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Trade liberalization, consumption shifting and pollution: Evidence from Mexico's used vehicle imports

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2022-02

Working Paper
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Trade Liberalization, Consumption Shifting and Pollution: Evidence from Mexico's Used Vehicle Imports*

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Abstract: This paper develops a model of used vehicle trade between countries with different environmental regulations regarding vehicle emissions. We show that the US, given its strict environmental regulations, has incentives to export used vehicles to Mexico, which impacts air pollution emissions caused by automobile driving in Mexico. Using a unique database on vehicle registration in Mexico and imports after the NAFTA enactment, we find that Mexico's used vehicle imports reduced average pollution emissions generated by vehicles, mainly due to the "technique effect" -differences in emissions of vehicles of comparable model and age between those that operate in the US before being imported (that emit less pollutants) and those operating in Mexico.
Keywords: Trade Liberalization, Used Vehicles, Pollution Emissions, Technique Effect
JEL Classification: F13, L62, Q56, Q51

Resumen: En este documento se desarrolla un modelo del comercio de vehículos usados entre países con diferentes regulaciones ambientales con respecto a las emisiones de autos. Se prueba que en EUA, dado las estrictas regulaciones ambientales, hay incentivos para exportar autos usados a México, lo cual afecta las emisiones de contaminación del aire por la movilidad vehicular en México. Utilizando una base de datos del registro de vehículos en México y de importaciones posteriores a la firma de TLCAN, se encuentra que las importaciones de vehículos usados de México redujeron el promedio de emisiones de contaminantes vehiculares debido principalmente al "efecto técnico" -diferencia de emisiones de vehículos de modelo y edad comparables entre los que circulan en EUA antes de ser importados (emiten menos contaminantes) y los que circulan en México.
Palabras Clave: Liberalización comercial, Autos usados, Emisiones de contaminantes, Efecto técnico

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1. Introduction

As different countries impose different quality standards on public goods like clean air, such asymmetries may lead to different economic and regulation settings. In particular, the linkage between the environment and trade is mainly focused on pollution generated from production, particularly in the manufacturing sector.[1] However, pollution generated from the consumption side has been less studied, even though it is a significant contributor to global pollution. A good example of consumption-generated pollution is vehicle driving, which accounts for a large fraction of air pollution emissions.[2] Moreover, the global trade in vehicles is large, a significant fraction of which involves used vehicles. For example, Japan exported nearly 4 million vehicles to the world in 2015, 32% of which were used vehicles, while the United States exported 2.4 million vehicles to other countries in 2015, 22% of which were used vehicles.[3] Therefore, in this article, we are interested in examining the effects of trade in used vehicles on pollution emissions generated by vehicle driving.

First, we develop a theoretical model of trade between two countries, the North and the South, differing in their environmental regulations on emissions, following Clerides and Hadjiyiannis (2008). Vehicles are assumed to exist for three periods in which they can be: new, used, or clunkers. The North has a monopoly on producing new vehicles and selling them in both countries. Used vehicles and clunkers can be sold in perfect second-hand markets without transaction costs. Consumers purchase at most one vehicle in each period, and consumers' preferences for a vehicle's quality are uniformly distributed in both the North and South to generate smooth aggregate demand. To simplify the dynamics, we solve the

[1] See Cherniwchan et al. (2017) for a recent survey on trade and the environment.

[2] Vehicle driving alone accounts for 53.6% of total carbon monoxide (CO) emissions, 57.7% of total nitrogen oxide (NOx) emissions, 23.4% of total emissions of volatile organic compounds (VOC), and 8.1% of total emissions of particulates in the United States in 2014. In the Mexico City Metropolitan Area, all types of driving vehicles accounted for 99% of CO emissions, 95% NOx, 44% of VOC, and 59% greenhouse gases of total emissions in 2012.

[3] In 2015, the portion of used vehicles that were exported as a percentage of total vehicle registration was 2.2% for Japan and 0.45% for the United States. Data for Japan were calculated by the authors based on Trade Statistics from Japan's Ministry of Finance. Data for the United States were calculated by the authors based on the United States International Trade Commission (USITC) Interactive Tariff and Trade DataWeb, using the commodity code HTS-8703: Motor vehicles and other motor vehicles designed to transport people.

model in stationary equilibrium in which the monopolist chooses a constant price path for the new vehicles in each period.

Within this context, we examine the effects of trade in used vehicles by comparing the equilibrium outcomes in three trade regimes: (1) no used vehicles are allowed to be traded ("Autarky" regime); (2) only used vehicles are allowed be traded ("UC" regime); and (3) both used vehicles and clunkers are allowed to be traded ("UCC" regime). We find that, in autarky, the North, the country with stricter emissions regulations, has a comparative advantage in used vehicles and clunkers which creates a motive for trading in used vehicles that is not exploited before trade liberalization. As a result, the North will export used vehicles and/or clunkers to the South in UC and/or UCC regimes when trade in used vehicles is open between the two countries, which shifts some of the consumption of new vehicles to older used vehicles in the South. The consumption shifting changes the size and composition of the new vehicles, used vehicles, and clunkers on the road in the South. These results imply that trade in used vehicles affects pollution emissions generated from vehicle driving in the South through three potential channels: scale effect, composition effect, and technique effect.

We then focus our analysis on empirically quantifying the effects of trade in used vehicles on pollution emissions. In particular, we examine used vehicle trade between Mexico and the United States after NAFTA, which is perhaps the best-documented example of North-South trade in used vehicles. Although NAFTA came into effect in 1994, Mexico was allowed to restrict its used vehicle imports until January 1, 2019. Imports of used vehicles into Mexico were strictly prohibited before 2005. After 2005, there were restrictions on the age of used vehicles allowed for import into Mexico, and these restrictions were gradually relaxed until 2019. We collect a unique dataset on used vehicle imports, new vehicle sales, vehicle registration by state and age in Mexico from 1995 to 2012 for implementing our empirical analysis.

Using the data, we first run regressions to investigate the effects of used vehicle imports on vehicle fleet size and composition in Mexico. Our estimation results demonstrate that when moving from the Autarky to the UC regime between 2005 and 2008 in Mexico (when

only vehicles between 10 and 15 years old were allowed to be imported), imports of used vehicles decreased new vehicle sales, conversely, when moving from the UC regime to the UCC regime from 2009 to 2012 (when restrictions on the age of used vehicles allowed for import were gradually relaxed beyond 10 to 15 years old), imports of used vehicles increased new vehicles sales. The regressions on the quantities of registered vehicles in the full sample for vehicles of all age ranges and subsamples for vehicles of different ages indicate that used vehicle imports in Mexico slightly increased the total fleet size of registered vehicles. Meanwhile, the estimated effects of used vehicle imports differ across subsamples for vehicles of different age ranges. These results suggest that used vehicle imports in Mexico affect the fraction of registered vehicles belonging to different age ranges, which suggests a composition effect.

Finally, we use our estimates to analyze the effects of used vehicle imports on pollution emissions generated by vehicle driving in Mexico. We focus our study on four major air pollutants: methane (CH_4), carbon monoxide (CO), oxides of nitrogen (NOx) and volatile organic compound (VOC). Our results demonstrate that although used vehicle imports increase the total number of used vehicles registered, they lowered pollution emissions per auto average by approximately 0.27%-14.68% in Mexico from 2005 to 2012, depending on the pollutants considered. We further decompose the total effects into *scale, composition and technique* effects. The decomposition of total emissions shows that the negative effect or drop in average emissions is explained by what we called the technique effect, created by the differences in emissions of vehicles of comparable model and age between those that originally operate in the United States before being imported and those vehicles in Mexico. More specifically, the scale effect (change in the total number of vehicles) increased emissions by 46.91%-54.13%, and the composition effect (change in proportions by age) increased the emissions by 2.18%-3.60%, while the technique effect decreased pollution emissions by 50.34%-72.42%, depending on the pollutants considered.

This paper contributes to a large body of literature examining the environmental consequences of trade liberalization. The argument made most frequently in the literature is the pollution haven hypothesis (PHH) proposed by Grossman and Krueger (1993) and later

formalized by Copeland and Taylor (1994). The debate on PHH has been largely settled by empirical work demonstrating that trade liberalization appears to have a small impact on production-generated pollution. For example, Antweiler et al. (2001) show that the composition effects of trade have only minor environmental consequences. Similarly, Levinson (2009) demonstrates that shifting polluting industries overseas has contributed at most 10% to the overall cleanup of US manufacturing. Even though there is some work on the consumption-generated pollution of trade liberalization,[4] there has been little empirical analysis of the topic.[5]

This paper also draws on the empirical literature on the effects of policy changes on vehicle emissions. Currently this empirical literature is very small.[6] Oliva (2015) finds that the effectiveness of compulsory vehicle emission inspections on vehicle emissions is compromised by corruption in Mexico City. The most closely related empirical paper is Davis and Kahn (2010) who also empirically study the environmental consequences of exporting used vehicles from the United States to Mexico in 2005-2008. They find that trade decreased average emission levels in the United States and increased average emission levels in Mexico for carbon dioxide by focusing on only scale and composition effects. In contrast, following the guidance of our theoretical model, we calculate the effects of used vehicle trade on pollution emissions generated from registered vehicles in Mexico by considering three effects: scale, composition, and technique effects. We argue that the overlooked technique effect is significantly large relative to the scale and composition effects.

The organization of the paper is as follows. In section 2, we present a theoretical model to analyze the Autarky equilibrium, explore countries' incentive to trade, and examine how trade affects vehicle consumption under both UC and UCC regimes. The empirical analysis is developed in Section 3, in which we quantify the effects of used vehicle imports on vehicle

[4] Copeland and Taylor (1995) first develop a theory to demonstrate how differences in environmental regulation for consumption-based pollution altered predictions from PHH, which is extended by McAusland (2008). Theoretical research on trade liberation and consumption-generated pollution also includes Hu and McKitrick (2016), Fujiwara (2010), and Kellenberg (2010).
[5] To our knowledge, the only exception is Davis and Kahn (2010).
[6] This is mainly limited by the lack of available data, as "high quality measures of emissions from consumption rarely exist, making empirical work difficult" (Holladay, 2008).

consumption in Mexico and the related effects on pollution emissions generated by vehicle driving. Section 4 offers some concluding remarks. The appendix includes all the proof and tables.

2. A Model of Trade in Used Vehicles

Our model extends the durable goods model featuring quality certification developed by Clerides and Hadjiyiannis (2008) by allowing vehicles to exist for three periods. We use this model to analyze how trade in used vehicles under different regimes affects the fleet size and composition of vehicles and the channels through which trade in used vehicles affects pollution emissions.

2.1 Model Setup

We consider any vehicle in use for all three of the following defined periods. A vehicle is considered to be "new" in period one of its life and it provides a predetermined level of quality denoted by s. In period two of its life, the vehicle becomes "used" and its quality drops to $k_u s$, with $k_u \in [0,1]$. In period three of its life, it becomes a "clunker" and its quality drops to $k_c s$, with $k_c \in [0,1]$ and $k_c \leq k_u$. At the end of period three, the vehicle is scrapped without quality. We hereafter use subscript "n" to denote variables for new vehicles, subscript "u" for used vehicles, and subscript "c" for clunkers.

New vehicles are produced by an infinitely lived monopolist, who produces vehicles without capacity constraints at a constant marginal cost of M. The monopolist chooses the price of new vehicles at the beginning of each period to maximize profit. To simplify the analysis, we follow Clerides and Hadjiyiannis (2008) by focusing on a stationary equilibrium in which the monopolist chooses a constant price path for new vehicles in every period; that is, there is only one price p_n for new vehicles in all periods. This implies that the market outcome will be identical in every period such that the prices of new and used vehicles, and clunkers are constant in every period, $p_{n,t} = p_n$, $p_{u,t} = p_u$, $p_{c,t} = p_c$ for all t, and then market demand for new vehicles is also constant at every period, $Q_{n,t} = Q_n$ for all t.

Used vehicles and clunkers are sold on the second-hand market without market frictions and transaction costs. Therefore, the number of used vehicles in each period is equal to the number of new vehicles in the previous period and, similarly, the number of clunkers in each period is equal to the number of used vehicles on the market in the previous period, $Q_{n,t} = Q_{u,t+1} = Q_{c,t+2}$. In stationary equilibrium, the number of new vehicles will be equal to that of used vehicles and clunkers for all periods, $Q_n = Q_u = Q_c$. To be sold, used vehicles and clunkers must pass a vehicle emission inspection, such as the emission inspection and maintenance (I/M) program in the United States.[7] To pass inspection, a used vehicle and a clunker incur costs T_u and T_c to the owner of the vehicle. We assume that $T_u \leq T_c$, as it is more costly to maintain a clunker to pass inspection than a used vehicle.

On the demand side, there is a constant density Φ of infinitely lived consumers demanding vehicles. All consumers are differentiated only in their willingness to pay for the quality of vehicles, v, and identical in all other aspects. We assume that v is uniformly distributed over the interval $[\underline{v}, \overline{v}]$ with density $f(v) = 1/(\overline{v} - \underline{v})$. At the beginning of each period, each consumer receives the same income flow of y, which will be allocated between a composite numeraire good and a vehicle. The assumption that used vehicles and clunkers can be sold without transaction costs in the second-hand market implies that owning a vehicle is equivalent to owning cash equivalent to the vehicle's value. Therefore, owning or not owning a vehicle does not affect consumers' purchase decisions.

The utility consumers derive from purchasing a new vehicle, used vehicle, clunker, and no vehicle in each period is then given by $U_n = y - (p_n - \delta p_u) + vs$, $U_u = y - (p_u + T_u - \delta p_c) + vk_u s$, $U_c = y - (p_c + T_c) + vk_c s$, and $U_0 = y$, respectively, where the second term in U_n, U_u, and U_c is the cost to own a vehicle, or the difference between purchasing price and resale price plus the inspection cost for reselling. Comparing the above four utility functions determines the demand functions for new vehicles, used vehicles, and clunkers, which are denoted by $Q_n(p_n, p_u, p_c)$, $Q_u(p_n, p_u, p_c)$ and

[7] According to the United States Environmental Protection Agency (EPA), "Vehicle inspection and maintenance programs (I/M) help improve air quality by identifying high-emitting vehicles in need of repair and causing them to be fixed as a prerequisite to vehicle registration within a given non-attainment area."

$Q_c(p_n, p_u, p_c)$, respectively. The explicit forms for these functions and their derivations are provided in the proof of Proposition 1 in Appendix A.

2.2 Autarky Equilibrium

We first solve for equilibrium prices and demand for new vehicles, used vehicles and clunkers in autarky. In this context, an economy of autarky refers to the conditions in which the international trade in used vehicles is closed. The equilibrium prices emerge from the monopolist's profit maximization condition for new vehicles and market clearing conditions for used vehicles and clunkers in second-hand markets. The first order condition of the monopolist's profit maximization problem is derived as[8]

$$p_n = \frac{1}{2}[\overline{v}s(1 - k_u) + (1 + \delta)p_u - \delta p_c + T_u + M]. \tag{1}$$

Market clearing conditions for used vehicles and clunkers imply that the supply of used vehicles and clunkers is equal to the demand for them in the second-hand market,

$$Q_n(p_n, p_u, p_c) = Q_u(p_n, p_u, p_c), \tag{2}$$

$$Q_u(p_n, p_u, p_c) = Q_c(p_n, p_u, p_c). \tag{3}$$

Equations (1)-(3) generate three equations to solve for three equilibrium (vehicle) prices p_n, p_u and p_c. Demand for the three types of vehicles can be derived by using the demand functions accordingly. Proposition 1 summarizes the effects of the emission inspection on these equilibrium prices and demand for new vehicles, used vehicles and clunkers.

Proposition 1. *Emission inspection in an autarky economy in used vehicles and clunkers leads to: (i) decreases in all prices of new vehicles, used vehicles, and clunkers; and (ii) decreases in the quantities of new vehicles, used vehicles, and clunkers sold in the market.*

Proof: See Appendix A. □

The reason that the emission inspection decreases the prices and quantities of used vehicles and clunkers is intuitive. The emission inspection increases the cost of owning these

[8] See Appendix for derivation.

vehicles, which drives down the demand and their prices. It seems counterintuitive that the inspection decreases the price and quantity of new vehicles. On the one side, the decrease in demand for used vehicles and clunkers might increase the demand for new vehicles because they are substitute. On the other side, the introduction of the emission inspection drives the prices of used vehicles and clunkers down, which decreases the cash value of owning a new vehicle. This income effect decreases the price and quantity of new vehicles and is larger than the substitution effect. As a result, the inspection will also decrease the price and quantity for new vehicles.

2.3 Effects of Trade in Used Vehicles and/or Clunkers

We now analyze how trade in used vehicles and/or clunkers affects market equilibrium demand for the three types of vehicles. To do so, we introduce a second country in which used vehicles and clunkers do not need to undergo an emission inspection. We call the original country the "North" and the second country the "South", and the variables relating to corresponding countries will be denoted using N and S, respectively. We also assume that the South does not produce new vehicles, such that the monopolist in the North produces and sells new vehicles in both countries. The two countries are identical in every other aspect.

When the two countries differ only in emission inspection policies, the North will have a comparative advantage in used vehicles and clunkers, which creates the motive for trade between the two countries. Proposition 1 implies that the emission inspection reduces the price of older vehicles more than that of newer vehicles in Autarky. As a result, the relative prices of newer vehicles compared to older vehicles in the North with the emission inspection will be higher than those in the South without the emission inspection in autarky. The following lemma confirms our intuition formally.

Lemma 1. *The North has higher prices for new vehicles relative to used vehicles than the South in autarky; The North also has higher prices for used vehicles relative to clunkers than the South in autarky. That is,*

$$\frac{p_n^N}{p_u^N} > \frac{p_n^S}{p_u^S}, \qquad \frac{p_u^N}{p_c^N} > \frac{p_u^S}{p_c^S}. \tag{4}$$

Proof: See Appendix A. □

The inequalities in (4) imply that it is relatively cheaper to own an older vehicle than to own a relatively newer vehicle in the North. Presumably, if older vehicles are relatively dirtier (emit more) than newer vehicles, Lemma 1 shows that the North with its stringent environmental regulations has a comparative advantage in relatively older and dirtier vehicles when pollution is generated by consumption, or vehicle driving. This differs from the main result in the pollution haven hypothesis (PHH) literature, which indicates that the country with stringent environmental regulations has a comparative advantage in cleaner goods when pollution is generated by production. Therefore, the difference in environmental regulations between countries in our context creates a motive for trade.

2.3.1 Trade in Used Vehicles (UC Regime)

In this section, we analyze the effects of trade in which only used vehicles can be traded (the UC regime) on market equilibrium demands for the three types of vehicles.[9] We first solve the market equilibrium prices by using the monopolist's profit maximization condition for new vehicles and market clearing conditions for used vehicles and clunkers in the second-hand markets in both countries. The first order condition of the monopolist's profit on new vehicle prices in both countries is derived as,

$$p_n^j = \frac{1}{2}\left[\overline{v}s\left(1 - \Delta_j k_u\right) + (1+\delta)p_u^j - \delta p_c^j + \Delta_j T_u + M\right],\ j \in \{N, S\}, \tag{5}$$

where $\Delta_j = 1$ for the North $j = N$ and $\Delta_j = 0$ for the South $j = S$. In this UC regime in which only used vehicles can be traded, the market clearing condition for used vehicles requires that the global quantity of new vehicles is equal to the global quantity of used

[9] The UC regime operates in some countries to avoid importing clunkers that will become the automotive waste in a short period. For instance, Cyprus prohibited imports of vehicles more than two years old before 1993. The Mexican government allowed imports of vehicles only between 10 and 15 years old, from 2005 to 2008.

vehicles, $Q_n^N + Q_n^S = Q_u^N + Q_u^S$, and the market clearing condition for clunkers requires that the quantity of used vehicles is equal to the quantity of clunkers in both countries, $Q_u^j = Q_c^j,\ j \in \{N, S\}$. Finally, free trade in used vehicles drives their prices to be equal across the two countries in equilibrium, which gives, $p_u^N = p_u^S$.

The above market equilibrium conditions provide us with six equations to solve six prices for new vehicles, used vehicles and clunkers in market equilibrium for both countries. The market equilibrium demands can then be derived by substituting these equilibrium prices into the demand functions. We then compare the market equilibrium demands in autarky with those in the UC regime to investigate the effects of trade in used vehicles on demand for the three types of vehicles. Proposition 2 summarizes the main results.

Proposition 2. *Moving from autarky to a UC regime leads to (i) an increase in the quantity of new vehicles in the North; (ii) a decrease in the quantities of both used vehicles and clunkers in the North; (iii) a decrease in the quantity of new vehicles in the South; and (iv) an increase in the quantities of both used vehicles and clunkers in the South.*

Proof: See Appendix A. □

The logic underlying these results is that free trade in used vehicles changes the cost gap between different types of vehicles. We focus on illustrating the results on the North. First, free trade in used vehicles reduces the price of new vehicles and increases the price of used vehicles, which narrows the difference in cost between owning new vehicles and used vehicles in the North. This induces some consumers to purchase new vehicles instead of used ones.

Second, free trade also increases the prices of clunkers, which also narrows the difference in cost between owning used vehicles and clunkers in the North, and shifting some consumers from purchasing clunkers to purchasing used vehicles or not purchasing a vehicle. The consumers shifting from used vehicles to new vehicles are more than those switching from clunkers to used vehicles, as some consumers buying clunkers in autarky shift to not

buying a vehicle. Therefore, the free trade in the UC regime increases the quantity of new vehicles and decreases the quantities of used vehicles and clunkers in the North. The effects on the quantities of the three types of vehicles in the South are the opposite of the effects seen in the North.

2.3.1 Trade in Both Used Vehicles and Clunkers (UCC Regime)

Finally, we investigate the effects of trade in the regime where both used vehicles and clunkers can be traded (the UCC regime) on market equilibrium demands for the three types of vehicles. As in the UC regime, market equilibrium prices are solved by using the monopolist's profit maximization conditions and market clearing conditions for used vehicles and clunkers in second-hand markets. The first order conditions from the monopolist's profit maximization problem are given by,

$$p_n^j = \frac{1}{2}\left[\overline{v}s\left(1 - \Delta_j k_u\right) + (1+\delta)p_u^j - \delta p_c^j + \Delta_j T_u + M\right],\ j \in \{N, S\}, \tag{6}$$

In the UCC regime, market conditions for used vehicles and clunkers in the world market require that the global quantity of new vehicles be equal to the global quantity of used vehicles, which is also equal to the global quantity of clunkers in equilibrium, $Q_n^N + Q_n^S = Q_u^N + Q_u^S = Q_c^N + Q_c^S$. Free trade in both used vehicles and clunkers will also equalize their prices across the two countries in equilibrium, which gives $p_u^N = p_u^S$, $p_c^N = p_c^S$.

The above conditions generate six equations to solve six market equilibrium prices for the three types of vehicles in both the North and the South. The market equilibrium demands for the three types of vehicles can be solved by substituting these prices into the demand functions. Proposition 3 summarizes the results regarding the effects of moving from the UC regime to the UCC regime in both countries.

Proposition 3. *Moving from the UC regime to the UCC regime leads to (i) a decrease in the quantities of new vehicles and clunkers in the North;(ii) an increase in the quantity of used*

vehicles in the North;(iii) an increase in the quantities of new vehicles and clunkers in the South; and (v) a decrease in the quantity of used vehicles in the South.

Proof: See Appendix A. □

We focus on explaining the logic behind the results in the North. Moving from the UC regime to the UCC regime increases the cost gap between owning new vehicles and owning used vehicles, which shifts some consumers from purchasing new vehicles to purchasing used vehicles in the North. Moving from the UC regime to the UCC regime narrows the cost gap between owning used vehicles and owning clunkers, which shifts some consumers from purchasing clunkers to purchasing used vehicles or not buying a vehicle. Therefore, free trade in both used vehicles and clunkers increases the quantity of used vehicles, but decreases the quantities of new vehicles and clunkers. The effects of free trade on purchase behavior among consumers in the South are the opposite of those in the North.

Based on the above analysis, we can see that free trade in used vehicles and/or clunkers affects the total quantity of vehicles, and also the fractions of the three types of vehicles in equilibrium in both countries. Moreover, a certain number of used vehicles and clunkers is also traded between the two countries, and model-age-comparable used vehicles and clunkers originally operated in different countries with different levels of stringency in environmental regulations may have different emission intensities. These facts imply that free trade in used vehicles and/or clunkers may affect pollution emissions through three potential channels: *scale* (the effect on the total number of vehicles), *composition* (the effect on the proportions of the three types of vehicles), and *technique* effects (due to the difference in the emission intensities of used vehicles originally operated in two countries). These three effects (scale, composition, and technique) will be formally defined in the empirical section.

3. Empirical Evaluation

In this section, we empirically quantify the effects of used vehicle imports on the quantity of vehicles registered and pollution emissions generated by vehicle driving in Mexico after NAFTA. Specifically, first we focus on how used vehicle imports in Mexico

affect new vehicle sales, and the number of registered used vehicles of different ages in Mexico. Subsequently, we empirically quantify the effect of used vehicle imports in Mexico on pollution emissions generated by vehicle driving. Moreover, we also decompose the total effects into the three components: the scale effect, the composition effect, and the technique effect.

3.1 Data

Although NAFTA came into force in 1994, Mexico was allowed to restrict imports of used vehicles until 2019 in order to protect its automobile industry. Used vehicles were not allowed to be imported to Mexico before 2005. From August 2005 to March 2008, Mexico allowed imports of used vehicles 10-15 years old from the United States and Canada. After 2008, the restriction was gradually relaxed. Hereafter, we refer to the period before the year 2005 as "Autarky", the period from 2005 to 2008 as "UC" regime, and the period after 2008 as "UCC" regime. Table 1 describes Mexico's used vehicles import policy in detail.

Table 1: Used Vehicles Import Policy in Mexico

Period	***Import Policies***	***Regimes***
Jul. 2005 and before	Strict Prohibition	Autarky
Aug. 2005−Mar. 2008	10-15 years old	UC Regime
Apr. 2008−Dec. 2008	10 years old	
Jan. 2009−Dec. 2010	≥10 years	
Jan. 2011−Dec. 2012	≥8 years	
Jan. 2013−Dec. 2014	≥6 years	UCC Regime
Jan. 2015−Dec. 2016	≥4 years	
Jan. 2017−Dec. 2018	≥2 years	
Jan. 2019 and after	all ages	

Source: Federal Official Gazette, Diario Oficial de la Federación.

To quantify the effects of used vehicle imports on new vehicle sales and the quantity of vehicles registered in Mexico, we collect data on the annual quantity of registered vehicles

in Mexico by state and age from 2000 to 2012[10], monthly total used vehicle imports in Mexico over the period from 2005 to 2015, and monthly new vehicle sales for four types of vehicles (subcompact, compact, luxury and sports, and light trucks) from 1995 to 2015. To quantify the effects of used vehicle imports on pollution emissions in Mexico, we gather data on the average emission intensities of four major pollutants and VKT (Vehicle Kilometers Travelled) for each age category of vehicles in both Mexico and the United States.[11]

The data on annual quantities of registered vehicles and monthly used vehicle imports are obtained from the Mexican Executive Secretary of National Public Safety and the Mexican Association of Automobile Distributions (AMDA), respectively.[12] The annual quantity of vehicles registered is approximately 2 million each year from 2002 to 2004 during the autarky period.[13] In the UC regime period from 2005 to 2008, the annual quantity of vehicles registered dropped to approximately 1.5 million, while imports of used vehicles between 10 and 15 years old were permitted and an average of 1 million used vehicles were imported to Mexico annually during that period. In the UCC regime period from 2009 to 2012, the annual quantity of registered vehicles gradually increased to approximately 2.2 million while the restriction on the age of imported vehicles was gradually lifted. However, the number of used vehicles imported dropped dramatically to approximately 0.45 million annually.[14] Table 6 in Appendix B provides summary statistics for annual quantities of registered vehicles and imported used vehicles in Mexico from 2000 to 2012.

[10] There are 32 states in Mexico, all included in our analysis. The six states of the Megalopolis in the central region (Ciudad de Mexico, Estado de Mexico, Morelos, Tlaxcala, Puebla, and Hidalgo) accounted for 43 percent of the national vehicle registry in 2016 whereas the six Mexican states along the border with the US (Baja California, Sonora, Chihuahua, Coahuila, Nuevo León, and Tamaulipas) accounted for 18.4 percent.

[11] We briefly discuss the vehicle registration and import data in this section and will introduce the new vehicle sales and emission data when we study the effects of trade in used vehicles on them.

[12] Vehicle registration data source: *https://www.infomex.org.mx/gobiernofederal/home.action*. Vehicle imports data source: *http://www.amda.mx.*

[13] A caveat of the annual vehicle registry before 2005 is the enactment of the National Public Vehicle Registry (REPUVE, by its Spanish acronym) one year earlier, in 2004. In fact, data before 2005 relies on records voluntarily shared to REPUVE by some Mexican States, which may not reflect the actual size of national vehicle fleet.

[14] The Mexican Association of Auto Dealers has claimed that the slow recovery of domestic demand for new vehicles since the 2009 financial crisis is due to the fact that Mexico's local vehicle market is saturated by used vehicles imported from the United States. The dramatic decrease in vehicle imports in 2009 is due to the financial crisis.

3.2 Effects on New Vehicle Sales

To examine the effects on pollution emissions, we first analyze the effects of used vehicle import policy on new vehicle sales in Mexico. There are many potential factors affecting new vehicle sales in Mexico. Therefore, we control for all possible factors we obtained from the data. In particular, to study the effects of used vehicle imports moving from autarky to the UC regime, we run the following regression using the data from 1995 to 2008,

$$y_{t,m} = \beta_0 + \beta_1 UC_{t,m} + \beta_2 \left(UC_{t,m} \times Import_{t,m} \right) + X_{t,m} \boldsymbol{\gamma} + \varepsilon_{t,m}, \tag{7}$$

where $y_{t,m}$ is the total quantity of new vehicles sold (number of vehicles in logs) in month m in year t in Mexico; $UC_{t,m}$ is a dummy variable, which equals 1 for the period between August 2005 and December 2008 and 0 before August 2005. $Import_{t,m}$ is the quantity of vehicles imported to Mexico in month m in year t. $X_{t,m}$ is a 1×4 row vector of control variables, including month and lagged month indicator variables for month m, quarterly GDP growth rate, and per capita household final consumption (in logs) in month m in year t in Mexico. β_0, β_1, and β_2 are scalar parameters to be estimated, while γ is a 4×1 column vector of parameters for the control variables to be estimated.

Monthly data on new car sales in Mexico are also obtained from AMDA, which provides information on total number of new car sales and sales of each different type of cars from 1995 to 2015. Table 2 presents the estimation results from regression equation (7) using data from 1995 to 2008 for the full sample and four subsamples divided by vehicles size. The estimates suggest that used vehicle imports may decrease new vehicle sales in Mexico. The results for new vehicle sales are consistent with the model prediction in Proposition 1. The coefficient associated with the interaction between the UC dummy and monthly used vehicle imports is significantly negative for new vehicle sales, which implies that more used vehicle imports decrease new vehicle sales. The coefficients of the UC dummies and the interaction terms in the subsample regressions are also negative, except for the coefficient of the UC dummy in the regression using the subsample of trucks and SUVs.

Table 2: Effects on New Vehicles Sold in the UC Regime Period in Mexico

	(1) Full Sample	(2) Subcompact	(3) Compact	(4) Luxury and Sports	(5) Trucks and SUVs
UC	-0.131**	-0.094	-0.423***	-0.253***	0.019
	(0.047)	(0.083)	(0.053)	(0.054)	(0.038)
UC*Import	-0.041***	-0.081***	-0.030***	-0.023***	-0.012**
	(0.005)	(0.008)	(0.004)	(0.004)	(0.004)
GDP Growth Rate	-0.002	-0.002	-0.004	0.002	0.004
	(0.011)	(0.017)	(0.010)	(0.012)	(0.009)
Final Consumption	6.958***	9.285***	6.606***	5.317***	5.504***
	(0.509)	(0.770)	(0.536)	(0.617)	(0.459)
One-month Lag	Yes	Yes	Yes	Yes	Yes
Observations	168	168	168	168	168

Note: Own estimates of model (7). We include *one-month lag variables for all five regressions due to the serial correlation of new vehicle sales.* Standard errors are in parentheses. * p < 0.05, ** p < 0.01, *** p < 0.001.
Sources: INEGI and Mexican Association of Automobile Distributions (AMDA).

To study the effects of used vehicle imports moving from the UC regime to the UCC regime, we run a similar regression using the data over the UC and UCC periods from 2005 to 2015,

$$y_{t,m} = \beta_0 + \beta_1 UCC_{t,m} + \beta_2 \left(UCC_{t,m} \times Import_{t,m} \right) + X_{t,m}\boldsymbol{\gamma} + \varepsilon_{t,m} \qquad (8)$$

where $UCC_{t,m}$ is a dummy variable, which equals 1 for the period after 2008 and 0 otherwise; the variables $y_{t,m}$, $Import_{t,m}$, $X_{t,m}$, and the parameters β_0, β_1, β_2, and $\boldsymbol{\gamma}$ are defined in the same way as in equation (7).

Table 3 presents the estimation results for regression equation (8), which suggest that, by moving from the UC regime to the UCC regime, imports of used vehicles may increase the total quantity of new vehicle sales in Mexico. This is consistent with the model prediction in Proposition 2. The estimate of the interaction between the UCC dummy and monthly used vehicle imports is significantly negative for the total number of new vehicle sales, which implies that greater used vehicle imports may decrease the effect of used vehicle imports. The coefficients associated with the UCC dummies and the coefficients associated with the

interaction between UCC dummies and imports in the subsample regressions are positive and negative, respectively, with the exception of the subsample of compact cars.

Table 3: Effects on New Vehicles Sold in the UCC Regime Period in Mexico

	(1) Full Sample	(2) Subcompact	(3) Compact	(4) Luxury and Sports	(5) Trucks and SUVs
UCC	0.814***	1.411***	-0.054	0.419	0.995***
	(0.195)	(0.358)	(0.183)	(0.241)	(0.198)
UCC*Import	-0.095***	-0.158***	0.0084	-0.047*	-0.121***
	(0.018)	(0.034)	(0.017)	(0.024)	(0.019)
GDP Growth Rate	0.018	0.030*	0.013	-0.002	0.013
	(0.009)	(0.013)	(0.009)	(0.011)	(0.008)
Final Consumption	3.400***	3.834***	4.190***	5.257***	2.346***
	(0.244)	(0.527)	(0.207)	(0.271)	(0.171)
One-month Lag	Yes	Yes	Yes	Yes	Yes
Observations	168	168	168	168	168

Note: Own estimates of model (8). We include *one-month lag variables for all five regressions due to the serial correlation of new vehicle sales.* Standard errors are in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Sources: INEGI and the Mexican Association of Automobile Distributions (AMDA).

3.3 Effects on the Scale and Composition of Vehicles

In this section, we investigate the effects of used vehicle imports on the scale and composition of vehicles registered in government offices in Mexico. The effect on the scale of registered vehicles captures the change in the total number of used vehicle imports on pollution emissions in Mexico, while the effect on the composition of vehicles captures changes in the proportions of the three types (by age) of used vehicle imports on pollution emissions. In the empirical analysis, the composition of vehicles is defined by the proportions of vehicles belonging to nine different age ranges, including new vehicles and other eight age ranges shown in Table 4.

We run the following regressions to quantify the effects of used vehicle imports on the quantity of registered vehicles by using vehicle registration data from 2000 to 2012 in Mexico for the full sample and 8 subsamples divided by the ages of vehicles,

$$y_{i,t} = \beta_0 + \beta_1 Import_t + X_{i,t}\boldsymbol{\gamma} + \varepsilon_{t,m} \quad (9)$$

where $y_{i,t}$ is the annual total quantity of registered vehicles (in logs) or the annual number of registered vehicles belonging to each age category in state i in year t in Mexico; $Import_t$ is the quantity of used vehicles (in logs) imported to Mexico in year t; $X_{i,t}$ is a 1×2 row vector of control variables, including state-level population and real GDP (in logs). β_0 and β_1 are parameters to be estimated, while $\boldsymbol{\gamma}$ is a 2×1 column vector of parameters for control variables to be estimated.

Table 4 presents the estimated coefficients for the nine regressions. Column (1) in Table 4 provides the estimates for the full sample regression, which shows that a 1% increase in the quantity of used vehicles imported to Mexico slightly increases the total quantity of vehicles registered annually from 2000 to 2010. Columns (2)-(10) in Table 4 present the estimates of the regressions for the nine subsamples. They show that the used vehicle import policy increases the quantities of vehicles registered for each age category of vehicles with the exception of new vehicles. Moreover, the estimates in columns (2)-(10) demonstrate that the magnitude of the effects on the quantity of vehicles registered differs across age categories, suggesting a composition effect.

Using the estimates in Table 4, we calculate the fitted quantities of vehicles that would have been registered in a counterfactual exercise in which used vehicle imports to Mexico were prohibited after 2005. The fitted quantities of vehicles registered in this counterfactual scenario and the observed quantities of vehicles registered for each age category are plotted in Figure 1.[15] The solid blue line represents the observed quantity of registered vehicles in the data, while the dashed red line represents the fitted quantity of registered vehicles in the counterfactual scenario. The figure demonstrates that the negative effect of used vehicle imports on the quantity of registered new vehicles is small, while the positive effect on the quantity of registered vehicles between 10 and 15 years old is the largest, and the positive effect on the quantity of registered vehicles older than 19 years old is the smallest. This is mainly because of the age constraint on used vehicle imports imposed by the Mexican

[15] Source: National Institute of Statistics and Geography (INEGI, by its Spanish acronym).

government from 2005 to 2008 -- only vehicles 10 to 15 years old were allowed to be imported to Mexico during this period.

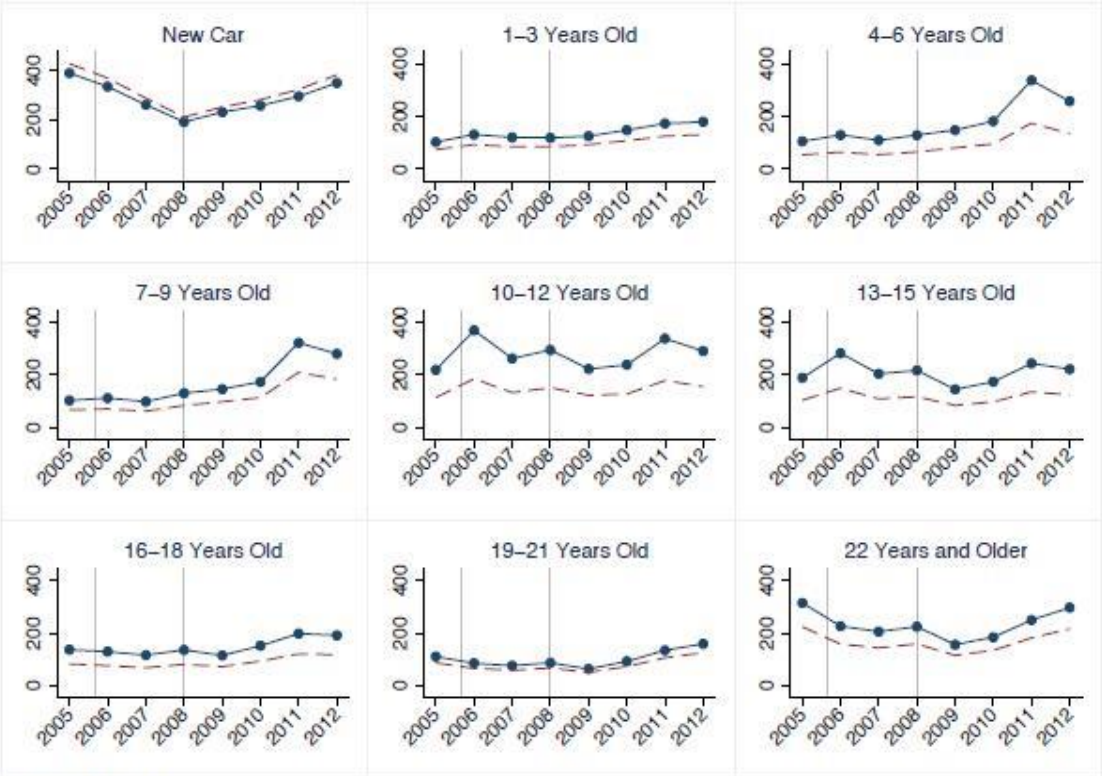
Table 4: Effects on the Quantity and Composition of Vehicles Registered in Mexico

	(1) All Ages	(2) New Cars	(3) Ages 1−3	(4) Ages 4−6	(5) Ages 7−9
Imports	0.048**	-0.007	0.025	0.050**	0.033*
	(0.018)	(0.022)	(0.018)	(0.016)	(0.016)
Population	0.341	0.416	0.444*	0.352*	0.287
	(0.187)	(0.224)	(0.186)	(0.160)	(0.170)
GDP	0.444**	0.575**	0.503**	0.696***	0.615***
	(0.171)	(0.208)	(0.172)	(0.148)	(0.157)
Constant	0.926	-3.128	-3.660	-3.873*	-2.040
	(2.005)	(2.414)	(2.002)	(1.724)	(1.823)
Observations	402	395	397	396	398

	(6) Ages 10−12	(7) Ages 13−15	(8) Ages 16−18	(9) Ages 19−21	(10) Ages ≥22
Imports	0.048**	0.045**	0.037*	0.018	0.025
	(0.016)	(0.016)	(0.017)	(0.017)	(0.018)
Population	0.795***	0.869***	0.744***	0.640***	0.418*
	(0.169)	(0.167)	(0.184)	(0.185)	(0.189)
GDP	0.144	-0.003	-0.027	0.063	0.169
	(0.155)	(0.154)	(0.168)	(0.170)	(0.173)
Constant	-5.298**	-5.427**	-3.781	-3.185	0.005
	(1.816)	(1.801)	(1.974)	(1.975)	(2.030)
Observations	396	394	397	396	398

Note: Own estimates of model (9). Standard errors are in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Sources: INEGI and the National Public Vehicle Registry.

Figure 1: Quantity of Registered Vehicles by Age Category (in thousands)



Source: INEGI

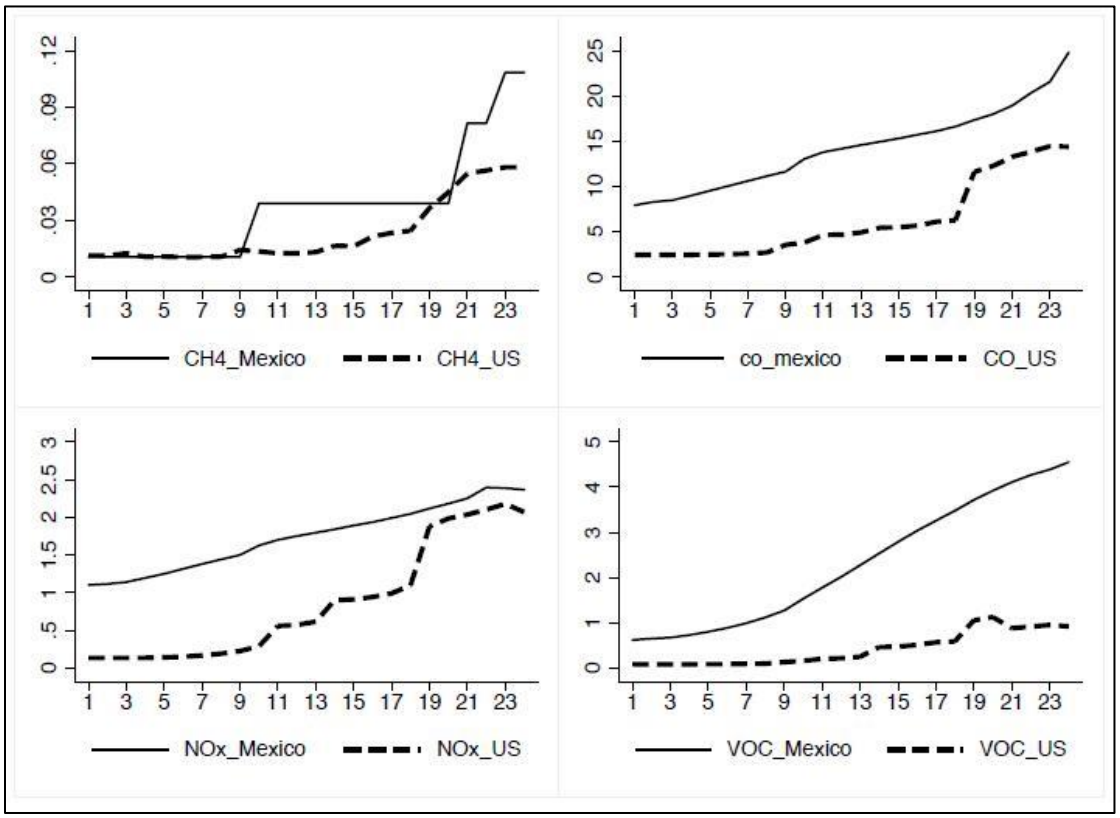
3.4 Effects on Pollution Emissions

One important goal of our empirical analysis is to quantify the effect of used vehicle import on the pollution emissions generated from vehicle driving by changing the quantity and composition of registered vehicles in Mexico. To do so, we collect data on the emission intensities of four major pollutants (CH4, CO, NOx, and VOC), Mexican and U.S. vehicles at different ages, and the Vehicle Kilometers Travelled (VKT) for vehicles in Mexico. The data on emission intensities and VKT for Mexico City and metropolitan area are obtained from the report "Inventory of Pollutant Emissions and Greenhouse Effect," while the data on emission intensities and VKT for the United States are collected from the technical report of Argonne National Laboratory (Cai et al., 2013).[16] The data on Mexico City in 2012 are used

[16] The Report on Pollutant Emissions and Greenhouse Effect (Inventario de Emisiones Contaminantes y de Efecto Invernadero 2012), by the Secretariat of the Environment of Mexico City, is available on line at http://www.aire.cdmx.gob.mx/descargas/publicaciones/flippingbook/inventario-emisioneszmvm2012/#p=1

to proxy the emission intensities for vehicles in the whole country. Our data demonstrate that emission intensities increase with a vehicle's age, and Mexican vehicles generally emit more than vehicles from the United States at the same age. See Figure 2.[17]

Figure 2: Emission Intensities (g/km) by Age



Notes: Own estimates based on the Report "Inventory of Pollutant Emissions and Greenhouse Effect" for Mexico, and for the U.S., the Technical Report of Argonne National Laboratory in Cai *et al.* (2013).

3.4.1 Quantitative Approach

We now describe the approach to quantifying the total effect of used vehicle imports on pollution emissions and how to decompose the total effect into scale, composition, and

[17] According to Pineda et al. (2018), updating gasoline and diesel sulfur standards in Mexico to align with the international best practices employed in the U.S. and Canada would importantly reduce air pollutant emissions, which would help to reduce the emissions gap of model-age-comparable vehicles between Mexico and the rest of North America.

technique effects. The total effect on pollution emissions can be obtained by comparing pollution emissions in two cases: the "actual" case observed in the data and the "counterfactual" case in which used vehicle imports are prohibited. In particular, the total amount of pollution emissions in the actual case can be calculated by using the observed data from the following formula,

$$E_t^a = \sum_j \left[Q_t^a \cdot (\theta_{j,t}^{aM} + \theta_{j,t}^{aU}) \cdot VKT_j \cdot e_j^M \right], \tag{10}$$

where Q_t^a is the actual observed total quantity of vehicles registered in Mexico in year t; $\theta_{j,t}^{aM}$ and $\theta_{j,t}^{aU}$ measure the actual proportions of vehicles originally operated in Mexico and the United States with ages belonging to the j category in year t; VKT_j denotes kilometers travelled per year for vehicles in category j; and e_j^M and e_j^U are the emission intensities for vehicles in category j in Mexico and the United States, respectively.

The total amount of pollution emissions in the counterfactual scenario is calculated from the fitted quantities of vehicles for each age category when trade in used vehicles is prohibited using the following formula:

$$E_t^c = \sum_j \left[Q_t^c \cdot \theta_{j,t}^{cM} \cdot VKT_j \cdot e_j^M \right], \tag{11}$$

where Q_t^c is the fitted quantity of all vehicles registered in Mexico in year t in the counterfactual scenario; $\theta_{j,t}^{cM}$ is the proportion of vehicles in age category j originally operated in Mexico in year t, if used vehicle imports are not allowed. The difference between pollution emissions calculated from equations (10) and (11) gives the total effect of used vehicle imports on pollution emissions,

$$\Delta E_t = E_t^c - E_t^a = \sum_j \left[Q_t^a \cdot \left(\theta_{j,t}^{aM} + \theta_{j,t}^{aU} \right) \cdot VKT_j \cdot e_j^M \right] - \sum_j \left[Q_t^c \cdot \theta_{j,t}^{cM} \cdot VKT_j \cdot e_j^M \right], \tag{12}$$

The total effect on pollution emissions can be decomposed into scale, composition, and technique effects as follows:

$$\Delta E_t = \underbrace{\Delta Q_t \left[\sum_j \left(\theta_{j,t}^{aM} + \theta_{j,t}^{aU} \right) \cdot VKT_j \cdot e_j^M \right]}_{Scale\ Effect} + \underbrace{Q_t^c \left(\sum_j \Delta\theta_{j,t} \cdot VKT_j \cdot e_j^M \right)}_{Composition\ Effect} + \underbrace{Q_t^c \left(\sum_j \theta_{j,t}^U \cdot VKT_j \cdot \Delta e_j^M \right)}_{Technique\ Effect}, \tag{13}$$

where $\Delta Q_t = Q_t^a - Q_t^c$ is t change in the total quantity of vehicles registered between the actual case and the counterfactual in year t (the scale effect), $\Delta\theta_{j,t} = \theta_{j,t}^{aM} + \theta_{j,t}^{aU} - \theta_{j,t}^{cM}$, is the change in the proportion of vehicles in age category j registered between the actual case and the counterfactual in year t (the composition effect), and $\Delta E_t = e_j^U - e_j^M$ is the difference in emission intensities of vehicles in category j originally operated the two countries (the technique effect).

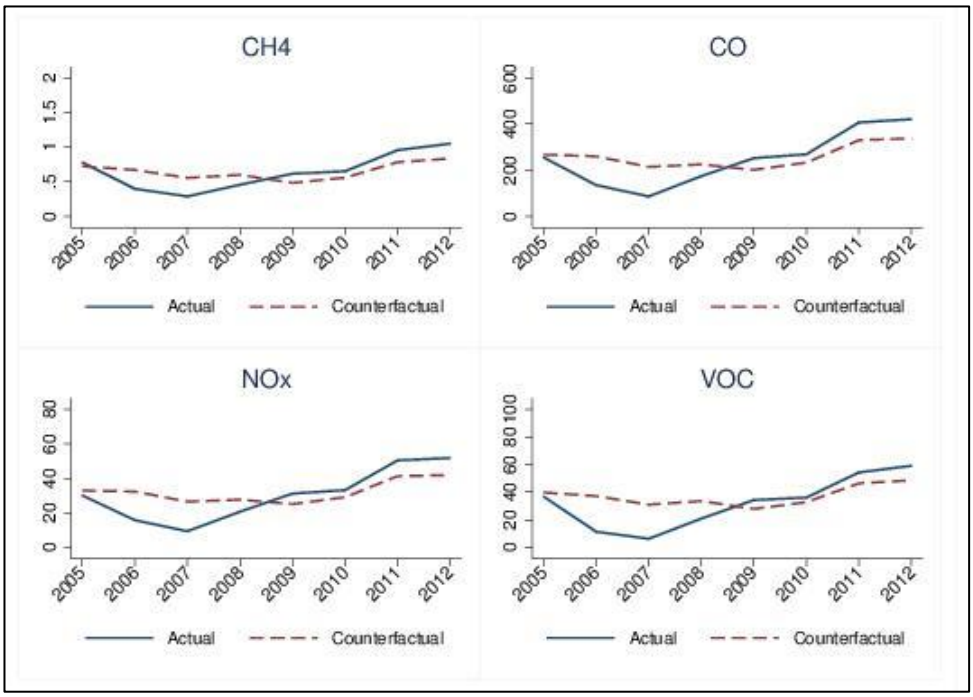
3.4.2 Main Results on Pollution Emissions

We use equations (12) and (13) to calculate the total effect of used vehicle imports on pollution emissions in Mexico after NAFTA and decompose it into scale, composition, and technique effects. To do so, we assume that all imported used vehicles will be registered in the import year. The age distribution of imported used vehicles is obtained from Davis and Kahn (2010) for 2005 to 2008, while the age distribution of imported used vehicles after 2008 is estimated by using the average age distribution between 2005 and 2008.

Figure 3 presents the total amount of pollution emissions in both the actual and counterfactual scenarios for four air pollutants: methane (CH_4), carbon monoxide (CO), oxides of nitrogen (NOx) and volatile organic compound (VOC). It demonstrates that the total effect of used vehicle imports on pollution emissions differs across the UC regime period (2005-2008) and the UCC regime period (2009-2012). Used vehicle imports lower emissions generated from registered vehicles in the UC regime period, while they increase emissions generated from registered vehicles in the UCC regime period for all pollutants.

We further decompose the total effect into the three effects: scale effect, composition effect, and technique effect.

Figure 3: Total Effect on Pollution Emissions (Thousands of Metric Tons)



Note: Own estimates of factual and counterfactual pollution emissions in expressions (10) and (11).

Table 5 summarizes the average proportions of the scale, composition and technique effects during the UC and UCC regime periods and the entire import period from 2005 to 2012 for all four pollutants. The results demonstrate that, in the UC regime period, the scale effect increases pollution emissions by 63.4%-90.2% and the composition effect increases pollution emissions by 3.7%-7.8%, depending on the pollutants considered. However, the technique effect decreases pollution emissions by more than 100% for all four pollutants, which leads to a decrease in aggregate pollution emissions by approximately 32.8%-87.8%, depending on the pollutant considered.

Table 5: Effects on Pollution Emissions

	Effects (in %)	CH4	CO	NOx	VOC
	Scale effect	63.40	68.31	71.45	90.19
2005−2008	Composition effect	5.42	4.26	3.67	7.77
(UC)	Technique effect	-101.56	-121.23	-132.37	-185.68
	Total effect	-32.75	-48.66	-57.25	-87.72
	Scale effect	37.62	36.61	36.74	39.34
2009−2012	Composition effect	1.45	1.74	1.50	1.89
(UCC)	Technique effect	-20.29	-20	-20.66	-25.95
	Total effect	18.78	18.34	17.58	15.28
	Scale effect	47.15	46.91	47.61	54.13
	Composition effect	2.92	2.56	2.18	3.60
2005−2012	Technique effect	-50.34	-52.91	-55.65	-72.42
	Total effect	-0.27	-3.44	-5.86	-14.68

Note: Own decomposition estimates of total effects on pollution emissions from equations (12) and (13).

In the UCC regime period, the scale effect is smaller so that pollution emissions decrease by 36.6%-39.3%. The composition effect is also smaller and pollution emissions decrease by less than 2% for all pollutants. The technique effect is also more contained with pollution emissions decreasing between 20% and 26% approximately. During this period, the total effect of used vehicle imports increases aggregate pollution emissions by 15.3%-18.8%. Overall, during the entire import period from 2005 to 2012, the scale effect increased pollution emissions by approximately 47%, the composition effect increased pollution emissions by 2.5%, and the technique effect reduced pollution emissions by more than 50% for all four pollutants. These results suggest that used vehicle imports decreased aggregate pollution emissions in Mexico, which is mainly due to the technique effect.

4. Conclusion

This paper examines the effects of trade in used vehicles on the fleet size and age of vehicles when countries differ in their environmental regulations and further quantifies the effects of used vehicle imports on the quantity of vehicles registered and pollution emissions for Mexico between 2005 and 2012. We develop a theoretical model to demonstrate that differences in environmental regulations across countries create a motive for trade, which shifts consumptions of older and dirtier goods from the country with stricter regulations to the country with more relaxed regulations. Using a unique dataset on used vehicle trade between Mexico and the United States from 2005 to 2012, we demonstrate that trade in used vehicles increased the quantities of used vehicles registered in Mexico, which is consistent with our model predictions. Our empirical results also demonstrate that used vehicle imports from the United States from 2000 to 2012 reduced average emissions from registered vehicles in Mexico by approximately 0.3%-15%, depending on the pollutants considered. This drop in average emissions is explained by what we called the *technique effect* created by the difference in emission intensities of vehicles of comparable mode and age between those that operate in the United States before being imported (emit less pollutants) and those vehicles in Mexico.

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Appendix A. Proofs to Propositions

Demand for Vehicles

First, by equating the utility from purchasing a new vehicle and the utility from purchasing a used vehicle, we obtain the marginal quality preference defined by $v_h = \{v|U_n = U_u\} = \frac{p_n-(1+\delta)p_u+\delta p_c-T_u}{s(1-k_u)}$. Using this definition and recalling that v is uniformly distributed over $[\underline{v}, \overline{v}]$, we can derive the demand function for new vehicles in each period,

$$Q_n(p_n, p_u, p_c) = \lambda(\overline{v} - v_h), \qquad \text{(A-1)}$$

where $\lambda = \Phi/(\overline{v} - \underline{v})$. Similarly, we derive the marginal quality preference levels, $v_m = \{v|U_u = U_c\} = \frac{p_u-(1+\delta)p_c+T_u-T_c}{s(k_u-k_c)}$ and $v_l = \{v|U_c = U_0\} = \frac{p_c+T_c}{sk_c}$, which give the following demand functions for used vehicles and clunkers,

$$Q_u(p_n, p_u, p_c) = \lambda(v_h - v_m), \qquad \text{(A-2)}$$

$$Q_c(p_n, p_u, p_c) = \lambda(v_m - v_1). \qquad \text{(A-3)}$$

Autarky

Proposition 1. *Emission inspection in an autarky economy in used vehicles and clunkers leads to: (i) a decrease in all prices of new vehicles, used vehicles, and clunkers; (ii) a decrease in the quantities of new vehicles, used vehicles, and clunkers sold in the market.*

Proof. We first derive the market equilibrium prices and demands for new vehicles, used vehicles and clunkers. Given those, the statement in Proposition 1 can be proved by taking derivatives of these prices and demands with respect to the emission inspection fees, T_u and T_c.

First, the prices of new vehicles, used vehicles and clunkers are derived by using the three relation equations (1), (2), and (3). Equation (1) gives an explicit relation of the three prices,

$$p_n = \frac{1}{2}[\overline{v}s(1-k_u) + (1+\delta)p_u - \delta p_c + T_u + M].$$

Substituting the demand functions of new vehicles and used vehicles, (A-1) and (A-2), into the second relation (2) give the second explicit relation of the three prices,

$$p_n = \frac{1}{2(k_u - k_c)}[\overline{v}s(1-k_u)(k_u - k_c) + (1 + (1+2\delta)k_u - 2(1+\delta)k_c)p_u]$$
$$-\frac{1}{2(k_u - k_c)}\Big[\big[\big(1+\delta-(1-\delta)\big)k_u - 2\delta k_c\big)\big]p_c - (1 + k_u - 2k_c)T_u + T_c\Big].$$

Substituting the demand functions of new vehicles and used vehicles, (A-2) and (A-3), into the second relation (3) give the third explicit relation of the three prices,

$$p_n = \frac{1}{(k_u - k_c)k_c}\big[[2k_c - (1+\delta)k_c^2 - (1+\delta)k_u k_c]p_u + (2 - 2k_u + k_u k_c - k_c^2)T_u\big]$$
$$-\frac{1}{(k_u - k_c)k_c}\big[[2(1+\delta) + k_u - k_c - k_u^2 - \delta k_c^2 - (1+\delta)k_u k_c]p_c + (k_u + k_c - k_c k_u - k_u^2)T_c\big].$$

Solving the equation system and simplifying the results give the market equilibrium prices for new vehicles, used vehicles, and clunkers,

$$p_n = \frac{M\big(1+k_u+k_c+2k_u\delta+k_c\delta(1+3\delta)\big)-(-1+k_u)(-\delta(T_u+T_c\delta)+\overline{v}s(1+\delta(k_u+k_c\delta)))}{2+2k_u\delta+k_c(1+\delta+3\delta^2)}, \quad \text{(A-4)}$$

$$p_u = \frac{k_u(2M+\overline{v}sk_c)+k_c(M-\overline{v}s-T_u)-2T_u+(k_c(3M+\overline{v}(-1+k_c)s)-(2+k_c)T_c)\delta}{2+2k_u\delta+k_c(1+\delta+3\delta^2)}, \quad \text{(A-5)}$$

$$p_c = \frac{\overline{v}k_c^2 s(1+\delta)-2(T_c+k_uT_c\delta)+k_c(3M-\overline{v}s-T_c-(\overline{v}k_u s-3T_u+T_c)\delta)}{2+2k_u\delta+k_c(1+\delta+3\delta^2)}. \quad \text{(A-6)}$$

Substituting the above equilibrium prices into the demand functions of new vehicles, used vehicles and clunkers, we can obtain the market equilibrium demand for the three types of vehicles as

$$Q_n = Q_u = Q_c = \Theta\frac{\overline{v}s\big(1+\delta(k_u+k_c\delta)\big) - M - \delta(T_u - T_c\delta)}{(\overline{v}-\underline{v})s(2+2k_u\delta+k_c(1+\delta+3\delta^2))}.$$

With the market equilibrium prices and demands for the three types of vehicles in hand, it is easy to verify that the derivations of them with respect to $T_u$and T_c are all negative. That is,

$$\frac{\partial p_j}{\partial T_u} < 0, \qquad \frac{\partial p_j}{\partial T_c} < 0, \qquad \frac{\partial Q_j}{\partial T_u} < 0, \qquad \frac{\partial Q_j}{\partial T_c} < 0,$$

for all $j \in \{n, u, c\}$. □

Lemma 1. *The North has a higher price of new vehicles relative to used vehicles than the South in autarky; The North also has higher price of used vehicles relative to clunkers than the South in autarky. That is,*

$$\frac{p_n^N}{p_u^N} > \frac{p_n^S}{p_u^S}, \ \frac{p_u^N}{p_c^N} > \frac{p_u^S}{p_c^S}. \qquad \text{(A-7)}$$

Proof. The prices of new vehicles, used vehicles, and clunkers in the autarky equilibrium in the North are given by (A-4)-(A-6) in the proof of Proposition 1, while the prices of new vehicles, used vehicles, and clunkers in the autarky equilibrium in the South are derived by setting the emission inspection fee $T_u = T_c = 0$ in the price equations (A-4)-(A-6). Using the prices of new vehicles and used vehicles in both the North and the South, we obtain the difference between the relative prices in the two countries,

$$\frac{p_n^N}{p_u^N} - \frac{p_n^S}{p_u^S} = \frac{\big((1 + k_u + k_c)M + \overline{v}(1 - k_u)s\big)(T_u + T_c\delta)\big(2 + 2k_u\delta + k_c(1 + \delta + 3\delta^2)\big)}{\Omega_1\Omega_2} > 0,$$

$\Omega_1 = k_u(2M + \overline{v}sk_c) + k_c(M - \overline{v}s - T_u) - 2T_u + (k_c(3M + \overline{v}(-1 + k_c)s) - (2 + k_c)T_c)\delta > 0$ as $p_u^N > 0$, and $\Omega_2 = k_u(2M + \overline{v}sk_c) + (k_c(M + 3M\delta + \overline{v}s(-1 + (-1 + k_c)\delta) > 0$ as $p_u^S > 0$. This proves the first part of the statement in Lemma 1.

Using the prices of used vehicles and clunkers in both the North and the South, we obtain the difference between the relative prices in the two countries,

$$\frac{p_u^N}{p_c^N} - \frac{p_u^S}{p_c^S} = \frac{\Omega_c(2 + 2k_u\delta + k_c(1 + \delta + 3\delta^2))}{\Omega_{c1}\Omega_{c2}} > 0,$$

$\Omega_c = -k_c(3M + \overline{v}(-1 + k_c)s)T_u + \big((2k_u + k_c)M + \overline{v}(-1 + k_u)k_c s\big)T_c > 0$ as $T_c > T_u$;

$\Omega_{c1} = \overline{v}k_c^2 s(1 + \delta) - 2(T_c + k_u T_c\delta) + k_c(3M - \overline{v}s - T_c - (\overline{v}k_u s - 3T_u + T_c)\delta) > 0$, as $p_c > 0$, and $\Omega_{c2} = k_c(3M + \overline{v}s(-1 + k_c + k_u\delta - k_c\delta)) > 0$ as $p_c > 0$.

This shows the second part of the statement in Lemma 1. □

Free Trade

Proposition 2. *Free trade in used vehicles leads to (i) an increase in the quantity of new vehicles in the North; (ii) a decrease in the quantities of both used vehicles and clunkers in the North; (iii) a decrease in the quantity of new vehicles in the South; (v) an increase in the quantities of both used vehicles and clunkers in the South.*

Proof. Using the equilibrium quantities of all three types of vehicles, we can calculate the changes in these quantities generated by moving from autarky to free trade in the UC regime. Let $\Delta Q_j^N = Q_j^{NT} - Q_j^{NA}$ for $j \in \{n, u, c\}$ and $\Delta Q_j^S = Q_j^{ST} - Q_j^{SA}$ for $j \in \{n, u, c\}$ denote the changes in the quantity of three types of vehicles in the North and South, respectively. First, consider the effect of trade in the North. Using the equilibrium quantities of new vehicles in autarky and with free trade in the North, it can be shown that $\Delta Q_n^N > 0$, which implies that trade leads to an increase in the quantity of new vehicles in the North. Similarly, we can show that $\Delta Q_u^N < 0$, which implies that trade leads to a decrease in the quantity of used vehicles in the North. We also know that in autarky and free trade, $Q_u^{NA} = Q_c^{NA}$ and $Q_u^{NT} = Q_c^{NT}$, which gives that $\Delta Q_c^N = \Delta Q_u^N < 0$. Thus, trade leads to a decrease in the quantity of clunkers in the North.

Now consider the effects of free trade in the South. Using the equilibrium quantities of new vehicles in autarky and with free trade in the South, it can be shown $\Delta Q_n^S < 0$, which implies that trade leads to a decrease in the quantity of new vehicles in the South. Similarly, we can show that $\Delta Q_u^S > 0$, which implies that trade leads to an increase in the quantity of used vehicles in the South. We also know that in autarky and free trade, $Q_u^{SA} = Q_c^{SA}$ and $Q_u^{ST} = Q_c^{ST}$, which gives that $\Delta Q_c^S = \Delta Q_u^S > 0$. Thus, trade leads to an increase in the quantity of clunkers in the South. □

Proposition 3. *Free trade from the UC regime to the UCC regime leads to (i) a decrease in the quantities of new vehicles and clunkers in the North; (ii) an increase in the quantity of used vehicles in the North; (iii) an increase in the quantities of new vehicles and clunkers in the South; (v) a decrease in the quantity of used vehicles in the South.*

Proof. Using the equilibrium quantities of all three types of vehicles, we can calculate the changes in these quantities generated by moving from free trade in the UC regime to free trade in the UCC regime. Let $\Delta Q_j^N = Q_j^{NUCC} - Q_j^{NUC}$ for $j \in \{n, u, c\}$ and $\Delta Q_j^S = Q_j^{SUCC} - Q_j^{SUC}$ for $j \in \{n, u, c\}$ and denote the changes in the quantity of three types of vehicles in the North and the South generated by moving from free trade in the UC regime to free trade in the UCC regime, respectively.

First, consider the effect from switching from the UC regime to the UCC regime in the North. Using the equilibrium quantities of new vehicles in the UC and UCC regimes in the North, it can be shown that $\Delta Q_n^N < 0$ when moving from the UC regime to the UCC regime, which implies that trade leads to a decrease in the quantity of new vehicles in the North. Similarly, it can be shown that $\Delta Q_u^N > 0$, which implies that trade leads to an increase in the quantity of used vehicles in the North. Finally, we can show that $\Delta Q_c^N < 0$ implying that trade leads to a decrease in the quantity of clunkers in the North.

Consider the effects from switching from the UC regime to the UCC regime in the South. Using the equilibrium quantities of new vehicles in the UC and UCC regimes in the South, it can be shown that $\Delta Q_n^S > 0$, which implies that trade leads to an increase in the quantity of new vehicles in the South. Similarly, we can show that $\Delta Q_u^S < 0$, which implies that trade leads to a decrease in the quantity of used vehicles in the South. Finally, we show that the change in the price of clunkers in the South is given by $\Delta Q_c^N > 0$. □

Appendix B.

Table 6: Annual Number of Registered and Imported Vehicles in Mexico

Year	***Annual Registered Vehicles***		***Imported Vehicles***		***Regimes***
	Number (Millions)	Age (Mean)	Number (Millions)	Age (Mean)	
2000	0.43	12.5	0	-	Autarky
2001	0.84	13.3	0	-	
2002	2.19	12.6	0	-	
2003	2.06	10.6	0	-	
2004	2.13	11.6	0	-	
2005	1.67	10.6	0.8	11.1	UC Regime
2006	1.8	10.5	1.71	11.5	
2007	1.45	10.4	1.54	11.3	
2008	1.53	11	1.12	11.4	
2009	1.35	9.5	0.24	NA	UCC Regime
2010	1.6	10.3	0.47	NA	
2011	2.29	10.2	0.6	NA	
2012	2.23	10.6	0.46	NA	

Notes: Own estimates based on National Public Vehicle Registry (REPUVE, by its Spanish acronym) and the Mexican Association of Automobile Distributions (AMDA).