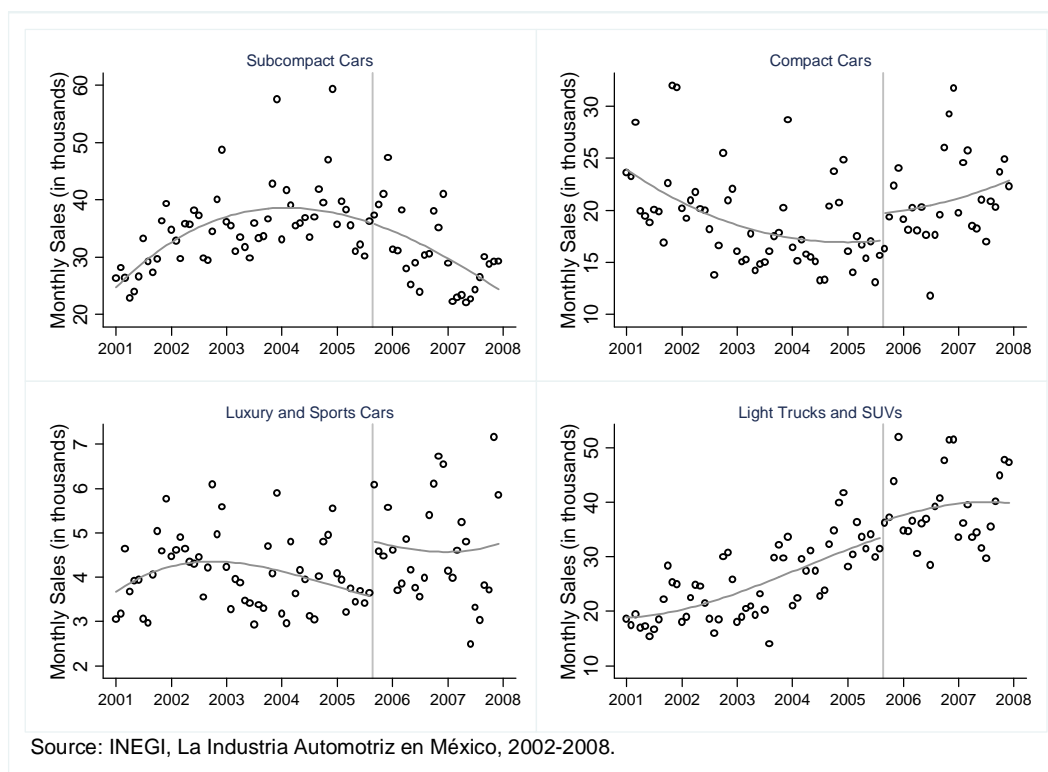


Table 6 reports coefficients and standard errors from an analogous regression analysis. Monthly sales of new vehicles in Mexico (in logs) are regressed on month indicator variables, a polynomial time trend, and an indicator for after NAFTA. To control for aggregate changes in demand, we also include the growth rate of GDP (available quarterly) from the Mexican National Statistics Institute, National System of Accounts. For second, third, and fourth order polynomials, the coefficient on NAFTA for total sales is near zero and not statistically significant. The null hypothesis of a 10% drop in total vehicle sales can be rejected at the 2% level across specifications. For subcompacts the coefficient is negative and near 5%, but not statistically significant. Compact and luxury car sales increase in all specifications.

In future work it would be valuable to examine trade's general equilibrium model based on structural estimates of household-level vehicle demand. See, e.g. Berry, Levinsohn, Pakes (1995), Goldberg (1999), and Bento, Goulder, Jacobsen, and von Haefen (2008). One potential challenge of estimating such a model in this context is the

difficulty of acquiring necessary Mexican data. Structural models of vehicle demand in the United States have been successful, in part, because researchers have access to detailed micro-level datasets like the National Household Travel Survey (NHTS) and the Consumer Expenditure Survey (CES). There is no dataset in Mexico comparable to the NHTS. The Mexico equivalent to the CES, the National Survey of Household Income and Expenditures includes basic household demographics and information about expenditures on vehicles, vehicle maintenance, vehicle insurance, and vehicle licensing and fees, but does not include the manufacturer, model, or vintage of household vehicles.

5.4 An Illustration of How Trade Can Increase Lifetime Carbon Emissions

In Section 5.1, we presented evidence that indicates that NAFTA had little effect on the total number of vehicles in circulation in the United States. Section 5.2 examined the distribution of vehicle age in both countries, finding evidence of dramatically lower retirement rates in Mexico. Finally, Section 5.3 showed that changes in new vehicle purchases in Mexico are too small to considerably offset the large influx of vehicles from the United States. These results together indicate that overall NAFTA is associated with a substantial net increase in the number of vehicles in circulation. In this section we evaluate the implications of this increase for lifetime greenhouse gas emissions. Although our analysis provides much of the information required for these calculations, these results do require us to make a number of additional assumptions, particularly about vehicle utilization.²⁹ As a result, we refer to these results as an “illustration” and these results should be interpreted with caution.

We consider both short-run and long-run thought experiments. For the short-run, we examine the change in annual global carbon emissions that results from increasing the number of vehicles in Mexico by 1,000,000. This corresponds closely with the annual level of imports during the period 2005-2008. For the long-run illustration,

²⁹ If the micro data existed, Goldberg’s (1999) structural model of the vehicle ownership decision and the utilization (miles driven) decision could be used to estimate the social cost of trade.

we calculate the lifetime increase in carbon emissions from these vehicles. The long-run cumulative impact of trade is particularly important in this context because vehicle retirement rates in Mexico are low, so these 1,000,000 vehicles continue to be used in Mexico for many years.

Short-run carbon emissions are the product of number of vehicles, number of miles driven annually, and emissions per mile:

$$\text{Short Run Emissions} = (\text{Number of Vehicles}) (\text{Miles Driven}) (\text{Emissions per Mile}) \quad (1)$$

Scale enters through the number of vehicles, and composition enters emissions per mile. Long-run carbon emissions are total lifetime emissions,

$$\text{Long Run Emissions} = \int_0^{\infty} (\text{Number of Vehicles}) (\text{Miles Driven}) (\text{Emissions per Mile}) \lambda e^{-\lambda} dy \quad (2)$$

where λ is the vehicle retirement rate. For λ we use .038, the average annual retirement rate for vehicles 10-30 years from section 5.2. For miles driven, we use the average number of miles driven annually per vehicle in each country. Vehicles in the United States travel an average of 12,408 miles annually compared to 6,100 miles annually in Mexico.³⁰ We would have preferred instead to use measures of miles driven that vary by vehicle model and vintage, but with no vehicle-level information available on miles driven in Mexico, this was not possible.

Table 7 reports the short-run and long-run increases in carbon. The impact of one year of trade is substantial, increasing carbon dioxide emissions by 2.6 million tons annually. To put these results in some context, using these same methods total annual emissions of carbon dioxide from vehicles in the United States and Mexico is 1.2 billion tons and 56 million tons, respectively. Using \$15 per ton for the social cost of carbon

³⁰ 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.

dioxide following Metcalf (2008), this implies social costs of \$39 million. Using \$85 per ton for the social cost of carbon dioxide following Stern (2007), social costs are \$219 million. The long-run results are considerably larger. The total lifetime increase in carbon dioxide emissions from these vehicles is 67.7 million tons. Total social cost ranges from \$1.02 billion to \$5.76 billion depending on the value used for the social cost of carbon.

It is important to emphasize that these thought experiments describe trade in vehicles during only a single 1-year period. To calculate the total lifetime impact of a permanent policy change it would be necessary to calculate and take the sum of lifetime emissions for each successive wave of imports. Moreover, because of the large stock of vehicles in the United States, it is not unrealistic to believe that trade flows of this magnitude from the United States to Mexico could continue at this rate over a long period of time. The stock of vehicles in the United States is approximately 10 times the stock in Mexico, and a flow of 1,000,000 annually can be maintained simply by siphoning off a fraction of the vehicles that otherwise would have been scrapped.

These results provide a valuable preliminary assessment of the total impact of U.S.-Mexico trade on carbon dioxide emissions. However, it is important to emphasize that these numbers are based on several assumptions, many of which can be only partially verified empirically. First, we are assuming implicitly that prior to driving an imported used car, Mexicans were generating no carbon dioxide 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.

Second, these results describe the social cost from carbon dioxide emissions, but not the social cost from emissions of local pollutants. There is reason to believe that the social cost from increased ambient pollution levels could be large relative to the costs associated with climate change. For example, World Bank (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 U.S. 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 incorporate the social costs of the resulting increases.

6 Conclusion

Wealthy nations demand a range of high-quality transportation equipment (trucks, trains, buses, boats, and planes), as well as residential durable goods (air conditioners, clothes washers, etc), commercial durables (computers, lighting, heating and cooling equipment, etc) and industrial durables (power generating equipment, metalworking equipment, construction machinery, etc). These durable goods depreciate in quality over time. Poorer nations want to purchase similar durable goods but due to 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 large implications for the environment. As we discuss in the paper, the effect of trade on average and total emissions depends on the relative magnitude of scale and composition effects. Trade provides rich countries with an outlet for low-quality durable goods. Because low-quality durables are typically also 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.

In the empirical analysis we focused on the deregulation of the market for used cars and trucks following NAFTA. Scale effects are immediate and large and 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, traded vehicles have significantly higher emissions than the stock in the United States, and significantly

lower emissions than the stock in Mexico. As a result, trade decreased average emissions of local pollutants in both countries. For carbon dioxide emissions, composition effects are much smaller, with traded vehicles marginally less fuel-efficient than the stock in either country.

Total emission levels decrease in the United States and increase in Mexico, with global carbon dioxide emissions increasing. Whereas trade has led to no discernible decrease in the number of vehicles in circulation in the United States, it has led to a large increase in the number of vehicles in Mexico. Furthermore, because vehicle retirement rates are low in Mexico, these vehicles will continue to be used for many years. This pattern is likely to be the case not just for NAFTA, but for North-South trade more generally. Although the magnitude of scale and composition will differ across contexts, this tendency of durable good lifespans to be increased by trade is likely to be repeated elsewhere as barriers to trade continue to fall.

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 global pollutants such as carbon dioxide where domestic policies designed to reduce emissions can be easily undermined by emissions increases abroad. As a result, unilateral policies aimed at reducing greenhouse gas emissions may not achieve aggregate gains when fuel inefficient vehicles can be traded.

Our results also have implications for predicting likely unintended consequences induced by pending United States climate change mitigation legislation. Today, California is leading an effort to unilaterally reduce its greenhouse gas emissions through AB32 legislation. Economists have pointed out that “leakage” can undermine the aggregate benefits of this initiative. Leakage takes place when regulation in one spatial sector, such as California, leads to migration of polluting activity away from the regulated area to an unregulated area.

Given that the transportation sector is a major producer of carbon dioxide emissions, the Congress continues to wrestle with raising fuel economy (CAFE) standards or raising gasoline taxes. Our results speak directly to the differential implications of these two policies. If CAFE standards increase sharply, exports of used vehicles to Mexico will decline. As articulated by Gruenspecht (1982), new vehicle regulations 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.

In contrast, increasing the gasoline tax would increase exports of used vehicles to Mexico. A gasoline tax in the United States would make large, fuel inefficient vehicles relatively more desirable in Mexico. We have shown that it was already the case that many of the vehicles exported to Mexico between 2005 and 2008 were trucks, minivans, and SUVs. This pattern would almost certainly be exacerbated by an increase in the gasoline tax, causing further decreases in emissions in the United States and further increases in emissions in Mexico. Thus, the broader conclusion of our analysis is that the composition of trade can change sharply as U.S incentives change.

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TABLE 1
Descriptive Statistics
Vehicles Exported from the United States to Mexico 2005-2008

Total Number of Vehicles	2,454,639
Year Traded (proportion)	
2005	.16
2006	.37
2007	.32
2008	.15
Vintage	
1991	.04
1992	.06
1993	.11
1994	.14
1995	.19
1996	.20
1997	.16
1998	.10
Vehicle Manufacturer	
Ford	.33
Chevrolet	.17
Dodge	.10
Nissan	.07
Jeep	.06
Plymouth	.05
Mercury	.04
GMC	.03
Chrysler	.03
Pontiac	.02
Other	.10

Note: As described in detail in the text, this table describes cars and trucks exported from the United States to Mexico between August 2005 and July 2008. These data were collected by the Mexican Customs Agency, a branch of the Mexican Ministry of Finance.

TABLE 2
 Top 10 Traded Models
 Vehicles Exported from the United States to Mexico 2005-2008

Rank	Manufacturer	Model	Proportion
1	Ford	Explorer (SUV)	.08
2	Chevrolet	S-10 (Truck)	.06
3	Dodge	Caravan (Minivan)	.05
4	Ford	Ranger (Truck)	.05
5	Ford	Windstar (Minivan)	.05
6	Chevrolet	Silverado (Truck)	.04
7	Ford	F-150 (Truck)	.04
8	Plymouth	Voyager (Minivan)	.03
9	Jeep	Cherokee (SUV)	.03
10	Ford	Taurus (Car)	.03

Notes: These data were collected by the Mexican Customs Agency, a branch of the Ministry of Finance and describe cars and trucks exported from the United States to Mexico between August 2005 and July 2008.

TABLE 3
The Effect of Trade Deregulation on the Composition of Vehicles in the United States and Mexico

	United States (1)	Traded Vehicles (2)	Mexico (3)
Local Pollutants:			
Hydrocarbons (parts per million)	38.9	43.6	49.3
Carbon Monoxide (percent)	.137	.146	.201
Nitrogen Oxide (parts per million)	239.2	300.4	310.8
Vehicle Vintage	1996.2	1995.1	1994.5
Global Pollutants:			
Miles Per Gallon	25.41	24.75	25.34
Vehicle Weight (pounds)	3515	3708	3462
Cylinders	5.84	6.01	5.75
Engine Size (liters)	3.46	3.68	3.44

Note: This table reports means of the variables listed in the row headings for the group listed at the top of the columns. Column (1) is the stock of vehicles in the United States as of October 2005. Column (2) is the vehicles exported from the United States to Mexico between August 2005 and July 2008. Column (3) is the stock of vehicles in Mexico as of 2008.

TABLE 4
Comparing Exported Vehicles to the Stock in the United States

	California				Illinois		
	With Vintage Fixed Effects (1)	With Make Vintage Interactions (2)	With Model Vintage Interactions (3)	With Model Vintage Interactions and Quadratic in Mileage (4)	With Vintage Fixed Effects (5)	With Make Vintage Interactions (6)	With Model Vintage Interactions (7)
Local Pollutants:							
Hydrocarbons (in logs)	.086 (.004)	.096 (.004)	.089 (.004)	.049 (.004)	.291 (.014)	.203 (.017)	.092 (.022)
Carbon Monoxide (in logs)	.104 (.004)	.084 (.004)	.062 (.004)	.023 (.004)	.150 (.013)	.085 (.017)	.004 (.022)
Nitrogen Oxide (in logs)	.135 (.005)	.075 (.005)	.067 (.005)	.014 (.005)	.067 (.013)	.015 (.016)	.016 (.021)
Miles on Odometer (1000s)	9.88 (.192)	11.20 (.183)	9.68 (.179)		-	-	-
Global Pollutants:							
Predicted Miles Per Gallon	-1.53 (.020)	-0.24 (.017)	0.05 (.013)		-	-	-
Vehicle Weight (pounds)	231.6 (3.16)	53.7 (2.82)	-0.7 (2.33)		-	-	-
Cylinders	0.29 (.005)	-0.11 (.004)	-0.06 (.003)		-	-	-
Engine Size (liters)	0.43 (.005)	-0.03 (.003)	-0.04 (.002)		-	-	-

Note: This table reports coefficients and standard errors corresponding to *1(Exported to Mexico)* from 36 separate OLS regressions. The row headings list the dependent variable used in each regression. The sample includes vehicles with model years 1990-1998. Local pollutants are measured in logs. All other vehicle characteristics are measured in levels. Out of 7.2 million vehicles in the California data, 83,095 vehicles were exported. Of the 835,000 vehicles in the Illinois data, 9,731 vehicles were exported.

TABLE 5
Are Exported Vehicles More Likely to be Super-Emitters?

	California Sample With Model Vintage Interactions
<i>1(Failed Emissions Test Once)</i>	1.20 (.013)
<i>1(Failed Emissions Test Twice)</i>	3.04 (.053)
<i>1(Failed Emissions Test Three or More Times)</i>	4.55 (.217)
<i>1(Gross Polluter Once)</i>	1.22 (.025)
<i>1(Gross Polluter Twice)</i>	3.18 (.109)
<i>1(Gross Polluter Three or More Times)</i>	5.45 (.514)

Note: This table reports results from 6 separate OLS regressions. The row headings list the dependent variable used in each regression. In each row we report how many times more likely it is for an exported vehicle to be in each category. For example, controlling for model vintage interactions, exported vehicles are 3.04 times more likely to have failed emissions testing twice. The sample includes all vehicles in the California dataset with model years 1990-1998.

TABLE 6
New Vehicle Sales in Mexico

	Total Vehicles	Subcompact Cars	Compact Cars	Luxury and Sports Cars	Trucks and SUVs
Second-Order Polynomial Time Trend	.018 (.032)	-.047 (.052)	.088 (.068)	.180 (.085)	.031 (.067)
Third-Order Polynomial Time Trend	-.015 (.033)	-.045 (.055)	.053 (.064)	.197 (.082)	-.054 (.054)
Fourth-Order Polynomial Time Trend	-.019 (.033)	-.044 (.056)	.048 (.064)	.196 (.082)	-.061 (.054)

Note: This table reports estimates that correspond to 15 separate OLS regressions. The dependent variable is monthly sales of new vehicles in Mexico (in logs) from *INEGI, La Industria Automotriz en México, 2002-2008* for total vehicles or for different vehicle segments as indicated in the column headings. The table reports coefficients and standard errors for $1(NAFTA)$, an indicator variable for the period after the liberalization of the used car market in August 2005. Specifications include flexible polynomial time trends as indicated in the row headings as well as the growth rate of GDP. In accordance with findings from standard diagnostic tests of serial correlation, reported standard errors are estimated following Newey and West (1987) with a 1-month lag.

TABLE 7
An Illustration of How Trade Can Increase Lifetime Emissions

	Short-Run	Long-Run
Carbon Dioxide (Millions of Tons)	2.6	67.7
Social Cost (Millions of Dollars)		
\$15 per ton of CO ₂ (Metcalf, 2008)	\$39	\$1,016
\$85 per ton of CO ₂ (Stern, 2007)	\$219	\$5,758

Note: This table describes the short-run (1 year) and long-run (lifetime) increase in carbon emissions associated with Mexico importing 1,000,000 vehicles from the United States. For details see section 5.4.