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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, 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 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

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-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 1000 people in the United States compared to 30 per 1000 in China and only 12 per 1000 in India.

In this paper we use theory and empirical evidence to evaluate the environmental implications of free trade in vehicles and other used durable goods between a high-income country and a lower-income trading partner. In our model preferences are non-homothetic such that demand for good quality is increasing in income. In autarky, used goods are relatively inexpensive in the high-income country and free trade causes these goods to be exported to the low-income country.

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 vehicles and other energy-using durable goods in the production of local and global pollutants. The direct effect of trade is to increase the number of vehicles in the low-income country and decrease the number of vehicles in the high-income country. Trade also affects the composition of the vehicle stock in each country. How average vehicle emissions change in both countries depends on how the environmental characteristics of traded vehicles 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

[1] Ward's Automotive Group (1992-2008), Dargay, Gately, and Sommer (2008).

accordance with the conditions of NAFTA, in August 2005 Mexico issued a decree allowing 10-15 year-old vehicles to be imported from the United States. 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 vehicle emissions in both countries.[2]

Total greenhouse gas emissions increase, primarily because trade gives new life to vehicles that otherwise would have been scrapped. Although trade led to no 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 how trade affects where goods are produced. Our analysis illustrates that trade also affects 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 durable

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[2] 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.

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 production and assembly whereas 93% come from fuel usage.[3]

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 A Model 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 cause used 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 discuss 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.

[3] This estimate is from Massachusetts Institute of Technology Energy Laboratory (2000) based on a total lifetime driving distance of 300,000 kilometers.

2.1 Non-Homothetic Preferences and Gains to Trade

Suppose preferences are non-homothetic such that demand for good quality is increasing in income.[4] 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

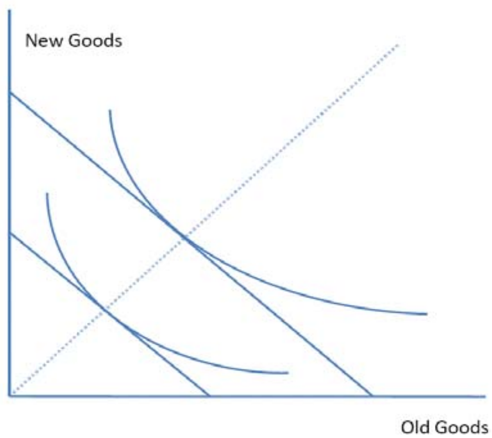


Figure 1b: Non-Homothetic Preferences

This framework implicitly assumes a vertical model of quality. Durable goods are differentiated products described by a vector of different utility-bearing attributes. 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

[4] 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 Ricardian trade models, with low-income countries having a comparative advantage in producing low-quality goods. It is not appropriate 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.

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.[5] When the proportion of new and old goods is fixed, however, relative prices must change to clear the market. In particular, as income 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 figure 1b.

[5] 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.

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.

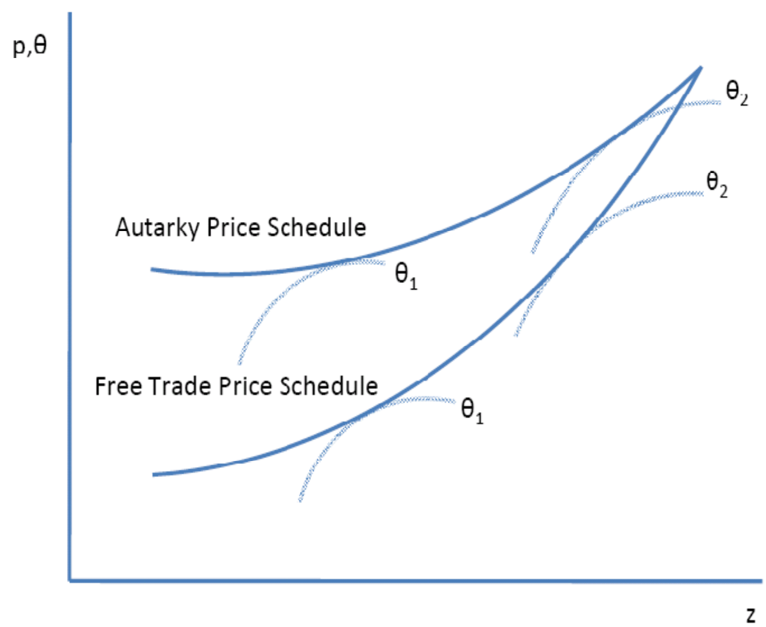
Results are similar allowing for endogenous retirement of old goods. In autarky durable good retirement rates are higher in high-income countries. Used goods are relatively cheap, so when faced with repair costs, durable good owners in high-income countries would rather replace than repair. In low-income countries, used goods are relatively expensive so durable good owners are willing to incur large repair costs to avoid retiring 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.

While non-homothetic preferences provide a plausible explanation for this pattern of trade, it is important to consider alternative explanations. Perhaps most importantly, differences in operating costs across countries provide an alternative rationale for trade. See e.g. Sen (1962), Thoumi (1975), Bond (1983), and Navaretti, Soloaga, and Takacs (2000). Older durable goods may require larger labor inputs, making them relatively more desirable in countries where wage rates are low. The operating cost framework generates a pattern of trade very similar to the pattern implied by non-homothetic preferences. In particular, with free trade, old durable goods are exported from high-wage to low-wage countries. In addition, the operating cost framework implies that trade patterns will be sensitive to energy prices, availability of replacement parts, access to specialized repair equipment, and supply of experienced repair technicians. In addition, environmental regulations can affect operating costs by, for example, requiring costly emissions testing. We view our approach as complementary to this existing literature.

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 Used 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 and 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 the price of quality by downgrading to lower quality, then average quality will fall.

Implicitly we are assuming that there is limited scope for producers of new durable goods to respond to competition from used goods.[6] We recognize, however, that changes in the prices of used 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 may want to, for example, increase the quality of new goods in order to differentiate them from used 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 play a central role in the production 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.[7]

[6] For example, trade in used durable goods may change incentives for producers by altering the market structure. 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 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 indirectly by increasing resale prices in high-income countries and decreasing resale prices in low-income countries.

[7] A similar distinction between consumption and production is made by McAusland (2008) which

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 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 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.

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examines theoretically how opposition to environmental regulations varies with whether pollution is generated by producers or consumers.

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 85% 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 is 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.[8]

[8] 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.[9] 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.[10] 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.[11] 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.

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

[10] 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.

[11] 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 used vehicles less than 10 years old and more than 15 years old. In continuing to restrict the importation of used vehicles less than 10 years old 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.[12]

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 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 private citizens bringing vehicles into Mexico.

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 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 U.S. and Canadian consumers, while a large portion of Mexican demand is satisfied by used cars."

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

[12] 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.

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.

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 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]

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.[15] Another prominent example of a vehicle importing country is Peru, where over 80% of the vehicles in circulation were imported 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

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[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 *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).

[16] 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.

any comprehensive measures of global trade. For example, WTO (2007) tracks "automobile products" but does not distinguish between new and used vehicles.

4 Empirical Analysis: Scale and Composition

In this section we measure the scale and composition of used vehicle trade between the United States and Mexico during the period 2005-2008. In section 4.1, we focus on 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. In section 4.3 we examine vehicle-level characteristics. 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.[17] Third, our objective is to document changes in emissions 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.

[17] In a different context, Davis (2008) examines used car prices in newspaper advertisements. However, this analysis is only for Mexico City and relies on advertised prices which may be a poor proxy for transaction prices.

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.[18] 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.[19]

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 will not be enough to cover the travel and administrative costs associated with importing a vehicle.[20] 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 by 2019. The observed pattern suggests that the policy might lead to substantial trade in vehicles less than 10 years old.

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[18] 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.

[19] 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.

[20] The Alchian-Allen, or "Shipping the Good Apples Out" theorem points out that fixed 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 Borcherding and Silberberg (1978) for details.

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.[21]

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 collected vehicle level data on emissions and vehicle attributes from the California and Illinois Environmental Protection Agencies. For California, these data describe emissions results for 7.2 million vehicles that were tested in 2005 under California's Smog Check program. For Illinois, these data describe emissions results for 835,000 vehicles that were tested in 2005. 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 million total

[21] 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 the first half of 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.

registered vehicles in the United States as of 2005. Other vehicle manufacturers are included in an "other" category.[22] 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,

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

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

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

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.[23] We filed the equivalent of a Freedom of

[22] 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.

[23] 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 a database of registered vehicles in Mexico by vehicle manufacturer, but not by vintage.

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. 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. Overall, these results imply that NAFTA led to a decrease in average emissions of local pollutants in both countries. The table indicates a clear ordering of vehicles by age. The stock in the United States is newer than the stock of vehicles in Mexico, with traded vehicles in between.[24] Based on the hedonic price for used vehicles results of Bin and Martins-Filho (2008), it is clear that the U.S is exporting lower value vehicles to Mexico.

The table also reports results for miles-per-gallon, vehicle weight, number of cylinders, and engine size.[25] These measures directly or indirectly measure vehicle fuel-efficiency and, therefore, carbon dioxide emissions which are proportional to total gasoline consumption. 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, though the differences are

[24] 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 to be persistent over time.

[25] 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.

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 carbon dioxide emissions.

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.

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,

$$\mathrm{y_i} = \beta_0 + \beta_1 1[Exported\ to\ Mexico]_\mathrm{i} + \delta_\mathrm{t} + \omega_\mathrm{jt} + \sigma_\mathrm{mt} + \varepsilon_\mathrm{i}.$$

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.[26] In this fully interacted specification β_1 describes how y varies compared to other vehicles of the same model and vintage.

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[26] 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 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 levels of emissions of local pollutants. 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 vintage, make, 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. 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 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 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 over four times more likely to have failed emissions testing three times, and over six times more likely to have been declared a gross polluter three or more times. This pattern could be evidence of differential asymmetric information, with Mexican buyers less able to identify high-emitting "lemons".

Overall the results of these vehicle-level regressions imply that exports are "browner" 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

In this section we examine new vehicle sales in Mexico and vehicle retirement in both countries. Adjustments in purchase and retirement behavior are important because they may mitigate the direct environmental impact of trade. This section has three main results. First, there is no evidence of a change in vehicle retirement rates in the United States. NAFTA has not substantially increased exit rates for 10-15 year old vehicles, suggesting that most of the vehicles exported to Mexico are vehicles that would have been scrapped otherwise. Second, although data limitations make it impossible to assess the impact of NAFTA on vehicle retirement rates in Mexico, the cross-sectional age distribution of vehicles is striking, and implies dramatically lower vehicle retirement rates that those in the United States. Even if NAFTA has led to a modest increase in vehicle retirement rates, traded vehicles are still likely to be used for many more years than they would have been in the United States. Third, there is no evidence that trade decreased sales of new vehicles in Mexico, providing evidence that NAFTA indeed led to a substantial net-increase in the number of vehicles in circulation.

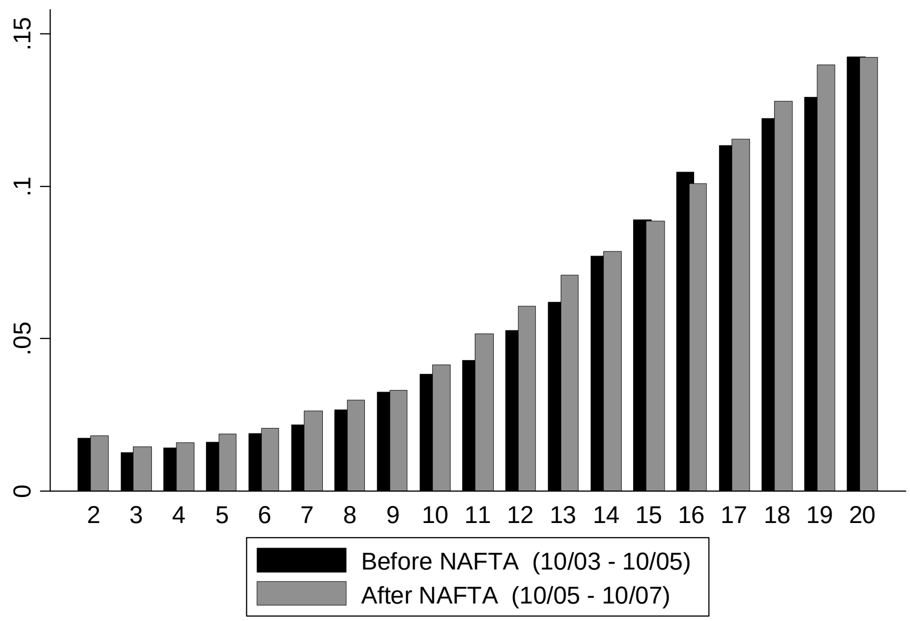
5.1 Vehicle Retirement in the United States

Figure 4 plots exit rates by vehicle age in the United States before and after NAFTA.[27] 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 modest increases in exit rates after NAFTA for 10-15 year old vehicles. Five out of the six differences are statistically significant at the 1% level. However, the increases imply only approximately 180,000 additional exits annually among 10-15 year old vehicles relative to the earlier period.[28] This is considerably smaller than the 1 million vehicles per year that were exported annually to Mexico during this period. We conclude 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. This is consistent with the evidence from section 4.3 that showed that very low-quality vehicles are more likely than other vehicles to be traded.

[27] 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.

[28] These data measure exits with a lag because vehicles are registered only once a year. Results are similar (315,000 additional exits), however, when we instead define the post-NAFTA period as October 2006 to October 2007, which includes exits from October 2006 to October 2007 and delayed exits from October 2005 to October 2006.

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



Source: R.L. Polk & Company.

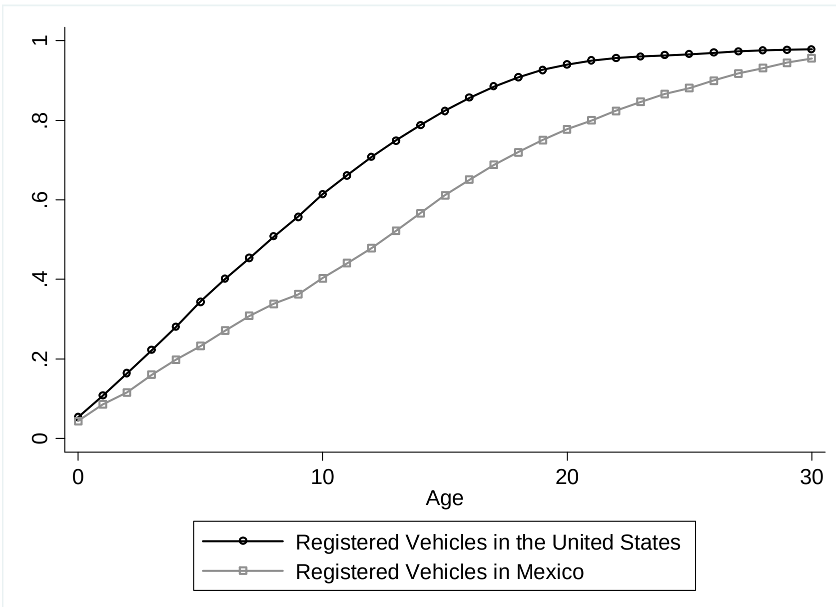
The fact that NAFTA appears to have had little effect on the number of registered vehicles in the United States is perhaps not surprising. The stock of used vehicles in the United States is large, so increased demand for used vehicles is unlikely to have raised used vehicle prices more than a few hundred 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 were retired annually in the United States, 2.1 million vehicles 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.

5.2 Differential Vehicle Retirement Rates in the United States and Mexico

Figure 5 plots the age distribution of vehicles in the United States and Mexico. Consistent with the predictions of the model, vehicles in Mexico tend to be much older. The age distribution of vehicles in Mexico is almost linear, implying vehicle retirement rates near zero. Overall, the average age of vehicles in the United States is 9.4 years compared to 13.5 years in Mexico and 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



Our model implies that trade liberalization will decrease used vehicle prices in Mexico, potentially leading to increased vehicle retirement rates as Mexicans can more easily afford to replace aging vehicles. Repeated cross-sections of the stock of registered vehicles in Mexico are not available, making it impossible to directly examine the impact of NAFTA on vehicle retirement. Still, in light of the very low retirement rates in Mexico, it seems unlikely that any increase in retirement rates would have meaningfully offset the direct influx of used vehicles from the United States. Moreover, it seems clear that traded vehicles are, on average, likely to be used for many more years than they would have been in the United States.

5.3 Vehicle Sales in Mexico

Our model implies that the increased availability 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.[29] 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 decrease during the post-NAFTA period, though sales appear 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.

Figure 6. Monthly Sales of New Vehicles in Mexico

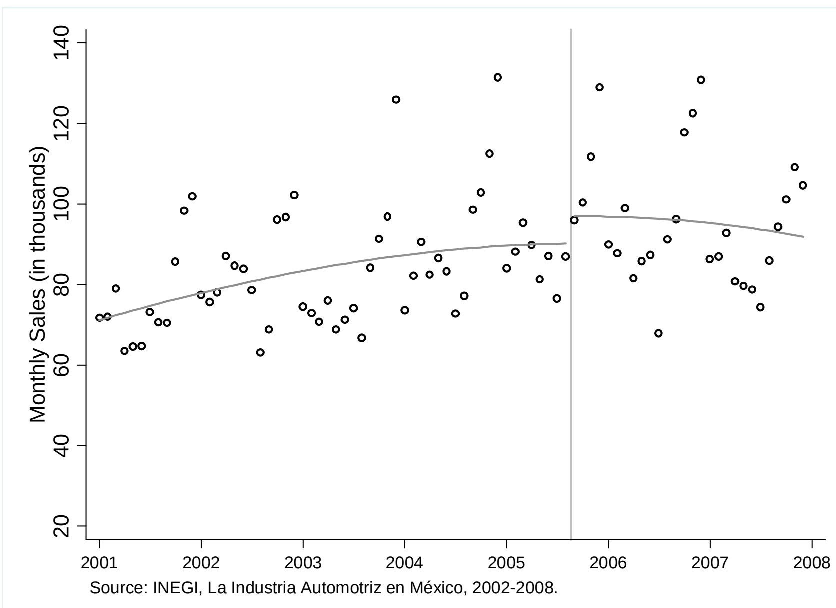


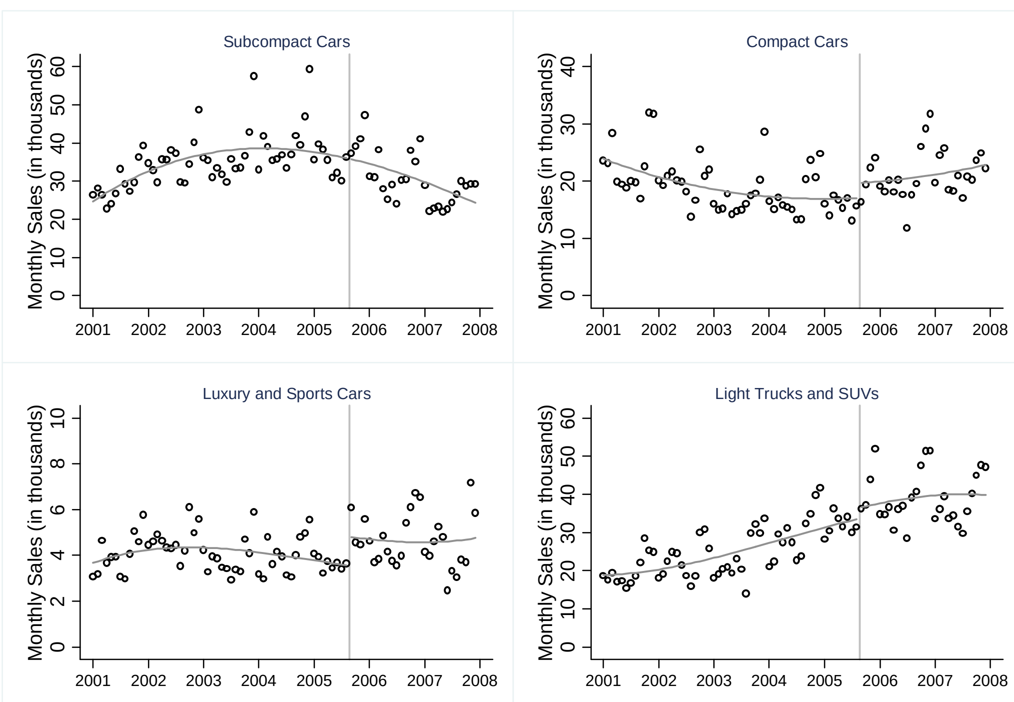
Figure 6 plots monthly sales of new vehicles in Mexico during the period January 2001 to December 2007, as well as a fitted cubic polynomial in time with intercept at

[29] Recent publications from the Mexican Association of Automobile Distributors describe trade in used vehicles as an environmental and commercial threat. 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.

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 compacts, luxury cars, 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 would make sense that this category would have been the most likely to be affected. Still, we are hesitant to make definitive statements about causality because the decline in subcompact sales appears to begin even prior to trade deregulation and seems to be offset by increases in the other three categories.

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



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

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. Overall, the vehicle sales data provide little evidence of substitution away from new vehicles.

In future work it would be valuable to examine trade's general equilibrium effects 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). In related work, Clerides (2008) uses a general equilibrium model of the automobile market to establish the gains from trade from a 1993 law that relaxed vehicle import restrictions in Cyprus, finding that welfare gains averaged $2000 per purchaser. 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.

6 An Illustration of How Trade Can Increase Lifetime Carbon Emissions

In this section we evaluate the implications of international trade in used vehicles between the United States and Mexico for carbon dioxide 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. 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 calculate the annual increase in global carbon emissions associated with Mexico importing a vehicle from the United States. Short-run carbon emissions are the product of the number of miles driven annually and emissions per mile:

$$Short\ Run\ Emissions\ =\ (Miles\ Driven)(Emissions\ per\ Mile).$$

For the long-run illustration, we calculate the lifetime increase per vehicle in carbon emissions,

$$Long\ Run\ Emissions = \int_0^\infty (Miles\ Driven)\ (Emissions\ per\ Mile)\ \lambda e^{-\lambda y} dy$$

where λ is the vehicle retirement rate. The long-run cumulative impact of trade is particularly important in this context because vehicle retirement rates in Mexico are low, so vehicles tend to be used for many years. For λ we use .038, the average annual retirement rate for vehicles 10-30 years from section 5.2. In addition, we assume that the maximum lifespan for the vehicle after entering Mexico is 30 years. For miles driven, we use the average number of miles driven annually per vehicle in each country. Vehicles in Mexico travel an average of 6,100 miles annually compared to 12,400 miles annually in the United States.[30] We would have preferred instead to use measures of miles driven

[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

that vary by vehicle vintage, but with no vehicle-level information available on miles driven in Mexico, this was not possible.

Table 7 reports the results. In the short-run, carbon dioxide emissions increase by 2.6 tons annually. Using $35 per ton carbon ($9.9 per ton of carbon dioxide) from Nordhaus (2009), this implies social costs of $25 per vehicle. The long-run results are considerably larger. The total lifetime increase in carbon dioxide emissions is 46.6 million tons. Total social cost, using a 1.5% annual discount rate from Nordhaus is $376. For the 2.5 million vehicles exported from the United States to Mexico during the period 2005-2008 these results imply total lifetime social costs of $940 million.

These results provide a valuable preliminary assessment of the impact of U.S.-Mexico trade in used vehicles on carbon dioxide emissions. However, it is important to emphasize that these results are based on several assumptions, many of which can be only partially verified empirically. Perhaps most importantly, we are assuming implicitly that prior to driving an imported used vehicle, 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.

It is also worth highlighting that 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 emissions of local pollutants could be large. 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 calculate the social costs of the resulting increases.

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differences in commuting patterns.

7 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 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 emissions of local and global pollutants 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 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, 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 decreases 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 tendency of trade to increase durable good lifespans is likely to be the case not just for the United States and Mexico, but for international trade more generally.

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 durable goods can be traded. For example, any policy that increases the cost of gasoline in the United States will likely increase exports of used vehicles, leading to increased emissions in importing countries. In contrast, increasing fuel economy standards or offering "cash for clunkers" (Blinder, 2008) would increase the price of used vehicles in the United States, decreasing trade.[31] Thus, the broader conclusion of our analysis is that the composition of trade can change sharply as U.S incentives change.

[31] As articulated by 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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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: 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	Tauras (Car)	.03

TABLE 3

Comparing Traded Vehicles to the Stock 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 stock of vehicles in the United States,vehicles exported from the United States to Mexico between August 2005 and July 2008, and the stock of vehicles in Mexico. See equations in section 4.2 for details.

TABLE 4

Comparing Traded Vehicles to the Stock in the United States, at the Vehicle-Level

	California				Illinois		
	With Vintage Fixed Effects	With Make Vintage Interactions	With Model Vintage Interactions	With Model Vintage Interactions and Quadratic in Mileage	With Vintage Fixed Effects	With Make Vintage Interactions	With Model Vintage Interactions
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Local Pollutants:							
Hydrocarbons (in logs)	.086	.097	.089	.048	.294	.152	.067
	(.004)	(.004)	(.004)	(.004)	(.014)	(.014)	(.013)
Carbon Monoxide (in logs)	.104	.084	.062	.022	.204	.086	.016
	(.004)	(.004)	(.004)	(.004)	(.017)	(.017)	(.016)
Nitrogen Oxide (in logs)	.135	.076	.068	.014	.091	.004	.016
	(.005)	(.005)	(.005)	(.005)	(.022)	(.022)	(.022)
Miles on Odometer (1000s)	9.88	11.21	9.68		-	-	-
	(.188)	(.179)	(.176)				
Global Pollutants:							
Predicted Miles Per Gallon	-1.54	-0.24	0.05		-	-	-
	(.020)	(.017)	(.013)				
Vehicle Weight (pounds)	231.7	53.8	-0.6		-	-	-
	(3.19)	(2.85)	(2.36)				
Cylinders	0.29	-0.11	-0.06		-	-	-
	(.005)	(.004)	(.003)				
Engine Size (liters)	0.43	-0.03	-0.04		-	-	-
	(.004)	(.003)	(.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 1991-1998. Local pollutants are measured in logs. All other vehicle characteristics are measured in levels. Out of 3.6 million vehicles in the California data, 83,057 vehicles were exported. Of the 503,000 vehicles in the Illinois data, 9,735 vehicles were exported.

TABLE 5

Are Exported Vehicles More Likely to be Super-Emitters?

	California Sample With Model Vintage Interactions
1(Failed Emissions Test Once)	1.21
	(.013)
1(Failed Emissions Test Twice)	3.15
	(.055)
1(Failed Emissions Test Three or More Times)	4.61
	(.224)
1(Gross Polluter Once)	1.25
	(.027)
1(Gross Polluter Twice)	3.54
	(.122)
1(Gross Polluter Three or More Times)	6.07
	(.589)

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 3.15 times more likely to have failed emissions testing twice. The sample includes all vehicles in the California dataset with model years 1991-1998.

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	-.047	.088	.180	.031
	(.032)	(.052)	(.068)	(.085)	(.067)
Third-Order Polynomial Time Trend	-.015	-.045	.053	.197	-.054
	(.033)	(.055)	(.064)	(.082)	(.054)
Fourth-Order Polynomial Time Trend	-.019	-.044	.048	.196	-.061
	(.033)	(.056)	(.064)	(.082)	(.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. The sample includes January 2001 to December 2007. 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 Emissions Per Vehicle (Tons)	2.6	46.6
Social Cost Per Vehicle (Dollars)	$25	$376

Note: This table describes the short-run (1 year) and long-run (lifetime) increase in carbon emissions associated with Mexico importing a vehicle from the United States. For details see section 6.