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NATURAL GAS VEHICLES: CONSEQUENCES TO FUEL MARKETS AND THE ENVIRONMENT

Roberto Amaral-Santos
Ariaster Chimeli
João Paulo Pessoa

TD Nereus 07-2023
São Paulo
2023

Natural Gas Vehicles: Consequences to Fuel Markets and the Environment[*]

Roberto Amaral-Santos[†] Ariaster Chimeli[‡] João Paulo Pessoa[§]

July 13, 2023

Abstract

Policies to adopt cleaner fuels have become increasingly important, but their impacts on incumbent fuel prices and resulting greenhouse gas emissions are unclear. We use a panel dataset on weekly prices at the gas station level in a large Brazilian state to study how the growth of natural gas, a cheaper and less carbon-intensive alternative to traditional fuels, affected retail prices and profit margins of gasoline and ethanol. Applying an IV strategy, we estimate that prices and margins have fallen. The intensified competition in the fuel market boosted fuel demand, leading to higher emissions of GHGs and other pollutants.

Keywords: Gasoline; Ethanol; Price Competition; Emissions; Brazil.

JEL Codes: L11, L13, Q31, Q41, Q42, Q48, Q53, Q55, Q58

[*]We thank Cristine Pinto, Leonardo Rezende, Ruozi Song, Flávio Malagutti and seminar participants at FGV-São Paulo School of Economics, University of California at Santa Barbara, Federal University of Juiz de Fora and Berkeley Summer School SCABS. We would also like to thank Marcos Antônio Carrili from Gás Brasiliano, Patrícia Zamorano from Abegás, José Lucivaldo dos Santos and Ricardo Vallejo from Comgás, Marcos Alexandre Correa from Gás Natural Fenosa, Tais Silva from Inmetro, Alexandre Carvalho from Agenersa and Marcelo de Guimarães Santos from Arsesp for helping us to better understand the natural gas sector in Brazil. Amaral-Santos gratefully acknowledges financial support from Instituto Escolhas and thanks its members for all their support.

[†]University of California at Santa Barbara

[‡]University of São Paulo

[§]FGV-Sao Paulo School of Economics and Centre for Economic Performance

1 Introduction

The search for alternative and more efficient energy sources has taken center stage in response to recurrent wars, oil price shocks, geopolitical concerns, and, more recently, climate change. Part of the solution relies on new technologies, which are capable of transforming market structures and the environment.[1] As a pressing issue, governments worldwide have promoted policies to foster technology adoption that augment fuel efficiency and reduce fuel consumption and emissions, with mixed implications for welfare.[2] Among the initiatives to promote fuel substitution, the expansion of markets for natural gas vehicles (NGVs) deserves attention.

Natural gas is a realistic fuel option for economic and environmental reasons: its price is relatively low, it is simple and affordable to convert cars to run on natural gas, and NGVs emit less CO_2 when compared to gasoline-powered vehicles (Ministério do Meio Ambiente, 2011; United States Department of Energy, 2023). In 2019, there were 28 million NGVs worldwide compared to 7.2 million electric vehicles, another relevant alternative in the transportation sector.[3] The low price of natural gas makes these vehicles particularly attractive in developing countries. China has 5 million NGVs, while Armenia, Pakistan, and Bolivia have 56%, 33%, and 30% of their fleet running on compressed natural gas (CNG), respectively. CNG-running cars are also present in developed economies, even though less pronouncedly. For example, the US has 1.5 million natural gas vehicles. The market for vehicles running on natural gas can offer important lessons on the impact of alternative fuels on incumbent fuel prices, fuel consumption, and the environment. Despite the extensive literature on alternative fuels,[4] the implications of the growth of the market for NGVs are relatively under-explored.

In this paper, we use an IV strategy to estimate how the expansion of the NGV fleet promoted by past Brazilian governments has affected the prices of gasoline and ethanol, the

[1] Jaffe et al. (2003) and Aghion et al. (2005) are examples.

[2] For example, Li (2018), and Li et al. (2013) investigate policies targeted at automobile use and fuel efficiency in China and the US, respectively.

[3] For a review of the literature on the adoption of electric vehicles and their environmental consequences, see Beresteanu and Li (2011), Michalek et al. (2011), Sallee (2011), Holtsmark and Skonhoft (2014), Archsmith et al. (2015), and Holland et al. (2016), DeShazo et al. (2017), Li et al. (2017), Muehlegger and Rapson (2018), Clinton and Steinberg (2019), and Springel (2021).

[4] Langer and McRae (2014), and Shriver (2015) are examples of studies on alternative fuels.

two main competitors of natural gas for vehicles, and the consequences of these price shifts on greenhouse gas emissions and other air pollutants. We focus on the Brazilian state with the largest NGV fleet in the country. The analysis can provide insights into local market power, which affects total fuel consumption and emissions and may need to be anticipated in the design of policies.[5] To the best of our knowledge, this is the first paper to causally estimate the linkages between NGVs, competition between alternative fuels, and the environment.

At the beginning of the 2000s, NGVs gained popularity in Brazil, becoming ubiquitous among frequent drivers in large cities, and eventually, the country accumulated one of the largest NGV fleets globally. During our analysis, Brazil had up to the third largest NGV fleet in the world. On the one hand, if a driver converts her car to run on natural gas, a generally cheaper fuel, she will demand less gasoline or ethanol.[6] On the other hand, increased competition may lower gasoline and ethanol prices, leading to higher fuel consumption in the intensive margin. Furthermore, lower natural gas prices may incentivize NGV drivers to use their cars more intensively. Therefore, the final impact of CNG on prices and margins of other fuels, and the contribution of these effects to emissions, is an empirical question that depends on dynamic adjustments in supply and market power by fuel stations.

Our primary source of identification is the variation of fuel prices and margins at the fuel station level. We use a detailed panel database of weekly fuel prices between 2001 and 2016 for a large sample of municipalities in Rio de Janeiro, the Brazilian state with the largest NGV fleet. We complement the data with monthly information on fleet size by fuel type at the municipality level. In order to deal with the potential simultaneity arising from the impact of gasoline and ethanol prices on the incentive to convert vehicles to run on CNG, we employ an instrumental variable strategy. Our instrument is the interaction between the percentage of NGV vehicles among out-of-sample municipalities and a municipal-level dummy variable for access to piped natural gas in 2002. The first term captures a non-local trend in the growth of the NGV fleet. The second term captures the effect of a local

[5] Market power in product markets may partially offset pollution externalities, and first-best Pigouvian taxes will reduce production and pollution beyond welfare maximizing quantities (Buchanan, 1969; Barnett, 1980) If market power in product markets leads to market power in pollution permits markets, the appropriate market design will be necessary Hahn (1984).

[6] Rare exceptions aside, NGVs are cars that originally ran on gasoline, ethanol, or were flex vehicles (cars that can run on gasoline, ethanol, or any combination of these two fuels). These cars were then converted to run on natural gas with the option of using their original fuel.

exogenous shifter on the cost of providing CNG.

We show that an increase in the NGV fleet led to a fall in the prices and margins of gasoline and ethanol. The results are robust to several different specifications. In particular, our baseline specification shows that a one p.p. increase in the NGV fleet led to a fall in gasoline and ethanol prices of 2 and 1 cents of Brazilian Reais, respectively. Retail margins also fell significantly, suggesting some degree of market power by local fuel retailers.

We also provide evidence of the environmental consequences of the NGV fleet growth motivated by changes in the prices of gasoline and ethanol. Because information on fuel sales at the station level is not available, we use a wide range of elasticities from the literature and simplifying assumptions to produce back-of-the-envelope calculations for the resulting emissions of GHGs and other air pollutants in the state of Rio de Janeiro in 2008.[7] The decrease in gasoline and ethanol prices due to the expanding NGV fleet should boost the consumption of these fuels. Our calculations for GHGs suggest that emissions increased between 12,759 and 193,614 tonnes of carbon dioxide equivalent over 2008. Considering a social cost of carbon (SCC) of USD 51 per tonne of CO_2, this corresponds to an aggregate SCC between USD 0.6 MM and USD 9 MM (in 2008 dollars).[8] Emissions of other air pollutants affecting human health have also increased. Hence, we describe two counteracting channels through which the growth of NGVs and competition in the fuel market impacted welfare: (i) the decrease in fuel prices benefits consumers, and (ii) the increase in emissions brings down welfare.

This paper contributes to an extensive and growing literature on the effects of policies to stimulate the adoption of cleaner vehicles and how these policies interact with market

[7] We also calculate the overall increase in emissions from the growth of NGVs. We account for the gasoline and ethanol price effects and the changes in the fleet composition due to the rise of CNG, finding substantial evidence that NGVs boosted overall emissions.

[8] When we consider the price effects and the changes in the fleet composition due to the rise of NGVs, the aggregate SCC ranges between USD 23 MM and USD 175 MM.

characteristics.[9] Despite the importance of NGVs, especially in the developing world, where car fleets are likely to grow as these economies develop, the economic literature on their expansion and possible consequences to emissions is still sparse.[10] In this paper, we provide a first causal estimate of the effect of NGVs penetration on the prices and margins of substitute fuels. We take it further by calculating the emissions of greenhouse gases and other air pollutants due to the price effects.

This paper is organized as follows. Section 2 summarizes the general characteristics of NGVs in Brazil. Section 3 describes the data, and section 4 discusses our empirical strategy. Section 5 presents and discusses the main results and some robustness checks. Section 6 presents the environmental impacts of the NGV fleet growth, and Section 7 concludes.

2 Background

NGVs were first introduced in Italy in the 1930s. They lacked popularity for decades until their fleet started to increase in the 1970s in Italy and, one decade later, in New Zealand, in response to the oil crises of that time. Although the conversion of vehicles to run on natural gas was first authorized in Brazil in 1996, it was only at the beginning of the 2000s that

[9] See, for example, Salvo and Huse (2013), DeShazo (2016), DeShazo et al. (2017), Leard et al. (2017), Li et al. (2017), Alberini et al. (2018), Yan and Eskeland (2018), Clinton and Steinberg (2019), Holland et al. (2019), Sanders and Sandler (2020), and Leard (2022) in the environmental economics literature, and Ferreira et al. (2009), Salvo and Huse (2011), Langer and McRae (2014), Shriver (2015), and Pessoa et al. (2019) in the industrial organization literature. Some of these papers (Ferreira et al., 2009; Salvo and Huse, 2011, 2013; Pessoa et al., 2019) explore the consequences of increases in the flex fleet, an event that generated economic impacts through channels that are different from the ones we are currently analyzing. For example, Pessoa et al. (2019) show that the penetration of flex cars contributed to lower fuel prices because of stronger competition between gasoline and ethanol at the pump. We find a similar effect through a distinct channel, a (negative) demand shock.

[10] There are notable exceptions. Walls (1996) structurally estimates consumer welfare changes from the growth of NGVs in the US by focusing on their undesirable attributes. She calculates losses between USD 1,100 and USD 3,200, which were on par with the cost of alternative approaches to reduce vehicular pollution available at the time. Pavan (2017) develops a model of joint supply of CNG and Liquefied Petroleum Gas (LPG) and demand for vehicles running on these fuels. She shows that subsidizing fuel retailers is more effective in increasing the demand for CNG and LPG vehicles than providing subsidies to consumers to buy such cars. Sopha et al. (2017) uses agent-based modeling to show that the long-run adoption of NGVs by consumers in Indonesia depends on the interaction of multiple policies (subsidies to convert, expansion of fuel stations offering CNG, among others). Pavan et al. (2020) studies the empirical dynamics of entry in CNG markets by fuel stations in Italy, concluding that a higher number of potential entrants leads to quicker entry decisions. We look at yet another dimension of NGV adoption: the unintended environmental consequences via impacts on fuel prices.

these vehicles became a noticeable phenomenon.

The development of a more significant natural gas market in Brazil started taking shape with the Brazilian government's National Plan for Natural Gas from 1987 meant to increase the participation of natural gas in the country's energy matrix.[11] In 1991, Brazil and Bolivia signed a letter of intentions to promote energy integration between both countries and setting the basis for the construction of the Bolivia-Brazil gas pipeline (GASBOL) to transport natural gas from the former country to the latter. The Brazilian government listed GASBOL as one of its top 42 undertakings in 1996 and eventually signed a contract for its construction in 1997.[12] An increase in imports of natural gas along with increasing extraction from the offshore Campos Basin along the coast of the state of Rio de Janeiro spurred a market for natural gas vehicles in the country.[13] Brazil continues to promote the expansion of natural gas markets and a "New Gas Act" of April 8, 2021 (federal Law 14.134) sought to lower gas prices by separating distribution of natural gas from production and consumption, assuring open access to pipeline infrastructure, changing infrastructure investment contracts from concessions to simpler authorization contracts and allowing underground storage.

In order to run on CNG, a vehicle needs to be modified. The driver needs to install a special tank consisting of an armored cylinder in the car and a special fuel injection system with a control unit, as well as carry some other minor modifications on the vehicle. After the conversion to run on CNG, a car can still run on its original fuel.

The conversion of vehicles to run on CNG is not the only challenge in building a NGV fleet. In order to fuel automobiles with natural gas, fuel stations need specialized infrastructure, including a compressor and special fueling pumps. The adaptation of the fueling station facilities for NGVs is costly. If the owner of a fuel station does not want to invest his own money in such infrastructure, the station's fuel distributor may finance the investment. In exchange, in areas without access to piped natural gas, the station usually agrees to an exclusive contract with the distributor. Alternatively, a station not subject to this kind of agreement can buy its natural gas directly from any distributor. In particular, in the state of Rio de Janeiro, stations can buy CNG from Ceg and Ceg-Rio, the two piped natural gas

[11] Fioreze et al. (2013).
[12] Passos (1998).
[13] Gutierrez (2022).

supplying firms. Both are privately owned regional regulated monopolists who operate in different municipalities. They acquired their distribution rights in the state privatization program in 1997. Natural gas can be supplied to fuel stations in one of two ways: via piped natural gas or tank trucks. The former option is cheaper than the latter.

Although some of the leading automakers in Brazil have manufactured NGVs, the overwhelming majority of the NGVs were initially sold as gasoline, ethanol, or flex-fuel vehicles and then converted to also run on CNG. The conversion of a car to run on CNG can be costly. In 2017, it cost approximately BRL 3,500.00 (approximately USD 1,122 using the USD-BRL conversion rate of July 2017) to convert a four-cylinder car in the retail conversion market. For vehicles with large engines, the conversion price is usually higher. Hence, NGVs are mostly sought by constant and long-distance drivers. Anecdotal evidence points to the ubiquity of converted cars among taxi drivers and lightweight freight transporters.

As of 2016, Brazil had the sixth largest NGV fleet in the world. However, during most of our analysis, Brazil had up to the third largest NGV fleet in the world. Table 1 illustrates this and provides the rank of the major NGV fleets in 2008 and 2016.

Table 1: Rank of Largest NGVs Fleets

Country	Rank 2016	Rank 2008	% NGV Fleet 2016	% NGV Fleet 2008
China	1	7	20.45%	4.16%
Iran	2	4	16.36%	10.39%
India	3	5	12.45%	6.76%
Pakistan	4	1	12.27%	20.8%
Argentina	5	2	9.39%	18.15%
Brazil	6	3	7.28%	16.51%
Italy	7	6	4.1%	6.03%
Colombia	8	8	2.28%	2.91%
Thailand	9	9	1.94%	1.33%
Uzbekistan	10	20	1.84%	0.49%

NOTES: The table provides a list of countries ranked by their NGV fleet size. The first two columns provide the ranks in 2016 and 2008. The last two columns show the size of the NGV fleet in the countries as a percentage of the world NGV fleet in 2016 and 2008. Source: iangv.org.

In Brazil, São Paulo and Rio de Janeiro stand out for the size of their NGV fleets. The Rio de Janeiro state has the largest NGV fleet among Brazilian states, probably due to its proximity to natural gas production fields and friendly legislation for NGVs.

In contrast to other Brazilian states, the Rio de Janeiro state offers a 75% discount on its vehicles' property tax to properly registered cars converted to run on CNG.[14] A conversion is only lawful (and therefore showing in our data) when done in an officially trusted mechanical shop. After the conversion, the car owner should properly register the fuel change of her car in the traffic department. A similar registration process needs to be carried out by the owner every year. The subsidy to NGVs has helped the state avoid illegal conversions, as owners of illegally converted vehicles do not enjoy the lower property taxes. This government incentive gives us confidence that our analysis captures most of the NGV fleet in the Rio de Janeiro market. During most of the period of our analysis, there was also a law obliging new fuel stations to offer natural gas whenever they had the technological conditions to do so while giving older stations five years to comply with mandatory natural gas supply.[15] Nevertheless, there is evidence that the enforcement of the law was weak.

3 Data

We employ several datasets in our analysis. The first one is a weekly survey that collects fuel prices in Brazil, the *Levantamento de Preços e de Margens de Comercialização de Combustíveis* from the Brazilian National Oil Agency (ANP). The survey randomly samples stations every week. It covers all stations in each municipality within a few weeks. In smaller municipalities, logistical constraints are not binding, and each station may be surveyed every week. The database has weekly wholesale and retail prices for gasoline, sugarcane ethanol, and CNG. It also contains information on the date of collection, address of the station, brand (if any), and a unique station identifier. We adjust the prices by the monthly Brazilian CPI (IPCA - Índice de Preços ao Consumidor) from the Brazilian Geography and Statistics Institute (IBGE) to December 2010 prices.

Most observations have gasoline and ethanol retail prices (98.71% and 94.32% out of 617,344 total observations), but gasoline and ethanol wholesale prices are scarcer (62.41% and 51.93%). Hence, our estimates for margins come from fewer observations. We define

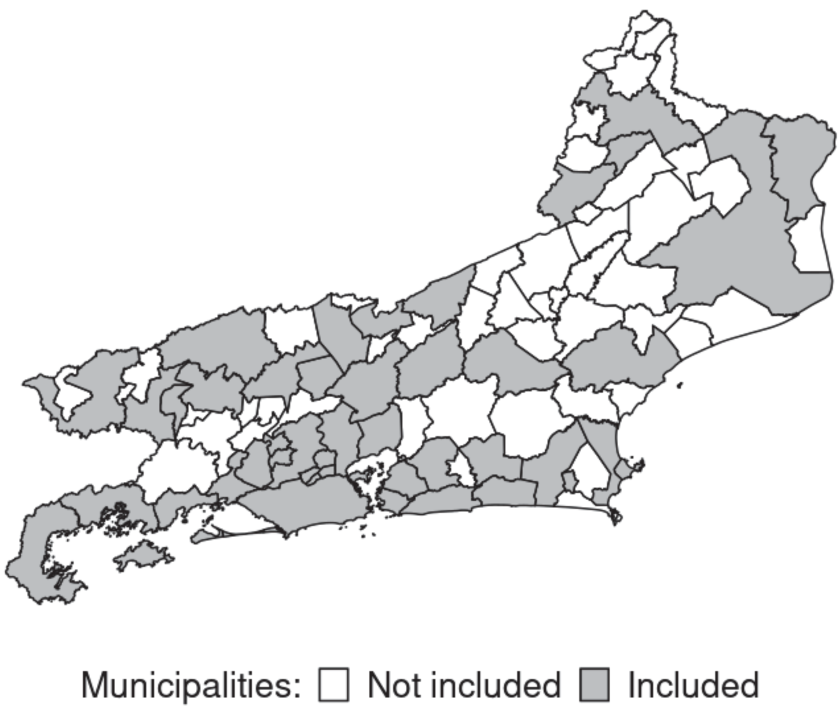
[14] State Law 3.335 of December 29, 1999.

[15] Rio de Janeiro Municipal Decree 19.392 of January 1, 2001.

margins as the difference between the retail and wholesale prices of fuels. The dataset covers the period from July 2001 to December 2016 for 44 out of 91 Rio de Janeiro municipalities. Figure 1 shows the municipalities in grey for which we have data on fuel prices for at least one period. Prices for all 47 municipalities in white are unavailable for the entire sample.

We obtain the monthly fleet of vehicles by fuel type and municipality from the Rio de Janeiro State Traffic Department (Detran-RJ) website. We also use data on piped gas existence (extensive margin) in each Rio de Janeiro municipality by year (2001- 2016) from the annual reports of Ceg and Ceg-Rio, the natural gas concessionaires of Rio de Janeiro. As mentioned previously, this is an important supply shifter that will help us to identify the effects of NGVs on fuel retail competition. Our data on nominal GDP and population by municipality, available for 2001-2014 and 2001-2016, respectively, comes from IBGE. The yearly national GDP deflator from IBGE adjusts the GDP data. We divide the real GDP obtained by population to get the yearly municipal real GDP per capita used in our regressions.

Figure 1: Municipalities in the Database

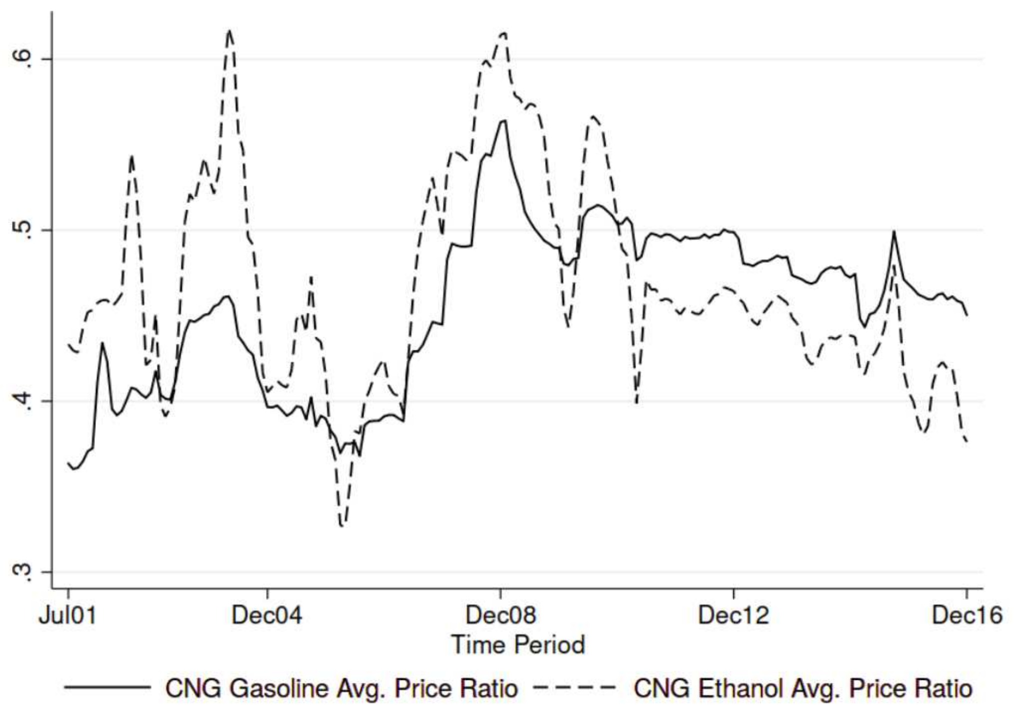


NOTES: The figure shows all municipalities in the Rio de Janeiro state. It highlights in gray the municipalities for which data on fuel prices are available for some (or the whole) period between July 2001 and December 2016.

3.1 Descriptive Analysis

CNG is a cheaper fuel by energy unit than gasoline or sugarcane ethanol. This price differential incentivizes the driver of an NGV to run on CNG whenever possible. Also, the high conversion costs for a vehicle to run on CNG help select those consumers who are most likely to fuel their cars with CNG after the conversion. Figure 2 shows the average relative price between CNG and gasoline and between CNG and ethanol at the station (per energy unit) throughout our sample. It is clear from the data that CNG is considerably cheaper than gasoline during our study period.

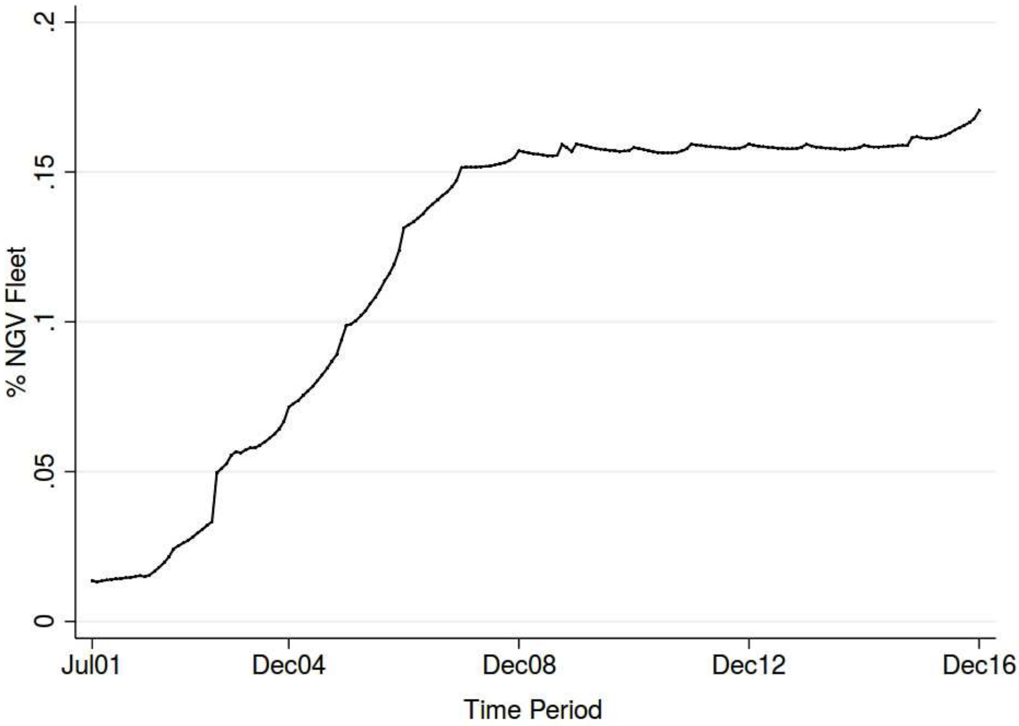
Figure 2: Fuel Relative Prices



NOTES: The figure shows the price ratios of CNG and gasoline and CNG and ethanol per energy unit on a monthly basis. We consider that CNG, gasoline and ethanol have 33 MJ/m^3, 27.9 MJ/l, and 20 MJ/l, respectively. Sources for these values can be found in: https://web.archive.org/web/20210916210143/https://autoentusiastas.com.br/2015/06/litros-metros-cubicos-ou-megajoules/

Figure 3 illustrates the NGV growth in Rio de Janeiro over time. Our dataset can be roughly divided into two main periods: when the NGV fleet was growing, which lasted roughly from July 2001 to June 2008, and when it was roughly constant between July 2008 and December 2016. Although it is beyond the scope of this paper to explain this trajectory, we believe that the distinct trend after 2008 can be related to three main reasons: the Bolivian-Brazilian quarrel over the nationalization of Petrobras' natural gas installation in Bolivia, the drought period that impacted Brazilian hydroelectric energy production leading to higher energy demand by natural gas thermoelectric facilities, and the saturation of the NGV market.

Figure 3: Share of NGVs



NOTES: The figure shows the average share of NGVs in the vehicle fleet across municipalities in the state of Rio de Janeiro (weighted by municipality population).

The lack of substantial post-2008 NGV growth also holds when we consider the evolution of the NGV fleet by municipality, as most cities face nearly constant NGV shares from 2008 onwards. Table 2 shows the standard deviation for each city in our database before and after June 2008.[16] We can see the drop in the variance of the second period, making it hard to identify the impacts of NGV growth after 2008. Therefore, we will focus on the period spanning from January 2002 to June 2008.

[16]Table 6 in the appendix shows the standard deviation of the error terms in the linear regression of penetration of NGV by municipality on a municipality fixed effect. The results are similar to the ones shown in Table 2.

Table 2: Standard Deviation of the Share of NGVs

Municipality	Until June 2008	After June 2008	Municipality	Until June 2008	After June 2008
Angra dos Reis	1.4	0.4	Nova Iguaçu	5.2	0.9
Araruama	4.3	0.2	Paraíba do Sul	0.9	0.5
Armação dos Búzios	3.1	0.8	Paraty	0.6	0.2
Barra do Piraí	4.6	0.5	Paty do Alferes	0.5	-
Barra Mansa	4.8	0.8	Petrópolis	3.1	0.2
Belford Roxo	7.6	0.3	Queimados	6.7	0.8
Cabo Frio	6.3	0.4	Resende	5.4	0.3
Campos dos Goytacazes	4.8	0.4	Rio Bonito	4.5	0.2
Duque de Caxias	4.5	1	Rio de Janeiro	4.5	0.2
Iguaba Grande	0.2	-	Santo Antônio de Pádua	0.2	0.6
Itaboraí	5.7	1.1	São Francisco de Itabapoana	1.2	0.5
Itaguaí	4.4	1.1	São Gonçalo	6	0.7
Itaperuna	0.4	0.1	São João de Meriti	5.6	1.1
Japeri	2.1	-	São José de Ubá	0.1	-
Macaé	4.1	0.6	Sapucaia	0.4	0.5
Magé	6.3	0.3	Saquarema	2.7	0.4
Mangaratiba	5.8	1.3	Seropédica	2	-
Maricá	5.6	0.2	Teresópolis	1.5	0.6
Mesquita	4.5	-	Três Rios	1.1	0.5
Nilópolis	6.9	0.2	Valença	2.6	0.8
Niterói	3.2	0.3	Vassouras	2.5	0.4
Nova Friburgo	0.9	0.4	Volta Redonda	6.3	0.3

NOTES: The table shows the standard deviation of the share of NGVs by municipality (in percentage points) for two periods: January 2001 to June 2008 and July 2008 to December 2016. Source: Detran-RJ.

4 Empirical Strategy

When a driver converts her car to run on CNG, she will most likely demand natural gas instead of gasoline or ethanol. Hence, the growth of the NGV fleet may impact the demand for gasoline and sugarcane ethanol. We estimate the impact of the NGV fleet growth on the prices of the two other fuels. We hypothesize that as the NGV fleet expanded, the demand for gasoline and ethanol dropped, leading to lower prices. We expect the price adjustment to happen via fuel station margins, given that fuel prices set by upstream distribution and production companies might not have been entirely responsive to market incentives. During our period of analysis, Petrobras, Brazil's major oil and gas producer, did not face much competition. The company also had a significant presence in the distribution sector. Most importantly, it was partially owned by the government, which regularly used the company to set prices with political objectives. Distinctly, fuel stations were privately held and set prices based on market forces.

We verify whether fuel stations have responded to the fall in demand for gasoline and ethanol by reducing their prices. It is important to note that this adjustment mechanism is possible in the Brazilian fuel retail market, as it is not perfectly competitive (Fetter, 2016; Merenstein, 2016; Silveira et al., 2021), and firms are not price takers. For intuition on our hypothesis, please see Appendix A, where a simple theoretical model illustrates the mechanism described above.

To test our hypothesis, we use the following econometric model:

$$Y_{smw} = \beta_1 NGV\ Share_{mt} + \beta_2 X_{smt} + \pi_s + \pi_t + \lambda_b + \epsilon_{smw}, \tag{1}$$

where s indexes the station, m indexes the municipality, w indexes the week-year period, and t indexes the month-year period. Y_{smw} is the outcome of interest, which can be gas prices, gas margins, ethanol prices, or ethanol margins at a given station, month, and municipality. $NGVShare_{mt}$ is the relative size of the monthly NGV fleet to the total fleet in a given municipality at time t (changing at monthly frequency), so β_1 is our coefficient of interest. X_{smt} is a set of controls including municipality, market, and fleet composition characteristics. π_s, π_t, and λ_b are, respectively, station, time, and station's brand fixed effects. ϵ_{smw} is an error term.

4.1 Instruments

CNG being a cheaper alternative to gasoline and ethanol may have led to the rise of the NGV fleet and changes in fuel retail prices. However, the price differential between CNG and other fuels incentivizes drivers to convert their cars. Therefore, when gasoline or ethanol prices go up relative to CNG, we expect a greater incentive for car owners to convert their automobiles, making the error terms in our model correlated with our variable of interest. This raises reverse causality concerns in our estimation. To deal with this simultaneity issue, we employ an instrumental variable strategy.

Our instrument, $IV_{mt}^{NGVFleet}$ is composed of two terms:

$$IV_{mt}^{NGVFleet} = Fleet_t^{RJ} \cdot I_m^{PipedGas}, \tag{2}$$

where $Fleet_t^{RJ}$ is the contemporaneous share of NGVs in the Rio de Janeiro municipalities not included in our fuel prices database (as shown in white in Figure 1) and $I_m^{PipedGas}$ is a dummy indicating if a municipality in our sample had access to piped gas in 2002.[17] The first term captures a non-local component of the growth of the NGV fleet that is driven, for example, by the discovery of new technologies that make engine conversion to CNG cheaper and more efficient but are not influenced by local fuel price shocks.

The second term of the interaction acts as a supply shifter. While stations in municipalities with access to piped natural gas will offer CNG supplied by this network,[18] stations in municipalities without this infrastructure will face a more expensive process to obtain natural gas, as it will have to be transported to them by truck. The lower cost of natural gas in the first set of municipalities should be reflected in lower average prices of CNG and,

[17] Appendix B Figure 4 shows the municipalities with piped natural gas in 2002, where this infrastructure was built between 2003 and 2016, and those without piped natural gas as of December 2016.

[18] Talks with natural gas distribution industry members suggest that once a station decides to offer CNG in a municipality with piped gas, even if it is not in an area currently served by the piped gas system, the natural gas distributor will expand its network to reach the station. They argue that fuel stations supplying CNG create a constant demand that helps finance and reduce the uncertainty on the returns of this network expansion. Later expansions to businesses and residencies near the station help make the investment profitable.

consequently, in further incentives for a larger NGV fleet. We believe the dummy for municipalities with access to piped gas in 2002 does not suffer from reverse causality[19] for two reasons. First, we consider municipalities' access to piped natural gas in the beginning of our period of analysis (2002), we expect these concerns to be attenuated. Second, distribution services of natural gas in Rio de Janeiro were privatized in 1997, and future expansions of the piped natural gas infrastructure were set by contract in that year. Privatization happened little after NGVs were approved in Brazil (1996) when they were still uncommon (and remained like this until the early 2000s).

Our instrument uses non-local variation and hence, avoids endogeneity from local components. Furthermore, the interaction of terms in our IV provides variation both in the cross-section (via $I_m^{PipedGas}$) and over time ($Fleet_t^{RJ}$). This instrument feature is essential given our panel data structure and fixed effects specifications. We also employ other instruments in Section 5.1 to verify the robustness of our results.

5 Results

Table 3 shows the estimates of the impact of the share of NGV vehicles on the four outcome variables: gasoline prices, gasoline margins, ethanol prices, and ethanol margins.[20] Specification 1 of Table 3 is estimated by an univariate OLS with a constant. Specification 2 includes station and month-year fixed effects. These fixed effects capture essential dynamics of fuel prices and margins (Pessoa et al., 2019). From specification 3 onward, we estimate the coefficients using our IV strategy. Specification 3 uses our IV strategy with the same set of controls as column 2. In the following specification, we add a brand fixed effect. In column 5 we add the sum of the shares of gas and flex vehicles (Panels A and B) and the sum of the shares of ethanol and flex vehicles (Panels C and D) as controls, while in column 6 we alternatively control for (yearly) municipal GDP per capita, the (monthly) NGV fleet

[19]If municipalities with high NGV fleets, or that expected a large growth of the NGV fleet, were more likely to bargain for piped gas.

[20]In Appendix B, tables 7-10 provide more details of the regressions presented in Table 3, including the coefficients of other control variables and first stage statistics. The results shown are for the period January 2002 to June 2008. Estimates for January 2002 to December 2016, as well as for July 2008 to December 2016, are available in tables 15 and 17 in Appendix B.

size to station ratio, and the (monthly) number of stations in each municipality. Column 7 considers all the previous controls.

Column 1 shows that retail margins are negatively affected by the growth of the NGV fleet, while price effects are either positive or non-significant. However, all results are negative and statistically significant once we include month-year and station fixed effects. In specification 3, the coefficients for the NGV fleet share for all outcomes remain negative and statistically significant once we deal with the potential reverse causality, but the results become stronger in absolute value, showing the OLS results are biased toward zero, possibly because (gasoline and ethanol) price shocks are positively correlated with the number of NGVs. The first stages are strong, as suggested by the Kleibergen-Paap statistics (significant at all reasonable levels). The estimates for specifications 3 - 7 are always negative and almost always significant at standard levels. The only exception is the effect on ethanol prices in the last column. Our preferred specification in column 7 shows that an increase of 1 p.p. in the NGV fleet decreased gasoline prices, gasoline margins, ethanol prices, and ethanol margins by approximately 1.9, 1.3, 0.8, and 1.2 cents of Brazilian Reais, respectively. These results align with the positive cross-price elasticity between CNG and either gasoline or ethanol estimated by Santos (2013).

We show in Table 4 the results for the first stage regressions associated with Table 3.[21] Specifications 1 to 5 refer to the first stage regressions of specifications 3 to 7, respectively, of Table 3. Municipalities with a piped gas network in the baseline should be more likely to be affected by non-local components in the NGV fleet growth. Hence, we expect our instrument to be positively correlated with the endogenous variable. In line with our expectations, all our first stage estimates for the instrument coefficient are positive and statistically significant.[22]

5.1 Robustness Checks

We test the robustness of our results obtained in Section 5 in several ways. First, a potential concern with our instrument is that price shocks in one municipality may affect fuel markets

[21]Results for the same regressions, but including the estimates for all controls, are available in tables 11-14 in Section B.

[22]Results for first stage regressions for January 2002 to December 2016, as well as for July 2008 to December 2016, are available in tables 16 and 18 in Appendix B.

Table 3: Regressions: 2002-2008

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS	(7) 2SLS
	Panel A - Gasoline Prices						
NGV Share	0.0336	-0.387***	-0.512***	-0.509***	-1.116	-0.640***	-1.178***
	(0.18)	(-5.58)	(-3.99)	(-3.98)	(-1.43)	(-5.41)	(-2.86)
	Panel B - Gasoline Margins						
NGV Share	-0.543***	-0.329***	-0.371***	-0.378***	-0.664	-0.514***	-0.861**
	(-9.15)	(-5.52)	(-3.30)	(-3.37)	(-1.08)	(-4.47)	(-2.26)
	Panel C - Ethanol Prices						
NGV Share	0.547**	-0.417***	-0.808***	-0.868***	-0.499***	-0.775***	-0.474***
	(2.06)	(-4.34)	(-3.73)	(-4.01)	(-2.98)	(-3.93)	(-2.90)
	Panel D - Ethanol Margins						
NGV Share	-0.697***	-0.394***	-0.923***	-0.885***	-0.762***	-0.972***	-0.915***
	(-13.05)	(-4.53)	(-4.88)	(-4.71)	(-5.01)	(-5.90)	(-6.16)
Instrumentalized Fleet	No	No	Yes	Yes	Yes	Yes	Yes
Station Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	No	No	Yes	Yes	Yes	Yes

NOTES: Table displays the estimated effects of the share of NGVs on gasoline retail prices (panel A), gasoline retail margins (panel B), ethanol retail prices (panel C), and ethanol retail margins (panel D). Shown in parentheses are the t-stats for the coefficients. Standard errors are clustered by city-month. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly IPCA. Over the period, the average gasoline price = BRL 3.04, and the average gasoline margin = BRL 0.35. The average ethanol price = BRL 2.00, and the average ethanol margin = BRL 0.33. Columns 1-2 are estimated by OLS and columns 3-7 by 2SLS. Columns 2-7 include station and monthly fixed effects and columns 4-7 include station-brand fixed effects as controls. Columns 5 and 7 also include the sum of the shares of gasoline and flex vehicles in the fleet as a control (fuel share control) in the gasoline retail prices and margins specifications. Columns 5 and 7 also include the sum of the share of ethanol and flex vehicles in the fleet as a control (fuel share control) in the ethanol retail prices and margins specifications. Column 6 and 7 add the following controls: yearly municipal GDP per capita, the NGV fleet divided by the monthly number of stations at the municipality level, and the monthly number of stations in each municipality (market controls). Instrument for the share of NGVs is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our price database. First stage statistics are available in Table 4 and in Appendix B Tables 11-14. Gasoline prices regressions have N = 297,489. Gasoline margins regressions have N = 206,442. Ethanol prices regressions have N = 277,201. Ethanol margins regressions have N = 159,286.

Table 4: Regressions - First Stage: 2002-2008

	(1)	(2)	(3)	(4)	(5)
	Panel A - Gasoline Prices 1^{st} Stage				
Piped Gas x Fleet RJ	0.460***	0.458***	0.0585***	0.497***	0.123***
	(11.59)	(11.56)	(2.82)	(14.26)	(7.46)
	Panel B - Gasoline Margins 1^{st} Stage				
Piped Gas x Fleet RJ	0.470***	0.469***	0.0701***	0.498***	0.140***
	(11.96)	(11.99)	(3.34)	(14.76)	(8.30)
	Panel C - Ethanol Prices 1^{st} Stage				
Piped Gas x Fleet RJ	0.468***	0.465***	0.557***	0.502***	0.588***
	(12.06)	(12.02)	(19.96)	(14.90)	(23.41)
	Panel D - Ethanol Margins 1^{st} Stage				
Piped Gas x Fleet RJ	0.501***	0.499***	0.565***	0.529***	0.586***
	(12.94)	(12.92)	(18.92)	(16.49)	(22.65)
Station Fixed Effect	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	Yes	Yes	Yes	Yes

NOTES: Table displays the first stage regressions of Table 3. The table shows the effects of the IV, shown as an independent regressor, on the share of NGVs for the gasoline retail prices regressions (panel A), gasoline retail margins regressions (panel B), ethanol retail prices regressions (panel C), and ethanol retail margins regressions (panel D). The IV is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our prices database. Shown in parentheses are the t-stats for the coefficients. Standard errors are clustered by city-month. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The dependent variable is the share of NGVs in the total vehicle fleet. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the IPCA. All Columns include station and monthly fixed effects and columns 2-5 include station-brand fixed effects as controls. Columns 3 and 5 also include the sum of the shares of gasoline and flex vehicles in the fleet as a control in the gasoline retail prices and margins specifications. Columns 3 and 5 also include the sum of the share of ethanol and flex vehicles in the fleet as a control in the ethanol retail prices and margins specifications. Columns 4 and 5 add yearly municipal GDP per capita, the NGV fleet divided by the monthly number of stations at the municipality level, and the monthly number of stations at each municipality as controls. Gasoline prices regressions have N = 297,489. Gasoline margins regressions have N = 206,442. Ethanol prices regressions have N = 277,201. Ethanol margins regressions have N = 159,286.

in neighboring municipalities, violating our exogeneity assumption. For instance, if gasoline price shocks in the municipality of Macaé impact the neighboring municipality of Rio das Ostras (whose fleet is used for calculating $Fleet_t^{RJ}$), then our instrument would not be valid. We address this potential issue by considering two different versions of our instrument. In both of them, we replace the fleet term in the original instrument with alternative terms that mitigate the concerns with spatial violations of the exogeneity assumption. The two versions are constructed by interacting the dummy for municipalities with a piped gas infrastructure in the baseline ($I_m^{PipedGas}$) with either (i) the number of stations supplying natural gas in the Southeast region of Brazil excluding the Rio de Janeiro State, or (ii) with a fleet of spatially-lagged municipalities of Rio de Janeiro that are within at least two spatial lags (neighbors of a neighbor) from this municipality.[23] Results are available in Appendices C and D and are generally robust to these alternative IV strategies.

We also estimate our model with a dummy indicating if CNG was available at the station. The availability of natural gas in a station may affect how a particular station prices gasoline and ethanol. We consider specifications adding this control (accounting for its potential endogeneity) in Appendix E. The effects of the NGV fleet on prices remain negative and significant in almost all specifications.

In a different robustness exercise, we use Driscoll-Kraay standard errors (Driscoll and Kraay, 1998), which correct for spatial and temporal autocorrelation. The statistical significance of the coefficients remain basically unchanged (see Appendix F).

Another concern is that fuel prices may directly impact some of our controls. More precisely, contemporaneous fuel prices likely affect the fleet shares of gasoline and flex-fuel and of ethanol and flex-fuel cars. To deal with that, we estimate equation (1) using lagged versions of fuel type fleet shares as controls instead of their contemporaneous versions. Results are negative and significant in all specifications, as shown in Appendix G.

[23] We consider all Rio de Janeiro municipalities, including the ones outside the fuel sample database.

Finally, we also check the robustness of our results to measurement error.[24] The fleet data from Detran-RJ on fleet size includes all kinds of vehicles, including some that do not usually run on CNG in Brazil, such as buses, trucks, agricultural vehicles, and motorcycles. We estimate our model excluding buses, trucks, and agricultural vehicles.[25] Our results are robust to this specification, as shown in Appendix H.

6 Environmental Consequences

As shown in Section 5, the growth in the NGV fleet caused the prices of ethanol and gasoline in Rio de Janeiro to fall. Although this effect has benefited owners of cars running on the former two fuels, it has also created an incentive for further fuel consumption by drivers. This implies longer distances traveled and, consequently, higher emissions of pollutants. Therefore, the rise of NGVs may prove detrimental to the environment compared to a counterfactual in which gasoline and ethanol prices had not been affected (for instance, if NGVs had not been introduced). In this section, we quantify the emissions of pollutants resulting from the growth of NGVs in Rio de Janeiro in 2008. In the first exercise, we focus solely on the gasoline and ethanol price effects estimated in the previous section, disregarding any changes in the fleet composition. In the second exercise, we calculate the overall emission impact from the growth of the NGV fleet, considering the effects of price and fleet composition changes. This includes substituting CNG for ethanol or gasoline upon conversion and potential increased usage intensity after CNG adoption.

In the first exercise, we calculate the emissions impacts as follows. First, we break the circulating Rio de Janeiro fleet by fuel and vintage. Second, we employ estimates from

[24] That said, there are a few reasons to believe that our measurement error is not changing the sign of our coefficient of interest (i.e. we only have attenuation bias). The fixed effects in panel data capture the measurement error's constant parts. Even for non-classical measurement error, attenuation bias is the most likely outcome in the univariate case (specification 3 in Table 3). We cannot be sure if multivariate specifications 5-7 suffer from attenuation or inflation bias, but since their estimates are similar to the one in specification 3, this gives confidence in our results. Additional measurement error may come from the fleet data including both vehicles that were and were not registered for circulating in a given year.

[25] In order to be able to estimate specifications 5 and 7 detailed in Section 5, we need an omitted category of vehicles so that the share of CNG, ethanol, gasoline, and flex vehicles are not collinear. In our main regressions, we have diesel vehicles as an omitted category. However, once we exclude buses, trucks, and agricultural vehicles, which mainly run on diesel, we need a new omitted class of vehicles. For this reason, we do not exclude motorcycles in this check.

the literature on the intensity of use of vehicles (by fuel and age) and estimates of price-demand elasticities for gasoline and ethanol. We use these estimates to calculate changes in fuel demand following a price fall. Third, we estimate pollutant emissions following the demand surge mentioned above in demand by age and fuel type and aggregate the results to the state level. We calculate the increased emissions under several assumptions detailed in Appendix I. In particular, we assume that all flex-fuel cars run on gasoline only (results considering that all flex-fuel cars run only on ethanol are similar and shown in Appendix I). Moreover, we consider two scenarios with different price-demand elasticities to provide bounds for pollutant emissions:

- Pessimistic Scenario: We employ the largest price-demand elasticities for gasoline and ethanol in our reviewed literature.[26] We use -3.848 and -3.583 as the price-demand elasticities for gasoline and ethanol, respectively, from Iootty et al. (2009). This gives the largest possible impact of the NGV fleet growth on emissions via price changes in gasoline and ethanol.
- Optimistic Scenario: We employ the lowest price-demand elasticities for gasoline and ethanol in our reviewed literature. We use -0.2 and -0.459 as the price-demand elasticities for gasoline and ethanol from Roppa (2005) and Azevedo (2007), respectively. This gives the lowest possible impact of the NGV fleet growth on emissions via price changes in gasoline and ethanol.

We consider the emissions of several pollutants. Three of them are associated with climate change impacts: CO_2 (carbon dioxide), CH_4 (methane), and NO_x (nitrogen oxides). The other four, although not impacting climate change directly, pose health threats to living beings: CO (carbon monoxide), aldehydes, $NHMC$ (non-methane hydrocarbons), and PM

[26]The following works were considered for price-demand elasticities for fuels in Brazil: Roppa (2005), Azevedo (2007), Schünemann (2007), Iootty et al. (2009), Pontes (2009), de Freitas and Kaneko (2011) and other studies reviewed on it, Orellano et al. (2013) and Santos (2013).

(particulate matter).[27] Since CO_2, CH_4, and NO_x have distinct global warming potentials, we also calculate the CO_2eq (equivalent carbon dioxide) emissions considering these three pollutants.

Table 5 shows calculated emissions[28] for the two scenarios in the state of Rio de Janeiro in 2008. We can put these estimates into perspective using emissions estimated from the Greenhouse Gases Emissions and Removals Estimates System (SEEG) (Azevedo et al., 2018). The total CO_2eq emissions under the optimistic and pessimistic scenarios, 12,759 and 193,614 tonnes, were equivalent to 0.02% and 0.3% of the total estimated CO_2eq emissions in the state in 2008.

Table 5: Emissions of Pollutants

	Pessimistic Scenario							
	CO_2	CH_4	NO_x	*Total* CO_2eq	CO	$NMHC$	*Aldehydes*	PM
Tonnes	105,725	46	291	193,614	2,456	239	15	1
% of RJ Emissions	0.22%	0.01%	0.12%	0.3%	0.95%	-	-	-
	Optimistic Scenario							
	CO_2	CH_4	NO_x	*Total* CO_2eq	CO	$NMHC$	*Aldehydes*	PM
Tonnes	5,765	4	23	12,759	206	20	1	0
% of RJ Emissions	0.01%	0.001%	0.01%	0.02%	0.08%	-	-	-

NOTES: Calculated decreased(-)/increased(+) emissions of pollutants from the gasoline/ethanol price effects arising from the growth of the NGV fleet in Rio de Janeiro in 2008. We consider high price-demand elasticities of gasoline and ethanol in the pessimistic scenario and low price-demand elasticities in the optimistic scenario. We assume that all flex-fuel cars run on gasoline only. Emissions shown as total tonnes or as a percentage of total emissions in Rio de Janeiro in 2008 for pollutants available in the Greenhouse Gases Emissions and Removals Estimates System (SEEG) - see Azevedo et al. (2018). Pollutants with global warming potential are CO_2 (Carbon Dioxide), CH_4 (Methane), NO_x (Nitrogen Oxides). Total CO_2eq considers the total value of the first three columns (CO_2, CH_4 and NO_x) in carbon dioxide equivalent. Local air pollutants with health impacts are CO (Carbon Monoxide), NMHC (Non-Methane Hydrocarbons), Aldehydes, and PM (Particulate Matter).

Assuming the most recent official American government values of the social costs of

[27] Only excessive exposition to CO may pose a health risk. Such levels of exposition are likely infeasible from the emissions in our setting. Carbon monoxide, though not a direct agent of Global Warming, is related to the latter through the formation of methane and carbon dioxide (Voiland (2015)). Aldehydes are generally reactive and, therefore, toxic to humans. $NMHC$ contributes to the formation of tropospheric ozone, damaging vegetation. Also, there is evidence of its adverser health impacts on humans (especially benzene and 1,3-butadiene). Although they are not direct contributors to climate change, they can, via oxidation, lead to the formation of CO_2.

[28] The emissions are calculated, not estimated, due to a lack of available data on emissions for most municipalities in the Rio de Janeiro state during our study period.

carbon (USD 51), methane (USD 1,500), and nitrous oxide (USD 18,000), converted to 2008 US dollars (White House, 2021),[29] the cost of greenhouse gas emissions was between USD 593,973 and USD 8,900,237 in 2008.

We also calculate the overall increase in emissions from the growth of NGVs, accounting for the changes in fleet composition and fuel prices. Details of the calculations are available in Appendix J. Under various scenarios, we show that NGVs led to increased emissions equivalent to 0.58% and 5.8% of the total estimated CO_2eq emissions in Rio de Janeiro in 2008. Assuming the most recent official American government values of the social costs of carbon, methane, and nitrous oxide, converted to 2008 US dollars (White House, 2021), the cost of greenhouse gas emissions was between US$ 23,607,776 and US$ 175,263,998. In sum, natural gas seems to be driving emissions up, which contradicts some policymakers' views that portray it as a green fuel.

7 Conclusion

We provide evidence that the increasing penetration of NGVs in a large Brazilian state has reduced retail prices and margins of ethanol and gasoline. The results are robust to several specifications. Consequently, NGVs lowered fuel costs not only for their drivers but also for owners of gasoline, ethanol, and flex-fuel cars. On the other hand, NGVs led to higher emissions of CO2eq, challenging the view that they are beneficial to the environment. NGVs also emit substantial amounts of non-greenhouse gases that can have large negative welfare effects.[30]

Our results underscore the importance of market forces and market power in designing policies to reduce emissions, a topic gaining momentum worldwide. In a broadly related subject, the European Commission is currently considering promoting environmental sustainability by relaxing anti-competitive policies in Article 101(3) of the Treaty on the

[29] We consider the average estimates assuming a 3% discount rate. The inflation rate between 2008-2020 in the US was 20.21%.

[30] For instance, Deschênes et al. (2017) estimate that emissions reductions due to the NOx Budget Program in the US produced large welfare gains. Using age-adjusted estimates of the value of a statistical life, they calculate that over 60% of the Program's benefits stem from avoided mortality.

Functioning of the European Union.[31] The literature on how alternative cleaner fuels affect equilibrium prices and quantities of incumbent energy sources is still developing, and we bring new insights from a large CNG market.

Better quantifying the pros and cons of expanding CNG markets and increasing fuel competition demands further research. One welcome extension would be to build and estimate a price formation model considering potential environmental externalities. This approach would allow for welfare calculations of the impact of the rise of NGVs.

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Online Appendix – Not for Publication

A Theoretical Model

Assume that there is a continuous variable between 0 and 1 of car owners (from here on called consumers). Each consumer owns exactly one car. We assume, without loss of generality, that this car can run on both ethanol or gas. Furthermore, assume that a station is faced with the aggregate demand $D(p, \theta) = (1 - \theta)a - p$, with $p = min\{p_e, p_g\}$, where p_e and p_g are, respectively, the prices for ethanol and gasoline in this station, θ is the share of NGVs owners among consumers of fuels and a is an exogenous demand component. The station maximizes its profit $(p - c)q$, where c is the marginal cost of the cheapest fuel between ethanol and gasoline and q is the number of liters of that fuel sold. Assume further that $p > c$.

$$\underset{p}{Max}\ [(1-\theta)a - p](p - c) \tag{3}$$

Maximizing the profit of the station (equation 3) when $q = D(p, \theta)$, defining $\theta = \theta(p)$[32] and rearranging we get:

$$p(a\theta' + 2) = a(1 - \theta) + c(1 + a\theta') \tag{4}$$

From (4) and the Implicit Function Theorem we have that:

$$\frac{\partial p}{\partial \theta}(a\theta' + 2) + ap\frac{\partial \theta'}{\partial \theta} = -a + ac\frac{\partial \theta'}{\partial \theta} \tag{5}$$

We know $\theta'^{-1} \circ \theta'(p) = p$[33]. Hence, by differentiating both sides with respect to θ we get $\frac{\partial \theta'}{\partial \theta} = \frac{\partial p}{\partial \theta}\theta'$. Substituting this last term in equation 5 and rearranging we have:

$$\frac{\partial p}{\partial \theta} = \frac{-a}{a\theta' + 2 + a\theta'(p - c)} < 0 \tag{6}$$

[32] This follows from the fact that the decision to convert a car to run on natural gas will depend on the price of the alternative fuels. Hence, the higher the price of gas or ethanol, the higher the incentive to convert one's vehicle. This dynamics reflect the source of endogeneity in our estimation.

[33] As from the Implicit Function Theorem, we are again implicitly assuming that the inverse of θ exists.

From this, we have that the price of ethanol and gasoline vary negatively with the growth of the NGV fleet.

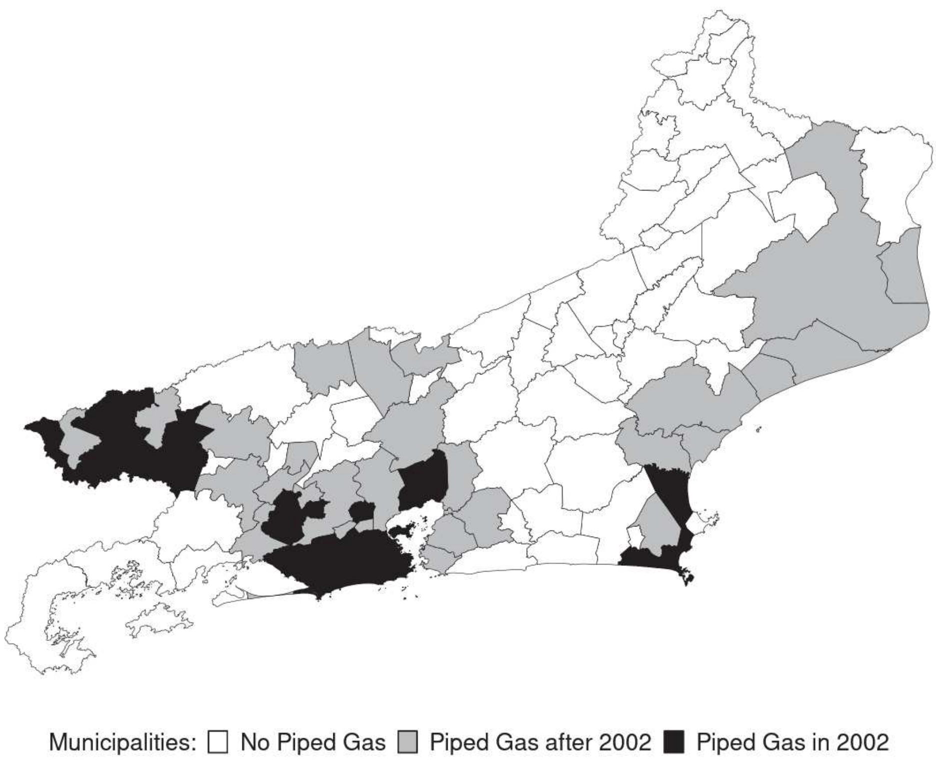
B Additional Tables for Main Results

Table 6: Standard Deviation of the share of NGVs - Error Terms

Municipality	Until June 2008	After June 2008	Municipality	Until June 2008	After June 2008
Angra dos Reis	3	0.2	Nova Iguaçu	0.9	0.7
Araruama	0.6	0.2	Paraíba do Sul	2.2	0.4
Armação dos Búzios	0.3	0.9	Paraty	2.5	0.1
Barra do Piraí	0.4	0.2	Paty do Alferes	1	-
Barra Mansa	0.8	0.5	Petrópolis	1.1	0.3
Belford Roxo	3.3	0.3	Queimados	2.2	0.6
Cabo Frio	2.1	0.5	Resende	1.1	0.3
Campos dos Goytacazes	0.5	0.6	Rio Bonito	1.5	0.3
Duque de Caxias	0.2	0.7	Rio de Janeiro	0.5	0.3
Iguaba Grande	0.1	-	Santo Antônio de Pádua	2.8	0.5
Itaboraí	1.4	0.9	São Francisco de Itabapoana	1.9	0.3
Itaguaí	0.4	0.8	São Gonçalo	1.7	0.4
Itaperuna	4.1	0.2	São João de Meriti	1.3	0.9
Japeri	0.7	-	São José de Ubá	0.7	-
Macaé	0.7	0.8	Sapucaia	2.7	0.3
Magé	2	0.3	Saquarema	0.4	0.2
Mangaratiba	2.7	1.5	Seropédica	1.1	-
Maricá	1.5	0.4	Teresópolis	3	0.4
Mesquita	2.6	-	Três Rios	3.2	0.3
Nilópolis	2.4	0.2	Valença	1.8	0.6
Niterói	1.3	0.4	Vassouras	0.6	0.2
Nova Friburgo	3.5	0.3	Volta Redonda	2	0.4

NOTES: The table shows the standard deviation of the error terms of the linear regression of the share of NGVs by municipality on a municipality fixed effect for two periods: January 2001 to June 2008 and July 2008 to December 2016. Source: Detran-RJ.

Figure 4: Municipalities with Piped Gas Infrastructure



NOTES: The figure shows the municipalities that had piped gas infrastructure in the state of Rio de Janeiro in 2002, municipalities that developed a piped gas infrastructure at some point between 2003 and 2016 and municipalities without access to piped gas over the entire period.

Table 7: Gasoline Prices 2002-2008

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS	(7) 2SLS
NGV Share	0.0336	-0.387***	-0.512***	-0.509***	-1.116	-0.640***	-1.178***
	(0.18)	(-5.58)	(-3.99)	(-3.98)	(-1.43)	(-5.41)	(-2.86)
Gas and Flex Share					-0.707		-0.742*
					(-0.89)		(-1.71)
GDP per Capita						8.697***	5.211**
						(6.14)	(2.14)
Fleet/Station						-0.0772	-0.0418
						(-0.68)	(-0.31)
Stations City-month						0.0834	0.274*
						(1.03)	(1.90)
Observations	297489	297489	297489	297489	297489	297489	297489
Instrumentalized Fleet	No	No	Yes	Yes	Yes	Yes	Yes
Station Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	No	No	Yes	Yes	Yes	Yes
Kleibergen-Paap LM statistic			166.0	165.3	9.603	166.0	59.35
Kleibergen-Paap LM p-value			5.41e-38	7.99e-38	0.00194	5.43e-38	1.32e-14

NOTES: Table displays the estimated effects of shares of NGVs on gasoline retail prices. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly Brazilian CPI (Índice de Preços ao Consumidor Amplo – IPCA). Columns 1-2 are estimated by OLS and columns 3-7 by 2SLS. Columns 2-7 include station and monthly fixed effects and columns 3-7 include station-brand fixed effects as controls. Columns 5 and 7 also include the sum of shares of the gasoline and flex fleet as a control. Finally, column 6 and 7 add yearly municipal GDP per capita (available only until 2015) divided by 100, the NGV fleet divided by the monthly number of stations at the municipality level divided by 10,000, and the monthly number of stations at each municipality divided by 100,000 as controls. Instrument for the share of NGVs is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our prices database. Standard errors are clustered by city-month. Shown in parentheses are the t-stats for the coefficients. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 8: Gasoline Margins 2002-2008

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS	(7) 2SLS
NGV Share	-0.543***	-0.329***	-0.371***	-0.378***	-0.664	-0.514***	-0.861**
	(-9.15)	(-5.52)	(-3.30)	(-3.37)	(-1.08)	(-4.47)	(-2.26)
Gas and Flex Share					-0.341		-0.502
					(-0.54)		(-1.24)
GDP per Capita						7.185***	4.742**
						(6.32)	(2.37)
Fleet/Station						0.228	0.226
						(0.67)	(0.67)
Stations City-month						0.174	0.290
						(1.49)	(1.59)
Observations	206442	206442	206442	206442	206442	206442	206442
Instrumentalized Fleet	No	No	Yes	Yes	Yes	Yes	Yes
Station Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	No	No	Yes	Yes	Yes	Yes
Kleibergen-Paap LM statistic			175.9	175.4	13.81	184.9	75.01
Kleibergen-Paap LM p-value			3.75e-40	4.90e-40	0.000203	4.06e-42	4.68e-18

NOTES: Table displays the estimated effects of shares of NGVs on gasoline retail margins. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly Brazilian CPI (Índice de Preços ao Consumidor Amplo – IPCA). Columns 1-2 are estimated by OLS and columns 3-7 by 2SLS. Columns 2-7 include station and monthly fixed effects and columns 3-7 include station-brand fixed effects as controls. Columns 5 and 7 also include the sum of shares of the gasoline and flex fleet as a control. Finally, column 6 and 7 add yearly municipal GDP per capita (available only until 2015) divided by 100, the NGV fleet divided by the monthly number of stations at the municipality level divided by 10,000, and the monthly number of stations at each municipality divided by 100,000 as controls. Instrument for the share of NGVs is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our prices database. Standard errors are clustered by city-month. Shown in parentheses are the t-stats for the coefficients. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 9: Ethanol Prices 2002-2008

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS	(7) 2SLS
NGV Share	0.547**	-0.417***	-0.808***	-0.868***	-0.499***	-0.775***	-0.474***
	(2.06)	(-4.34)	(-3.73)	(-4.01)	(-2.98)	(-3.93)	(-2.90)
Ethanol and Flex Share					-1.317***		-1.206***
					(-8.15)		(-7.68)
GDP per Capita						3.799	1.309
						(1.56)	(0.60)
Fleet/Station						0.116	0.102
						(0.36)	(0.30)
Stations City-month						0.823***	0.432**
						(4.05)	(2.37)
Observations	277201	277201	277201	277201	277201	277201	277201
Instrumentalized Fleet	No	No	Yes	Yes	Yes	Yes	Yes
Station Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	No	No	Yes	Yes	Yes	Yes
Kleibergen-Paap LM statistic			168.3	166.9	154.7	166.6	143.0
Kleibergen-Paap LM p-value			1.74e-38	3.47e-38	1.65e-35	4.12e-38	5.84e-33

NOTES: Table displays the estimated effects of shares of NGVs on ethanol retail prices. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly Brazilian CPI (Índice de Preços ao Consumidor Amplo – IPCA). Columns 1-2 are estimated by OLS and columns 3-7 by 2SLS. Columns 2-7 include station and monthly fixed effects and columns 3-7 include station-brand fixed effects as controls. Columns 5 and 7 also include the sum of shares of the ethanol and flex fleet as a control. Finally, column 6 and 7 add yearly municipal GDP per capita (available only until 2015) divided by 100, the NGV fleet divided by the monthly number of stations at the municipality level divided by 10,000, and the monthly number of stations at each municipality divided by 100,000 as controls. Instrument for the share of NGVs is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our prices database. Standard errors are clustered by city-month. Shown in parentheses are the t-stats for the coefficients. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 10: Ethanol Margins 2002-2008

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS	(7) 2SLS
NGV Share	-0.697***	-0.394***	-0.923***	-0.885***	-0.762***	-0.972***	-0.915***
	(-13.05)	(-4.53)	(-4.88)	(-4.71)	(-5.01)	(-5.90)	(-6.16)
Ethanol and Flex Share					-0.559***		-0.324**
					(-3.86)		(-2.42)
GDP per Capita						12.23***	11.27***
						(6.28)	(5.69)
Fleet/Station						2.237***	2.403***
						(2.90)	(2.97)
Stations City-month						1.866***	1.808***
						(5.86)	(5.62)
Observations	159286	159286	159286	159286	159286	159286	159286
Instrumentalized Fleet	No	No	Yes	Yes	Yes	Yes	Yes
Station Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	No	No	Yes	Yes	Yes	Yes
Kleibergen-Paap LM statistic			179.0	178.3	151.6	180.5	143.9
Kleibergen-Paap LM p-value			7.89e-41	1.13e-40	7.84e-35	3.86e-41	3.65e-33

NOTES: Table displays the estimated effects of shares of NGVs on ethanol retail margins. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly Brazilian CPI (Índice de Preços ao Consumidor Amplo – IPCA). Columns 1-2 are estimated by OLS and columns 3-7 by 2SLS. Columns 2-7 include station and monthly fixed effects and columns 3-7 include station-brand fixed effects as controls. Columns 5 and 7 also include the sum of shares of the ethanol and flex fleet as a control. Finally, column 6 and 7 add yearly municipal GDP per capita (available only until 2015) divided by 100, the NGV fleet divided by the monthly number of stations at the municipality level divided by 10,000, and the monthly number of stations at each municipality divided by 100,000 as controls. Instrument for the share of NGVs is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our prices database. Standard errors are clustered by city-month. Shown in parentheses are the t-stats for the coefficients. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 11: Gasoline Prices 2002-2008 - First Stage

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS
Piped Gas x Fleet RJ	0.460***	0.458***	0.0585***	0.497***	0.123***
	(11.59)	(11.56)	(2.82)	(14.26)	(7.46)
Gas and Flex Share			-1.016***		-1.036***
			(-55.96)		(-71.32)
GDP per Capita				-1.693***	-5.286***
				(-4.30)	(-15.76)
Fleet/Station				0.284**	0.120**
				(2.35)	(2.18)
Stations City-month				0.429***	0.372***
				(7.14)	(14.44)
Observations	297489	297489	297489	297489	297489
Station Fixed Effect	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	Yes	Yes	Yes	Yes

NOTES: Table displays the first stage for the regression on the estimated effects of shares of NGVs on gasoline retail prices. The dependent variable is the share of NGVs in the total automobile's fleet. The instrument, here shown as an independent regressor, is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our prices database. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly Brazilian CPI (Índice de Preços ao Consumidor Amplo – IPCA). All Columns include station and monthly fixed effects and columns 2-5 include station-brand fixed effects as controls. Columns 3 and 5 also include the sum of shares of the gasoline and flex fleet as a control. Finally, column 4 and 5 add yearly municipal GDP per capita (available only until 2015) divided by 100, the NGV fleet divided by the monthly number of stations at the municipality level divided by 10,000, and the monthly number of stations at each municipality divided by 100,000 as controls. Standard errors are clustered by city-month. Shown in parentheses are the t-stats for the coefficients. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 12: Gasoline Margins 2002-2008 - First Stage

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS
Piped Gas x Fleet RJ	0.470^{***}	0.469^{***}	0.0701^{***}	0.498^{***}	0.140^{***}
	(11.96)	(11.99)	(3.34)	(14.76)	(8.30)
Gas and Flex Share			-1.013^{***}		-1.040^{***}
			(-51.21)		(-66.03)
GDP per Capita				-1.179^{***}	-5.392^{***}
				(-3.35)	(-15.71)
Fleet/Station				0.714^{***}	0.196^{**}
				(4.51)	(2.55)
Stations City-month				0.565^{***}	0.398^{***}
				(8.38)	(12.89)
Observations	206442	206442	206442	206442	206442
Station Fixed Effect	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	Yes	Yes	Yes	Yes

NOTES: Table displays the first stage for the regression on the estimated effects of shares of NGVs on gasoline retail margins. The dependent variable is the share of NGVs in the total automobile's fleet. The instrument, here shown as an independent regressor, is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our prices database. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly Brazilian CPI (Índice de Preços ao Consumidor Amplo – IPCA). All Columns include station and monthly fixed effects and columns 2-5 include station-brand fixed effects as controls. Columns 3 and 5 also include the sum of shares of the gasoline and flex fleet as a control. Finally, column 4 and 5 add yearly municipal GDP per capita (available only until 2015) divided by 100, the NGV fleet divided by the monthly number of stations at the municipality level divided by 10,000, and the monthly number of stations at each municipality divided by 100,000 as controls. Standard errors are clustered by city-month. Shown in parentheses are the t-stats for the coefficients. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 13: Ethanol Prices 2002-2008 - First Stage

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS
Piped Gas x Fleet RJ	0.468***	0.465***	0.557***	0.502***	0.588***
	(12.06)	(12.02)	(19.96)	(14.90)	(23.41)
Ethanol and Flex Share			-0.701***		-0.689***
			(-17.44)		(-18.57)
GDP per Capita				-1.524***	-3.209***
				(-3.65)	(-7.75)
Fleet/Station				0.284**	0.324**
				(2.40)	(2.17)
Stations City-month				0.425***	0.274***
				(6.97)	(5.02)
Observations	277201	277201	277201	277201	277201
Station Fixed Effect	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	Yes	Yes	Yes	Yes

NOTES: Table displays the first stage for the regression on the estimated effects of shares of NGVs on ethanol retail prices. The dependent variable is the share of NGVs in the total automobile's fleet. The instrument, here shown as an independent regressor, is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our prices database. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly Brazilian CPI (Índice de Preços ao Consumidor Amplo – IPCA). All Columns include station and monthly fixed effects and columns 2-5 include station-brand fixed effects as controls. Columns 3 and 5 also include the sum of shares of the ethanol and flex fleet as a control. Finally, column 4 and 5 add yearly municipal GDP per capita (available only until 2015) divided by 100, the NGV fleet divided by the monthly number of stations at the municipality level divided by 10,000, and the monthly number of stations at each municipality divided by 100,000 as controls. Standard errors are clustered by city-month. Shown in parentheses are the t-stats for the coefficients. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 14: Ethanol Margins 2002-2008 - First Stage

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS
Piped Gas x Fleet RJ	0.501***	0.499***	0.565***	0.529***	0.586***
	(12.94)	(12.92)	(18.92)	(16.49)	(22.65)
Ethanol and Flex Share			-0.600***		-0.604***
			(-12.00)		(-13.75)
GDP per Capita				-0.783**	-2.646***
				(-2.07)	(-6.61)
Fleet/Station				0.633***	1.009***
				(3.58)	(3.74)
Stations City-month				0.562***	0.513***
				(7.98)	(6.03)
Observations	159286	159286	159286	159286	159286
Station Fixed Effect	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	Yes	Yes	Yes	Yes

NOTES: Table displays the first stage for the regression on the estimated effects of shares of NGVs on ethanol retail margins. The dependent variable is the share of NGVs in the total automobile's fleet. The instrument, here shown as an independent regressor, is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our prices database. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly Brazilian CPI (Índice de Preços ao Consumidor Amplo – IPCA). All Columns include station and monthly fixed effects and columns 2-5 include station-brand fixed effects as controls. Columns 3 and 5 also include the sum of shares of the ethanol and flex fleet as a control. Finally, column 4 and 5 add yearly municipal GDP per capita (available only until 2015) divided by 100, the NGV fleet divided by the monthly number of stations at the municipality level divided by 10,000, and the monthly number of stations at each municipality divided by 100,000 as controls. Standard errors are clustered by city-month. Shown in parentheses are the t-stats for the coefficients. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 15: Regressions 2002-2016

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS	(7) 2SLS
	Panel A - Gasoline Prices						
NGV Share	-1.501***	0.390***	1.117***	1.090***	-1.417***	0.114	-2.734**
	(-12.80)	(8.34)	(5.33)	(5.29)	(-4.52)	(0.89)	(-2.14)
	Panel B - Gasoline Margins						
NGV Share	-0.352***	0.219***	0.751***	0.766***	-1.088***	-0.153	-2.144***
	(-9.64)	(5.36)	(4.31)	(4.38)	(-3.31)	(-1.25)	(-2.99)
	Panel C - Ethanol Prices						
NGV Share	0.0649	0.406***	0.841***	0.769***	0.744***	0.446***	0.436***
	(0.44)	(6.31)	(4.00)	(3.73)	(4.46)	(2.81)	(2.73)
	Panel D - Ethanol Margins						
NGV Share	-0.465***	0.0755	0.117	0.137	0.112	-0.162	-0.163
	(-13.95)	(1.37)	(0.64)	(0.74)	(0.81)	(-1.16)	(-1.17)
Instrumentalized Fleet	No	No	Yes	Yes	Yes	Yes	Yes
Station Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	No	No	Yes	Yes	Yes	Yes

NOTES: Table displays the estimated effects of the share of NGVs on gasoline retail prices (panel A), gasoline retail margins (panel B), ethanol retail prices (panel C), and ethanol retail margins (panel D). Shown in parentheses are the t-stats for the coefficients. Standard errors are clustered by city-month. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to December 2016. All prices are expressed in BRL real terms, deflated by the monthly IPCA. Columns 1-2 are estimated by OLS and columns 3-7 by 2SLS. Columns 2-7 include station and monthly fixed effects and columns 4-7 include station-brand fixed effects as controls. Columns 5 and 7 also include the sum of the shares of gasoline and flex vehicles in the fleet as a control (fuel share control) in the gasoline retail prices and margins specifications. Columns 5 and 7 also include the sum of the share of ethanol and flex vehicles in the fleet as a control (fuel share control) in the ethanol retail prices and margins specifications. Column 6 and 7 add the following controls: yearly municipal GDP per capita, the NGV fleet divided by the monthly number of stations at the municipality level, and the monthly number of stations in each municipality (market controls). Instrument for the share of NGVs is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our price database. Gasoline prices regressions have N = 540,669. Gasoline margins regressions have N = 342,812. Ethanol prices regressions have N = 515,673. Ethanol margins regressions have N = 282,558.

Table 16: Regressions - First Stage 2002-2016

	(1)	(2)	(3)	(4)	(5)
	Panel A - Gasoline Prices 1^{st} Stage				
Piped Gas x Fleet RJ	0.292***	0.291***	-0.106***	0.451***	0.0411***
	(11.17)	(11.16)	(-7.76)	(18.68)	(4.73)
	Panel B - Gasoline Margins 1^{st} Stage				
Piped Gas x Fleet RJ	0.256***	0.255***	-0.0873***	0.403***	0.0675***
	(10.12)	(10.19)	(-6.72)	(17.73)	(7.73)
	Panel C - Ethanol Prices 1^{st} Stage				
Piped Gas x Fleet RJ	0.297***	0.295***	0.382***	0.452***	0.441***
	(11.66)	(11.64)	(21.08)	(19.18)	(26.10)
	Panel D - Ethanol Margins 1^{st} Stage				
Piped Gas x Fleet RJ	0.264***	0.262***	0.363***	0.424***	0.421***
	(10.94)	(10.95)	(19.45)	(18.76)	(25.20)
Station Fixed Effect	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	Yes	Yes	Yes	Yes

NOTES: Table displays the estimated effects of the share of NGVs on gasoline retail prices (panel A), gasoline retail margins (panel B), ethanol retail prices (panel C), and ethanol retail margins (panel D). Shown in parentheses are the t-stats for the coefficients. Standard errors are clustered by city-month. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The dependent variable is the share of NGVs in the total vehicle fleet. The instrument, here shown as an independent regressor, is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our prices database. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to December 2016. All prices are expressed in BRL real terms, deflated by the IPCA. All Columns include station and monthly fixed effects and columns 2-5 include station-brand fixed effects as controls. Columns 3 and 5 also include the sum of the shares of gasoline and flex vehicles in the fleet as a control in the gasoline retail prices and margins specifications. Columns 3 and 5 also include the sum of the share of ethanol and flex vehicles in the fleet as a control in the ethanol retail prices and margins specifications. Columns 4 and 5 add yearly municipal GDP per capita, the NGV fleet divided by the monthly number of stations at the municipality level, and the monthly number of stations at each municipality as controls. Gasoline prices regressions have N = 540,669. Gasoline margins regressions have N = 342,812. Ethanol prices regressions have N = 515,673. Ethanol margins regressions have N = 282,558.

Table 17: Regressions 2008-2016

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS	(7) 2SLS
				Panel A - Gasoline Prices			
NGV Share	-0.464***	0.115	-2.943***	-2.932***	-3.823***	-2.254***	-3.380***
	(-9.47)	(1.20)	(-9.31)	(-9.58)	(-9.22)	(-4.95)	(-4.93)
				Panel B - Gasoline Margins			
NGV Share	-0.287***	0.0681	-1.584***	-1.564***	-2.809***	-0.579*	-1.801**
	(-13.81)	(0.58)	(-5.69)	(-5.83)	(-6.13)	(-1.82)	(-2.54)
				Panel C - Ethanol Prices			
NGV Share	-0.132**	0.341***	-1.167***	-1.174***	-1.194***	-1.412**	-1.429***
	(-2.27)	(2.70)	(-2.92)	(-2.94)	(-3.13)	(-2.52)	(-2.63)
				Panel D - Ethanol Margins			
NGV Share	-0.0506**	-0.124	-1.423***	-1.445***	-1.425***	-1.591***	-1.599***
	(-2.18)	(-0.92)	(-4.13)	(-4.29)	(-4.31)	(-3.35)	(-3.37)
Instrumentalized Fleet	No	No	Yes	Yes	Yes	Yes	Yes
Station Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	No	No	Yes	Yes	Yes	Yes

NOTES: Table displays the estimated effects of the share of NGVs on gasoline retail prices (panel A), gasoline retail margins (panel B), ethanol retail prices (panel C), and ethanol retail margins (panel D). Shown in parentheses are the t-stats for the coefficients. Standard errors are clustered by city-month. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from July 2008 to December 2016. All prices are expressed in BRL real terms, deflated by the monthly IPCA. Columns 1-2 are estimated by OLS and columns 3-7 by 2SLS. Columns 2-7 include station and monthly fixed effects and columns 4-7 include station-brand fixed effects as controls. Columns 5 and 7 also include the sum of the shares of gasoline and flex vehicles in the fleet as a control (fuel share control) in the gasoline retail prices and margins specifications. Columns 5 and 7 also include the sum of the share of ethanol and flex vehicles in the fleet as a control (fuel share control) in the ethanol retail prices and margins specifications. Column 6 and 7 add the following controls: yearly municipal GDP per capita, the NGV fleet divided by the monthly number of stations at the municipality level, and the monthly number of stations in each municipality (market controls). Instrument for the share of NGVs is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our price database. Gasoline prices regressions have N = 246,065. Gasoline margins regressions have N = 138,312. Ethanol prices regressions have N = 241,310. Ethanol margins regressions have N = 124,963.

Table 18: Regressions - First Stage 2008-2016

	(1)	(2)	(3)	(4)	(5)
	Panel A - Gasoline Prices 1^{st} Stage				
Piped Gas x Fleet RJ	-0.924***	-0.923***	-0.747***	-0.785***	-0.554***
	(-21.99)	(-22.06)	(-19.69)	(-13.98)	(-12.85)
	Panel B - Gasoline Margins 1^{st} Stage				
Piped Gas x Fleet RJ	-1.070***	-1.082***	-0.716***	-1.013***	-0.563***
	(-29.44)	(-29.73)	(-21.06)	(-19.43)	(-10.80)
	Panel C - Ethanol Prices 1^{st} Stage				
Piped Gas x Fleet RJ	-0.954***	-0.949***	-0.994***	-0.804***	-0.833***
	(-21.43)	(-21.65)	(-23.88)	(-14.00)	(-15.18)
	Panel D - Ethanol Margins 1^{st} Stage				
Piped Gas x Fleet RJ	-1.154***	-1.156***	-1.173***	-1.082***	-1.078***
	(-29.87)	(-30.33)	(-26.36)	(-20.62)	(-20.19)
Station Fixed Effect	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	Yes	Yes	Yes	Yes

NOTES: Table displays the estimated effects of the share of NGVs on gasoline retail prices (panel A), gasoline retail margins (panel B), ethanol retail prices (panel C), and ethanol retail margins (panel D). Shown in parentheses are the t-stats for the coefficients. Standard errors are clustered by city-month. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The dependent variable is the share of NGVs in the total vehicle fleet. The instrument, here shown as an independent regressor, is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our prices database. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from July 2008 to December 2016. All prices are expressed in BRL real terms, deflated by the IPCA. All Columns include station and monthly fixed effects and columns 2-5 include station-brand fixed effects as controls. Columns 3 and 5 also include the sum of the shares of gasoline and flex vehicles in the fleet as a control in the gasoline retail prices and margins specifications. Columns 3 and 5 also include the sum of the share of ethanol and flex vehicles in the fleet as a control in the ethanol retail prices and margins specifications.e fleet as controls in the ethanol retail prices and margins specifications. Columns 4 and 5 add yearly municipal GDP per capita, the NGV fleet divided by the monthly number of stations at the municipality level, and the monthly number of stations at each municipality as controls. Gasoline prices regressions have N = 246,065. Gasoline margins regressions have N = 138,312. Ethanol prices regressions have N = 241,310. Ethanol margins regressions have N = 124,963.

C Further Analysis - Southeast Fuel Stations IV

Table 19: IV - Piped Gas x Number of Fuel Stations: 2002-2008

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS	(7) 2SLS
	Panel A - Gasoline Prices						
NGV Share	0.0336	-0.387***	-0.585***	-0.583***	-1.371**	-0.722***	-1.555***
	(0.18)	(-5.58)	(-4.48)	(-4.48)	(-2.33)	(-5.86)	(-3.36)
	Panel B - Gasoline Margins						
NGV Share	-0.543***	-0.329***	-0.490***	-0.498***	-1.280***	-0.657***	-1.446***
	(-9.15)	(-5.52)	(-4.17)	(-4.25)	(-2.61)	(-5.41)	(-3.40)
	Panel C - Ethanol Prices						
NGV Share	0.547**	-0.417***	-0.934***	-1.017***	-0.685***	-1.058***	-0.723***
	(2.06)	(-4.34)	(-4.05)	(-4.42)	(-3.73)	(-4.61)	(-3.81)
	Panel D - Ethanol Margins						
NGV Share	-0.697***	-0.394***	-0.860***	-0.800***	-0.709***	-1.051***	-0.987***
	(-13.05)	(-4.53)	(-4.87)	(-4.58)	(-4.73)	(-5.85)	(-6.10)
Instrumentalized Fleet	No	No	Yes	Yes	Yes	Yes	Yes
Station Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	No	No	Yes	Yes	Yes	Yes

NOTES: Table displays the estimated effects of the share of NGVs on gasoline retail prices (panel A), gasoline retail margins (panel B), ethanol retail prices (panel C), and ethanol retail margins (panel D). Shown in parentheses are the t-stats for the coefficients. Standard errors are clustered by city-month. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly IPCA. Over the period, the average gasoline price = BRL 3.04, and the average gasoline margin = BRL 0.35. The average ethanol price = BRL 2.00, and the average ethanol margin = BRL 0.33. Columns 1-2 are estimated by OLS and columns 3-7 by 2SLS. Columns 2-7 include station and monthly fixed effects and columns 4-7 include station-brand fixed effects as controls. Columns 5 and 7 also include the sum of the shares of gasoline and flex vehicles in the fleet as a control (fuel share control) in the gasoline retail prices and margins specifications. Columns 5 and 7 also include the sum of the share of ethanol and flex vehicles in the fleet as a control (fuel share control) in the ethanol retail prices and margins specifications. Column 6 and 7 add the following controls: yearly municipal GDP per capita, the NGV fleet divided by the monthly number of stations at the municipality level, and the monthly number of stations in each municipality (market controls). Instrument for the share of NGVs is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the number of fuel stations supplying CNG in the Southeastern region of Brazil except Rio de Janeiro. The number of stations was calculated smoothed from the data in our main database. Gasoline prices regressions have N = 297,489. Gasoline margins regressions have N = 206,442. Ethanol prices regressions have N = 277,201. Ethanol margins regressions have N = 159,286.

D Further Analysis - No Neighbour IV

Table 20: IV - Piped Gas x Fleet RJ ex-Neighbours: 2002-2008

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS	(7) 2SLS
	Panel A - Gasoline Prices						
NGV Share	0.0336	-0.387***	-0.548***	-0.541***	-1.732	-0.702***	-1.558***
	(0.18)	(-5.58)	(-3.96)	(-3.93)	(-1.51)	(-5.67)	(-3.20)
	Panel B - Gasoline Margins						
NGV Share	-0.543***	-0.329***	-0.384***	-0.391***	-0.923	-0.559***	-1.104**
	(-9.15)	(-5.52)	(-3.16)	(-3.24)	(-1.03)	(-4.65)	(-2.48)
	Panel C - Ethanol Prices						
NGV Share	0.547**	-0.417***	-0.928***	-0.980***	-0.678***	-0.917***	-0.667***
	(2.06)	(-4.34)	(-4.22)	(-4.49)	(-3.70)	(-4.57)	(-3.72)
	Panel D - Ethanol Margins						
NGV Share	-0.697***	-0.394***	-0.846***	-0.809***	-0.726***	-0.943***	-0.903***
	(-13.05)	(-4.53)	(-4.69)	(-4.51)	(-4.73)	(-5.87)	(-6.06)
Instrumentalized Fleet	No	No	Yes	Yes	Yes	Yes	Yes
Station Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	No	No	Yes	Yes	Yes	Yes

NOTES: Table displays the estimated effects of the share of NGVs on gasoline retail prices (panel A), gasoline retail margins (panel B), ethanol retail prices (panel C), and ethanol retail margins (panel D). Shown in parentheses are the t-stats for the coefficients. Standard errors are clustered by city-month. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly IPCA. Over the period, the average gasoline price = BRL 3.04, and the average gasoline margin = BRL 0.35. The average ethanol price = BRL 2.00, and the average ethanol margin = BRL 0.33. Columns 1-2 are estimated by OLS and columns 3-7 by 2SLS. Columns 2-7 include station and monthly fixed effects and columns 4-7 include station-brand fixed effects as controls. Columns 5 and 7 also include the sum of the shares of gasoline and flex vehicles in the fleet as a control (fuel share control) in the gasoline retail prices and margins specifications. Columns 5 and 7 also include the sum of the share of ethanol and flex vehicles in the fleet as a control (fuel share control) in the ethanol retail prices and margins specifications. Columns 6 and 7 add the following controls: yearly municipal GDP per capita, the NGV fleet divided by the monthly number of stations at the municipality level, and the monthly number of stations in each municipality (market controls). Instrument for the share of NGVs is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities that have at least two spatial lags from the instrumented municipality. First stage statistics are available in Table 4 and in Appendix B Tables 7-10. Gasoline prices regressions have N = 297,489. Gasoline margins regressions have N = 206,442. Ethanol prices regressions have N = 277,201. Ethanol margins regressions have N = 159,286.

E Further Analysis - CNG Dummy

Not only can the penetration of NGVs impact the prices and margins of gasoline and ethanol, but the decision of the station to offer CNG may have an effect on the prices and margins of other fuels sold at that station. The effect would arise from the residual demand for ethanol or gasoline among NGV owners. For the engine to last longer, a driver should cold start her car on gasoline or ethanol and, only after having heated the engine, should she change to operation on natural gas. Albeit owners of vehicles converted to run on CNG will, whenever possible, run their cars on natural gas, there is still the aforementioned technological restriction which creates a residual demand for gasoline or ethanol by the drivers[34]. This fact may give the opportunity to stations supplying natural gas to charge a higher price for other fuels (gasoline or ethanol), as consumers of natural gas would prefer to fill their tanks with gasoline or ethanol in these stations, even though they are more expensive there than elsewhere, instead of facing travel costs to stations offering cheaper fuel.

To evaluate this second effect, we modify our main empirical model to include a dummy indicating if a station was offering natural gas at a given moment[35]. We also need an additional instrument for this new dummy. Hence, in addition to the instrument in equation 2, we use an instrument given by the interaction between the two variables described in equation 7.

$$IV_{st}^{DummyNGV} = Stations_t^{SWex-RJ} . I_s^{DistancetoPipelines}, \tag{7}$$

where $Stations_t^{SWex-RJ}$ is the monthly number of stations offering natural gas in the Southeast of Brazil (outside the Rio de Janeiro state) and $I_s^{DistancetoPipelines}$ is a dummy equal to 1 if an station is less than 20 kilometers from one of Rio de Janeiro's main gas

[34]The technology of the conversion kits for cars to run on natural gas has developed between 2001 and 2016. Older conversion kits came with a fuel shift button. The driver needed to press this button in order to change from gasoline/ethanol to natural gas and vice-versa. Newer kits had an eletronic system that would choose gasoline/ethanol whenever the car was cold, shifting to natural gas automatically as soon as the engine heated.

[35]Our dummy is 1 for stations supplying natural gas, and 0 otherwise. It is constructed by observing if a given station had CNG prices registered for a given moment in time or not.

pipelines[36]. Again, the first term of the interaction reflects a non-local growth tendency, but this time for the supply of natural gas for vehicles. The second term reflects the fact that Ceg and Ceg-Rio will expand their piped natural gas network to serve stations within 20 kilometers of an already existing piped gas infrastructure. Therefore, stations within this distance of gas pipelines[37] built before the expansion of the piped gas network may have a greater chance of having access to piped gas after the later phenomenon. It should be noted that we do not have access to the real distance between stations and the gas pipelines, but only to a proxy distance calculated considering a straight line between the initial and final points of the gas pipelines. Table 21 shows the pipelines considered in the dummy construction and the proxy length, as well as the real length of the gas pipelines.

Table 21: Gas Pipelines in Rio de Janeiro

Name	Extension	Calculated Extension	In Operation Since	Start	End
GASDUC I	184 km	169 km	1982	Macaé - RJ	Duque de Caxias - RJ
GASDUC II	182 km	169 km	1996	Macaé - RJ	Duque de Caxias - RJ
GASBEL	357 km	316 km	1996	Duque de Caxias - RJ	Betim - MG
GASPAL	325 km	-	1988	Volta Redonda - RJ	Capuava - SP
GASVOL	6 km	-	1986	Volta Redonda - RJ	Volta Redonda - RJ
GASVOL I	95 km	85 km	1986	Duque de Caxias - RJ	Volta Redonda - RJ
GASCAB I	67 km	-	1982	Macaé - RJ	Macaé - RJ

NOTES: The table shows the gas pipelines existing in the Rio de Janeiro State before the beginning of our sample. The second column shows the real extension of the pipeline, while the third column shows the extension of a straight line linking the two endpoints of a pipeline (available only for intermunicipal pipelines). The extreme points of the gas pipelines were obtained in the Petrobras website. The last two columns show, respectively, the municipalities where the starting and ending points of the pipelines are located. Source: Gasnet and Petrobras.

We could not find evidence of the effect of CNG availability at the station. Nevertheless, our results for the impact of the NGV fleet on the price of gasoline and ethanol still hold as shown in Table 22. As in the Results section, the two first specifications shown in the tables are estimated with OLS, while the other five are by 2SLS. The estimation period was from January 2002 to June 2008. The specifications going from (1) to (7) are the same as the ones in Table 3.

[36]We call gas pipelines the pipe structures used to transport natural gas over long distances and/or being part of a national infrastructure of natural gas transportation. On the other hand, we use piped gas infrastructure to refer to the network within a municipality used to supply consumers with natural gas. In Rio de Janeiro it is easy to separate one from another as gas pipelines are operated by Transpetro and the piped natural gas infrastructure is granted to Ceg and Ceg-Rio.

[37]We only consider gas pipelines completed until 1996.

Table 22: Regressions 2002-2008 with CNG Offer Dummy

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS	(7) 2SLS
				Panel A - Gasoline Prices			
% NGV Fleet	0.0336	-0.387***	-0.303*	-0.252	-3.120***	-0.543***	-2.602***
	(0.18)	(-5.58)	(-1.75)	(-1.39)	(-6.61)	(-3.98)	(-5.83)
NG Supply Indicator			-0.442***	-0.501***	-0.236**	-0.254***	-0.376***
			(-4.72)	(-4.92)	(-2.46)	(-4.37)	(-5.44)
				Panel B - Gasoline Margins			
% NGV Fleet	-0.543***	-0.329***	-0.0794	-0.0281	-2.760***	-0.427***	-2.415***
	(-9.15)	(-5.52)	(-0.48)	(-0.16)	(-7.07)	(-3.28)	(-5.53)
NG Supply Indicator			-0.503***	-0.552***	-0.280***	-0.250***	-0.418***
			(-5.82)	(-5.70)	(-3.37)	(-4.87)	(-6.61)
				Panel C - Ethanol Prices			
% NGV Fleet	0.547**	-0.417***	-0.699***	-0.746***	-0.346*	-0.703***	-0.403**
	(2.06)	(-4.34)	(-2.65)	(-2.78)	(-1.71)	(-3.29)	(-2.33)
NG Supply Indicator			-0.238*	-0.252*	-0.343***	-0.216**	-0.282***
			(-1.81)	(-1.86)	(-2.91)	(-2.36)	(-3.28)
				Panel D - Ethanol Margins			
% NGV Fleet	-0.697***	-0.394***	-0.879***	-0.810***	-0.693***	-0.976***	-0.917***
	(-13.05)	(-4.53)	(-3.77)	(-3.33)	(-3.43)	(-5.77)	(-6.03)
NG Supply Indicator			-0.0802	-0.132	-0.127	0.0267	0.0238
			(-0.71)	(-1.07)	(-1.07)	(0.38)	(0.33)
Instrumentalized Fleet	No	No	Yes	Yes	Yes	Yes	Yes
Station Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	No	No	Yes	Yes	Yes	Yes

NOTES: Table displays the estimated effects of the share of NGVs and NG offer by the station on gasoline retail prices (panel A), gasoline retail margins (panel B), ethanol retail prices (panel C), and ethanol retail margins (panel D). Shown in parentheses are the t-stats for the coefficients. Standard errors are clustered by city-month. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly IPCA. Over the period, the average gasoline price = BRL 3.04, and the average gasoline margin = BRL 0.35. The average ethanol price = BRL 2.00, and the average ethanol margin = BRL 0.33. Columns 1-2 are estimated by OLS and columns 3-7 by 2SLS. Columns 2-7 include station and monthly fixed effects and columns 4-7 include station-brand fixed effects as controls. Columns 5 and 7 also include the sum of the shares of gasoline and flex vehicles in the fleet as a control (fuel share control) in the gasoline retail prices and margins specifications. Columns 5 and 7 also include the sum of the share of ethanol and flex vehicles in the fleet as a control (fuel share control) in the ethanol retail prices and margins specifications. Columns 6 and 7 add the following controls: yearly municipal GDP per capita, the NGV fleet divided by the monthly number of stations at the municipality level, and the monthly number of stations in each municipality (market controls). The instrument for the share of NGVs is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our prices database. The instrument for the NG offer by the station dummy is the interaction between the monthly number of stations offering natural gas in the Southeast of Brazil ex-Rio de Janeiro State and a dummy whether a station is less than 20 kilometers from one of Rio de Janeiro's main gas pipelines. Gasoline prices regressions have N = 297,489. Gasoline margins regressions have N = 206,442. Ethanol prices regressions have N = 277,201. Ethanol margins regressions have N = 159,286.

F Spatial Analysis

Table 23 implements the Driscoll-Kraay errors considering the position for an observation for a given station-month as the time unit. For example, the first time a station is surveyed in a given month, the observation is assigned position 1 no matter in which week it was surveyed or if other stations had already been surveyed multiple times in that month. We exclude any observation whose position in the month for a given station is above 5. This excludes 16 observations.

Table 24 implements the Driscoll-Kraay errors considering the position within 6-days periods for an observation for a given station-month as the time unit. For instance, if an observation was collected between days 1 and 6 we assign it week 1. If it was collected between days 7 and 12, we assign it week 2, and so on so forth. Observations collected on day 31 are assigned week 5as are those collected from days 25 to 30. We exclude any observation that were not the first collected ones in a given 6-days week for a given station-month. This excludes 4,821 observations.

Table 23: IV - Piped Gas x Fleet RJ with Driscoll-Kraay Errors (Position Lags): 2002-2008

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS	(7) 2SLS
				Panel A - Gasoline Prices			
NGV Share	0.0336	-0.387***	-0.512***	-0.509***	-1.117*	-0.640***	-1.179***
	(0.16)	(-6.00)	(-5.73)	(-5.67)	(-1.65)	(-7.23)	(-3.27)
				Panel B - Gasoline Margins			
NGV Share	-0.543***	-0.328***	-0.371***	-0.378***	-0.666	-0.514***	-0.861***
	(-9.59)	(-5.67)	(-4.44)	(-4.47)	(-1.45)	(-5.77)	(-2.81)
				Panel C - Ethanol Prices			
NGV Share	0.547*	-0.417***	-0.808***	-0.868***	-0.499**	-0.775***	-0.474**
	(1.70)	(-3.22)	(-3.67)	(-4.00)	(-2.32)	(-3.54)	(-2.33)
				Panel D - Ethanol Margins			
NGV Share	-0.697***	-0.394***	-0.923***	-0.885***	-0.763***	-0.973***	-0.915***
	(-10.33)	(-4.56)	(-6.02)	(-5.68)	(-5.49)	(-6.70)	(-6.82)
Instrumentalized Fleet	No	No	Yes	Yes	Yes	Yes	Yes
Station Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	No	No	Yes	Yes	Yes	Yes

NOTES: Table displays the estimated effects of the share of NGVs on gasoline retail prices (panel A), gasoline retail margins (panel B), ethanol retail prices (panel C), and ethanol retail margins (panel D). Shown in parentheses are the t-stats for the coefficients. Standard errors are Driscoll-Kraay with 5 lags. Lags are on the position of an observation within a given month-station. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly IPCA. Over the period, the average gasoline price = BRL 3.04, and the average gasoline margin = BRL 0.35. The average ethanol price = BRL 2.00, and the average ethanol margin = BRL 0.33. Columns 1-2 are estimated by OLS and columns 3-7 by 2SLS. Columns 2-7 include station and monthly fixed effects and columns 4-7 include station-brand fixed effects as controls. Columns 5 and 7 also include the sum of the shares of gasoline and flex vehicles in the fleet as a control (fuel share control) in the gasoline retail prices and margins specifications. Columns 5 and 7 also include the sum of the share of ethanol and flex vehicles in the fleet as a control (fuel share control) in the ethanol retail prices and margins specifications. Column 6 and 7 add the following controls: yearly municipal GDP per capita, the NGV fleet divided by the monthly number of stations at the municipality level, and the monthly number of stations in each municipality (market controls). Instrument for the share of NGVs is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our price database. Gasoline prices regressions have N = 297,485. Gasoline margins regressions have N = 206,438. Ethanol prices regressions have N = 277,197. Ethanol margins regressions have N = 159,283.

Table 24: IV - Piped Gas x Fleet RJ with Driscoll-Kraay errors (Week Lags): 2002-2008

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS	(7) 2SLS
	Panel A - Gasoline Prices						
NGV Share	0.0363	-0.386***	-0.507***	-0.504***	-1.083	-0.637***	-1.167***
	(0.17)	(-5.96)	(-5.63)	(-5.57)	(-1.64)	(-7.27)	(-3.32)
	Panel B - Gasoline Margins						
NGV Share	-0.541***	-0.329***	-0.370***	-0.377***	-0.655	-0.514***	-0.857***
	(-9.63)	(-5.64)	(-4.51)	(-4.54)	(-1.49)	(-5.96)	(-2.93)
	Panel C - Ethanol Prices						
NGV Share	0.549*	-0.420***	-0.819***	-0.881***	-0.507**	-0.788***	-0.485**
	(1.70)	(-3.26)	(-3.67)	(-3.99)	(-2.34)	(-3.55)	(-2.35)
	Panel D - Ethanol Margins						
NGV Share	-0.698***	-0.396***	-0.926***	-0.887***	-0.763***	-0.971***	-0.913***
	(-10.56)	(-4.58)	(-6.11)	(-5.75)	(-5.53)	(-6.84)	(-6.94)
Instrumentalized Fleet	No	No	Yes	Yes	Yes	Yes	Yes
Station Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	No	No	Yes	Yes	Yes	Yes

NOTES: Table displays the estimated effects of the share of NGVs on gasoline retail prices (panel A), gasoline retail margins (panel B), ethanol retail prices (panel C), and ethanol retail margins (panel D). Shown in parentheses are the t-stats for the coefficients. Standard errors are Driscoll-Kraay with 5 lags. Lags are on the position of 6-days periods of an observation within a given month-station. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly IPCA. Over the period, the average gasoline price = BRL 3.04, and the average gasoline margin = BRL 0.35. The average ethanol price = BRL 2.00, and the average ethanol margin = BRL 0.33. Columns 1-2 are estimated by OLS and columns 3-7 by 2SLS. Columns 2-7 include station and monthly fixed effects and columns 4-7 include station-brand fixed effects as controls. Columns 5 and 7 also include the sum of the shares of gasoline and flex vehicles in the fleet as a control (fuel share control) in the gasoline retail prices and margins specifications. Columns 5 and 7 also include the sum of the share of ethanol and flex vehicles in the fleet as a control (fuel share control) in the ethanol retail prices and margins specifications. Column 6 and 7 add the following controls: yearly municipal GDP per capita, the NGV fleet divided by the monthly number of stations at the municipality level, and the monthly number of stations in each municipality (market controls). Instrument for the share of NGVs is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our price database. Gasoline prices regressions have N = 294,783. Gasoline margins regressions have N = 204,559. Ethanol prices regressions have N = 274,639. Ethanol margins regressions have N = 157,762.

G Lagged Fleet Controls

Table 25: IV - Piped Gas x Fleet RJ - Lagged Fleets: 2002-2008

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent Variable	Gasoline Prices		Gasoline Margins		Ethanol Prices		Ethanol Margins	
Lag	6M	1Y	6M	1Y	6M	1Y	6M	1Y
NGV Share	-1.195***	-1.255***	-0.996***	-1.077***	-0.549***	-0.661***	-0.939***	-0.965***
	(-3.38)	(-4.27)	(-3.01)	(-3.82)	(-3.29)	(-3.73)	(-6.18)	(-6.03)
Gas and Flex Share - Lagged 6 Months	-0.797**		-0.739**					
	(-2.14)		(-2.09)					
Gas and Flex Share - Lagged 1 Year		-0.935***		-0.931***				
		(-3.02)		(-3.06)				
Gas and Flex Share - Lagged 6 Months					-1.419***		-0.328*	
					(-6.89)		(-1.90)	
Gas and Flex Share - Lagged 1 Year						-1.846***		-0.362
						(-6.26)		(-1.51)
Kleibergen-Paap LM statistic	58.39	53.18	70.90	62.86	141.2	140.1	140.5	137.2
Kleibergen-Paap LM p-value	2.15e-14	3.04e-13	3.76e-17	2.22e-15	1.48e-32	2.52e-32	2.07e-32	1.07e-31

NOTES: Table displays the estimated effects of shares of NGVs on gasoline retail prices (panel A), gasoline retail margins (panel B), ethanol retail prices (panel C), and ethanol retail margins (panel D). Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly Brazilian CPI (Índice de Preços ao Consumidor Amplo - IPCA). All columns include station, monthly and station-brand fixed effects, as well as yearly municipal GDP per capita (available only until 2015), the NGV fleet divided by the monthly number of stations at the municipality level, and the monthly number of stations at each municipality as controls. Columns 1-4 also include the sum of lagged shares of the gasoline and flex fleet as a control. Columns 5-8 also include the sum of lagged shares of the ethanol and flex fleet as a control. Odd numbered columns use a lag of 6 months. Even numbered columns use a lag of 1 year. Instrument for the share of NGVs is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet in the Rio de Janeiro state municipalities not included in our prices database. Standard errors are clustered by city-month. Gasoline prices regressions have N = 297,489. Gasoline margins regressions have N = 206,442. Ethanol prices regressions have N = 277,201. Ethanol margins regressions have N = 159,286. Shown in parentheses are the t-stats for the coefficients. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

H Regressions with Alternative Fleet Measurement

Table 26: IV - Piped Gas x Fleet RJ Ex-Trucks: 2002-2008

	(1) OLS	(2) OLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS	(7) 2SLS
	Panel A - Gasoline Prices						
NGV % Fleet Ex-Trucks	0.0643	-0.354***	-0.516***	-0.513***	-0.619***	-0.655***	-0.720***
	(0.37)	(-5.40)	(-3.96)	(-3.95)	(-4.35)	(-5.39)	(-5.54)
	Panel B - Gasoline Margins						
NGV % Fleet Ex-Trucks	-0.495***	-0.297***	-0.373***	-0.379***	-0.469***	-0.527***	-0.581***
	(-8.74)	(-5.26)	(-3.28)	(-3.35)	(-3.78)	(-4.45)	(-4.59)
	Panel C - Ethanol Prices						
NGV % Fleet Ex-Trucks	0.529**	-0.389***	-0.812***	-0.874***	-0.476***	-0.790***	-0.457***
	(2.11)	(-4.19)	(-3.67)	(-3.94)	(-2.90)	(-3.88)	(-2.82)
	Panel D - Ethanol Margins						
NGV % Fleet Ex-Trucks	-0.657***	-0.350***	-0.918***	-0.881***	-0.753***	-0.985***	-0.917***
	(-12.93)	(-4.21)	(-4.78)	(-4.61)	(-4.98)	(-5.78)	(-6.09)
Instrumentalized Fleet	No	No	Yes	Yes	Yes	Yes	Yes
Station Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Time Fixed Effect	No	Yes	Yes	Yes	Yes	Yes	Yes
Brand Fixed Effect	No	No	No	Yes	Yes	Yes	Yes

NOTES: Table displays the estimated effects of shares of NGVs ex-trucks on gasoline retail prices (panel A), gasoline retail margins (panel B), ethanol retail prices (panel C), and ethanol retail margins (panel D). Shown in parentheses are the t-stats for the coefficients. Standard errors are clustered by city-month. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Regressions consider a station i located in municipality m in week t as the unit of analysis, and the sample period goes from January 2002 to June 2008. All prices are expressed in BRL real terms, deflated by the monthly Brazilian CPI (Índice de Preços ao Consumidor Amplo - IPCA). Columns 1-2 are estimated by OLS and columns 3-7 by 2SLS. Columns 2-7 include station and monthly fixed effects and columns 3-7 include station-brand fixed effects as controls. Columns 5 and 7 also include the sum of the shares of gasoline and flex vehicles in the fleet as a control (fuel share control) in the gasoline retail prices and margins specifications. Columns 5 and 7 also include the sum of the share of ethanol and flex vehicles in the fleet as a control (fuel share control) in the ethanol retail prices and margins specifications. Finally, column 6 and 7 add yearly municipal GDP per capita (available only until 2015), the NGV fleet divided by the monthly number of stations at the municipality level, and the monthly number of stations at each municipality as controls. Instrument for the share of NGVs is the interaction between a dummy reflecting the availability of piped gas at a given municipality in 2002 and the share of the NGV fleet ex-trucks in the Rio de Janeiro state municipalities not included in our prices database. Standard errors are clustered by city-month. Gasoline price regressions have N = 297,489. Gasoline margins regressions have N = 206,442. Ethanol prices regressions have N = 277,201. Ethanol margins regressions have N = 159,286.

I Environmental Consequences - Price Effects

In order to calculate the environmental consequences of the NGV fleet expansion in the state of Rio de Janeiro we employ data from various sources. The data on the circulating fleet of light and light commercial vehicles in Brazil by vintage in 2008 come from the Automotive Vehicles Components Industry National Syndicate (Sindipeças). Data on the number of light and light commercial vehicles in Brazil by original fuel type and vintage come from the Automotive Vehicles Manufacturers National Association (Anfavea). Data are available for vintages starting 1969 and 1973 for light and light commercial vehicles, respectively. By assuming that vehicles of the same vintage faced the same rate of scrappage,[38] we can calculate the percentage of vehicles by fuel type and vintage in the circulating fleet.

The data on the circulating fleet are at the national level. We assume that this national level distribution of vehicles by fuel type and vintage holds in the state of Rio de Janeiro. Using data on the size of the Rio de Janeiro light and light commercial vehicles fleet by fuel from our database, we estimate the breakdown of the circulating Rio de Janeiro fleet by vintage and fuel type. In this step we are only interested in the share of vehicles running on different fuels according to our database. Hence, the fact that the fleet in our main database is greater than the circulating fleet does not seem to pose a problem.

The data on pollutants' emissions constants (for instance, how many grammes per kilometer of aldehydes does an ethanol car produced in 2001 emit) by fuel type and year[39] and the data on the average fuel efficiency of vehicles by fuel type come from Ministério do Meio Ambiente (2011). The information on average fuel efficiency of vehicles by fuel type is available for every year since 1983, and for the period 1969-1982 in aggregated form.

Data on average vehicle's annual mileage by fuel type and age come from Bruni and

[38]Early ethanol vehicles were known to have quality issues that may have made them more likely to be scrapped than gasoline vehicles of the same age. Hence, we believe this assumption might be overestimating the circulating ethanol fleet and underestimating the gasoline one.

[39]The fuel types considered in this case are: gasoline, ethanol, ethanol and gasoline when used by flex-fuel vehicles. It should be noted that the constants are usually for the vehicles when new, as mileage increases the emissions by a car. Hence, whenever possible, adjustment factors for mileage (as suggested in Ministério do Meio Ambiente (2011)) were applied to the constants for new cars. We have yearly data for gasoline and ethanol vehicles spanning from 1988 to 2006. For any vehicles produced before and in 1983 the constants are the same. Also, vehicles produced in (i) 1984 and 1985; (ii) 1986 and 1987 are considered to have the same constants. Finally, we have yearly constants for gasoline in 2007 and 2008 too. For flex-fuel vehicles running on ethanol or gasoline yearly data are available from the start of their production in 2003.

Bales (2013).[40] Such data are used to determine baseline demand for fuels by vehicle age which is needed for calculating fuels' demand increase following the decrease in their prices. For gasoline vehicles, data are available for vehicles aged 0 to 48 years old (produced from 1960 to 2008). Data for ethanol vehicles are only available for cars produced between 1979 and 2002. Hence, for newer vehicles (those produced between 2003 and 2006) we assume the mileage to be the same as the one for cars produced in 2002 (almost no ethanol cars were produced after 2002). For flex-fuel vehicles, we have data on vehicles produced from 2003 to 2007 and 2008 cars are assumed to have the same intensity of use as vehicles one year older. Finally, estimated price-demand elasticities for both ethanol and gasoline follow from two scenarios detailed below.

Using the data on intensity of use of vehicles by fuel type and age and estimated price-demand elasticities for gasoline and ethanol from the literature, we are able to calculate how the estimated gasoline and ethanol prices shifts (we consider the estimated effects from specification 7 in Table 3), given the average gasoline and ethanol prices in our database for June 2008, affect the consumption of gasoline and ethanol by drivers of gasoline, ethanol and flex-fuel cars. We then apply the pollutants emissions constants from Ministério do Meio Ambiente (2011) to these calculated incremental demands of fuels considering the fuel efficiency of a vehicle of a given fuel type and age. Finally, we aggregate the emissions to the state level considering the fleet composition in the state.

Our results for pollutant emission impacts of the growth of the NGV fleet via change in ethanol and gasoline prices in the state of Rio de Janeiro are presented under two scenarios:

- Pessimistic Scenario: We employ the largest price-demand elasticities for gasoline and ethanol in our reviewed literature.[41] This gives the largest possible impact of the NGV fleet growth on emissions via the price changes in gasoline and ethanol that it is driving. We use -3.848 and -3.583 as the price-demand elasticities for gasoline and

[40] The fuel type categories in this case are gasoline, ethanol, and flex-fuel. The study estimates the annual mileage for vehicles of distinct fuel types from the city of São Paulo. We assume that these values are reasonable for vehicles on the Rio de Janeiro State. We believe these estimates are more accurate than the ones for the national fleet available on Ministério do Meio Ambiente (2011).

[41] The following works, were considered for price-demand elasticities for fuels in Brazil: Roppa (2005), Azevedo (2007), Schünemann (2007), Iootty et al. (2009), Pontes (2009), de Freitas and Kaneko (2011) and other studies reviewed on it, Orellano et al. (2013) and Santos (2013).

ethanol, respectively. These values come from Iootty et al. (2009).

- Optimistic Scenario: We employ the lowest price-demand elasticities for gasoline and ethanol in our reviewed literature. This gives the lowest possible impact of the NGV fleet growth on emissions via the price changes in gasoline and ethanol that it is driving. We use -0.2 and -0.459 as the price-demand elasticities for gasoline and ethanol, respectively. These values come from Roppa (2005) and Azevedo (2007), respectively.

The results are presented in Table 27 assume that all flex-fuel cars are run on ethanol only. For results assuming that all flex-fuel cars are run on gasoline only see Section 6. In calculating the CO_2eq I use global warming potential (GWP) over 100 years of CH_4 and NO_2. NO_x emissions are assumed to all be NO_2 emissions in calculating the CO_2eq. The GWP for CH_4 and NO_2 are 25 and 298 times greater than that of CO_2 according to Environmental Protection Agency (2018).

Table 27: Emissions of Pollutants

				Pessimistic Scenario				
	CO_2	CH_4	NO_x	*Total* CO_2eq	CO	$NMHC$	*Aldehydes*	PM
Tonnes	92,721	46	305	184,659	2,503	345	96	1
% of RJ Emissions	0.19%	0.01%	0.12%	0.28%	0.96%	-	-	-
				Optimistic Scenario				
	CO_2	CH_4	NO_x	*Total* CO_2eq	CO	$NMHC$	*Aldehydes*	PM
Tonnes	5,376	4	25	13,009	216	34	12	0
% of RJ Emissions	0.01%	0.001%	0.01%	0.02%	0.08%	-	-	-

NOTES: Calculated decreased(-)/increased(+) emissions of pollutants from the gasoline/ethanol price effects arising from the growth of the NGV fleet in Rio de Janeiro in 2008. We consider high price-demand elasticities of gasoline and ethanol in the pessimistic scenario and low price-demand elasticities in the optimistic scenario. We assume that all flex-fuel cars run on ethanol only. Emissions shown as total tonnes or as a percentage of total emissions in Rio de Janeiro in 2008 for pollutants available in the Greenhouse Gases Emissions and Removals Estimates System (SEEG) - see Azevedo et al. (2018). Pollutants with global warming potential are CO_2 (Carbon Dioxide), CH_4 (Methane), NO_x (Nitrogen Oxides). Total CO_2eq considers the total value of the first three columns (CO_2, CH_4 and NO_x) in carbon dioxide equivalent. Local air pollutants with health impacts are CO (Carbon Monoxide), NMHC (Non-Methane Hydrocarbons), Aldehydes, and PM (Particulate Matter).

Assuming the most recent official American government values of the social costs of carbon (USD 51), methane (USD 1,500), and nitrous oxide (USD 18,000), converted to 2008

US dollars (White House, 2021),[42] the cost of greenhouse gas emissions was between USD 607,417 and USD 8,558,166 in 2008.

It should be noted that assuming that all flex-fuel cars are run on ethanol or gasoline only reflect extreme cases. At any given point, some owners of flex-fuel vehicles may fuel their cars with ethanol, while others will do so with gasoline. Most of them should change between ethanol and gasoline often. Hence, increased emissions from the fuel price changes motivated by the growth of the NGV fleet should be somewhere in between these extreme cases. Moreover, we assume away any residual consumption of gasoline and ethanol by NGVs (lower prices of these fuels may also motivate NGV driver to drive more).

J Environmental Consequences - Overall Emissions

CNG is commonly marketed as a cleaner fuel than gasoline. Indeed, data on CO_2 emissions for vehicles running on different kinds of fuel corroborate this notion.[43]. For instance, according to Ministério do Meio Ambiente (2011),[44] a 2008 new vehicle converted to run on CNG emits, approximately, 167 g/km of carbon dioxide, compared to the 233 g/km of a gasoline car, 171 g/km of an ethanol car,[45] and 160g/km and 191g/km of a flex-fuel car running on ethanol and gasoline, respectively. Hence, the growth of NGVs could have led to lower emissions of carbon dioxide, benefiting the environment.

The growth of the NGV fleet could also impact emissions through other channels such as increased/decreased emissions of other pollutants for converted cars, increased intensity of use of their vehicles by NGV owners and increased gasoline and ethanol demand due to NGV motivated price changes in these fuels (as discussed in section 6). Therefore, it is not clear at first sight if the rise of NGVs has proven overall beneficial to the environment or not.

[42] We consider the average estimates assuming a 3% discount rate. The inflation rate between 2008-2020 in the US was 20.21%.

[43] The same cannot be said about other pollutants according to Ministério do Meio Ambiente (2011) For example, CO, CH_4, aldehydes, $NMHC$ and NO_x are higher per kilometer for new 2008 NGVs than for new 2008 gasoline cars. However, CNG does not emit particulate matter while gasoline does.

[44] All the pollutant emission data from Ministério do Meio Ambiente (2011) consider vehicles on road use.

[45] Note that this is the emission level of an engine running on ethanol. This number does not take into account the fact that sugarcane, from which Brazil's ethanol comes from, is a renewable resource and one that sequesters carbon while growing.

In order to investigate this question, we calculate the differential pollutants' emissions from the growth of the NGV fleet and its effects on fuel prices to the counterfactual scenario in which the fleet had grown the same, but NGV vehicles were running on their original fuels. On the one hand, we have the emissions generated by the converted NGVs[46] and by the increased use of the gasoline and ethanol run vehicles. On the other hand, if gasoline, ethanol and flex-fuel had never been converted to NGVs, we would have had greater pollutants emissions from the larger unconverted fleets. In this way, we can calculate the avoided/increased pollution due to the NGV fleet growth in Rio de Janeiro.

We employ data from various sources. The data on the circulating fleet of light and light commercial vehicles in Brazil by vintage in 2008 come from the Automotive Vehicles Components Industry National Syndicate (Sindipeças). Data on the number of light and light commercial vehicles in Brazil by original fuel type and vintage come from the Automotive Vehicles Manufacturers National Association (Anfavea). Data are available for vintages starting 1969 and 1973 for light and light commercial vehicles, respectively. By assuming that vehicles of the same vintage faced the same rate of scrappage,[47] we can calculate the percentage of vehicles by fuel type and vintage in the circulating fleet.

The data on the circulating fleet are at the national level. We assume that this national level distribution of vehicles by fuel type and vintage holds in the state of Rio de Janeiro. Using data on the size of the Rio de Janeiro light and light commercial vehicles fleet by fuel from our database, we estimate the breakdown of the circulating Rio de Janeiro fleet by vintage and fuel type.[48] In this step we are only interested in the share of vehicles running on different fuels according to our database. Hence, the fact that the fleet in our main database

[46]For simplification, we assume that the NGVs are always fuelled only with CNG, although a residual demand for ethanol and/or gasoline of converted vehicles exists, as described in Section 2.

[47]Early ethanol vehicles were known to have quality issues that may have made them more likely to be scrapped than gasoline vehicles of the same age. Hence, we believe this assumption might be overestimating the circulating ethanol fleet and underestimating the gasoline one.

[48]The NGV fleet is an exception in this case, as we cannot apply the described process to estimate its circulating fleet because the manufacturing of NGVs was negligible and is not included in the Anfavea data we used to divide the circulating fleet into vehicles running on different fuels. Hence, we use the number of NGVs from our main database to calculate the NGV fleet size by year, considering that the vehicles were produced in the same year they have been converted. We further assume that there was no NGV fleet before 2001 as Detran data are only available that far. As NGVs emissions do not grow with mileage according to the pollutants' emissions constants we are considering and because of the shape of average mileage by vintage, this last assumption either does not impact our results or biases them towards less avoided pollution by NGVs depending on which scenario we consider.

is greater than the circulating fleet does not seem to pose a problem.

The data on pollutants' emissions constants (for instance, how many grammes per kilometer of aldehydes does an ethanol car produced in 2001 emit) by fuel type[49] and vintage[50] and the data on the average fuel efficiency of vehicles by fuel type come from Ministério do Meio Ambiente (2011). The information on average fuel efficiency of vehicles by fuel type is available for every vintage since 1983, and for the period 1957-1982 in aggregated form.

Data on average vehicle's annual mileage by fuel type and age come from Bruni and Bales (2013).[51] For gasoline vehicles, data are available for vehicles aged 0 to 48 years old (produced from 1960 to 2008). Data for ethanol vehicles are only available for cars produced between 1979 and 2002. Hence, for newer vehicles (those produced between 2003 and 2006) we assume the mileage to be the same as the one for cars produced in 2002 (almost no ethanol cars were produced after 2002). For flex-fuel vehicles, as well as for NGVs previously running on gasoline or on both ethanol and gasoline (flex-fuel), we have a similar situation. For flex-fuel cars, we have data on vehicles produced from 2003 to 2007 and 2008 cars are assumed to have the same intensity of use as vehicles one year older. For NGVs that can also run on gasoline, we have data for vehicles aged 20 to 3 years old. For flex-fuel vehicles converted to run on CNG we have data for cars aged 5 to 2 years old. Newer NGVs of both kinds are assumed to have the same intensity of use as the last available year. Finally, estimated price-demand elasticities for both ethanol and gasoline follow from postulates 1 and 2 describe below.

[49]The fuel types considered in this case are: gasoline, ethanol, CNG, ethanol and gasoline when used by flex-fuel vehicles. It should be noted that the constants are usually for the vehicles when new, as mileage increases the emissions by a car. Hence, whenever possible, adjustment factors for mileage (as suggested in Ministério do Meio Ambiente (2011)) were applied to the constants for new cars. NGVs were the only kind of vehicles for which the mileage adjustments were not done in our exercise, as there was no mention about them in the literature. This may be biasing our results downwards, as NGVs have the highest average intensity of use among the different kinds of fuel types considered. Nevertheless, the emissions' constant for NGVs is probably taking into account that these vehicles were not converted when new.

[50]We have yearly data for gasoline and ethanol vehicles spanning from 1988 to 2006. For any vehicles produced before and in 1983 the constants are the same. Also, vehicles produced in (i) 1984 and 1985; (ii) 1986 and 1987 are considered to have the same constants. Finally, we have yearly constants for gasoline in 2007 and 2008 too. For flex-fuel vehicles running on ethanol or gasoline yearly data are available from the start of their production in 2003.

[51]The fuel type categories in this case are gasoline, ethanol, flex-fuel, gasoline converted to run on CNG and flex-fuel converted to run on CNG. The study estimates the annual mileage for vehicles of distinct fuel types from the city of São Paulo. We assume that these values are reasonable for vehicles on the Rio de Janeiro State. We believe these estimates are more accurate than the ones for the national fleet available on Ministério do Meio Ambiente (2011).

Using the data on intensity of use of vehicles by fuel type and age and estimated price-demand elasticities for gasoline and ethanol from the literature, we are able to calculate how the estimated gasoline and ethanol prices shifts (we consider the estimated effects from specification 7 in Table 3), given the average gasoline and ethanol prices in our database for June 2008, affect the consumption of gasoline and ethanol by drivers of gasoline, ethanol and flex-fuel cars. We then apply the pollutants emissions constants from Ministério do Meio Ambiente (2011) to these calculated incremental demands of fuels considering the fuel efficiency of a vehicle of a given fuel type and age. Finally, we aggregate the emissions to the state level considering the fleet composition and subtract estimates of emissions from the counterfactual scenario without NGVs to obtain the results shown in Tables 28 and 29.

We calculate increased emissions under several assumptions and considering four scenarios and four sets of postulates detailed below that provide extreme cases for pollutant emissions. The estimates are for annual emissions in the year 2008. We consider emissions of several pollutants as in section 6. Three of them are associated with climate change: CO_2 (carbon dioxide), CH_4 (methane), and NO_x (nitrogen oxides). The other four, although not impacting climate change directly, pose health threats to living beings: CO (carbon monoxide), aldehydes, $NHMC$ (non-methane hydrocarbons) and PM (particulate matter). Since CO_2, CH_4, and NO_x have distinct global warming potentials, we also calculate the CO_2eq (equivalent carbon dioxide) emissions considering these three pollutants.

The four postulates are the following:

- Postulate 1: We employ the largest price-demand elasticities for gasoline and ethanol in our reviewed literature.[52] This gives the largest possible impact of the NGV fleet growth on emissions via the price changes in gasoline and ethanol that it is driving. We use -3.848 and -3.583 as the price-demand elasticities for gasoline and ethanol, respectively. These values come from Iootty et al. (2009).

- Postulate 2: We employ the lowest price-demand elasticities for gasoline and ethanol in our reviewed literature. This gives the lowest possible impact of the NGV fleet growth

[52] The following works, were considered for price-demand elasticities for fuels in Brazil: Roppa (2005), Azevedo (2007), Schünemann (2007), Iootty et al. (2009), Pontes (2009), de Freitas and Kaneko (2011) and other studies reviewed on it, Orellano et al. (2013) and Santos (2013).

on emissions via the price changes in gasoline and ethanol that it is driving. We use -0.2 and -0.459 as the price-demand elasticities for gasoline and ethanol, respectively. These values come from Roppa (2005) and Azevedo (2007), respectively.

- Postulate 3: In the counterfactual scenario (if NGVs had never been converted), we assume that NGVs would have an intensity of use equal to vehicles of their original fuels. This implies that NGVs would not be very pollutant if they had not been converted due to moderate use and provides a higher bound on the emissions' results. This situation would arise if all the extra use of NGVs is coming from their fuelling being cheaper than that of gasoline, ethanol and flex cars.

- Postulate 4: In the counterfactual scenario (if NGVs had never been converted), we assume that NGVs would have an intensity of use equal to their current one. This implies that NGVs would be very pollutant if they had not been converted due intense use and provides a lower bound on the emissions' results. This situation would arise if NGV owners would drive the same independently of converting their cars, as if they were inelastically high intensity of use type drivers.

The four scenarios are the following:

- Scenario 1: All NGVs were originally gasoline run vehicles and all flex-fuel cars are run on gasoline only.

- Scenario 2: All NGVs were originally gasoline run vehicles and all flex-fuel cars are run on ethanol only.

- Scenario 3: All NGVs were originally flex-fuel vehicles and all flex-fuel cars are run on gasoline only.

- Scenario 4: All NGVs were originally flex-fuel vehicles and all flex-fuel cars are run on ethanol only.

Panel A of Table 28 shows the calculated net CO_2 emissions in June 2008 in the Rio de Janeiro state. Panel B shows the calculated net equivalent CO_2 emissions in June 2008 in the Rio de Janeiro state. In calculating the CO_2eq I use global warming potential (GWP) over 100 years of CH_4 and NO_2. NO_x emissions are assumed to all be NO_2 emissions in calculating the CO_2eq. The GWP for CH_4 and NO_2 are 25 and 298 times greater than that of CO_2 according to Environmental Protection Agency (2018). Specifications (1) to (4) refer to scenarios 1 to 4, respectively. Results on CO_2 emissions are ambiguous under all scenarios. However, CO_2eq emissions are unambiguously higher, implying that NGVs worsened overall greenhouse pollutants' emissions. Using emissions estimated from the Greenhouse Gases Emissions and Removals Estimates System (SEEG) (Azevedo et al., 2018), we can put these numbers into perspective. The calculated minimum and maximum amounts of CO_2eq (375,927 and 3,776,579 tonnes) emitted in 2008 were equivalent to 0.58% and 5.8% of the total estimated CO_2eq emissions for the state of Rio de Janeiro in the same period.

Table 28: Emissions of CO_2 and CO_2 Equivalent

Panel A - CO^2 Emmissions (tonnes)				
	(1)	(2)	(3)	(4)
Postulates 1 + 3	1,064,466	1,051,461	1,848,646	1,835,642
Postulates 1 + 4	-506,749	-519,754	-943,314	-956,318
Postulates 2 + 3	964,505	964,117	1,748,686	1,748,297
Postulates 2 + 4	-606,710	-607,099	-1,043,274	-1,043,663
Panel B - CO^2eq Emmissions (tonnes)				
()	(1)	(2)	(3)	(4)
Postulates 1 + 3	2,366,124	2,357,170	3,776,579	3,767,624
Postulates 1 + 4	556,782	547,827	683,032	674,078
Postulates 2 + 3	2,185,269	2,185,520	3,595,724	3,595,974
Postulates 2 + 4	375,927	376,177	502,177	502,428

NOTES: Calculated decreased(-)/increased(+) emissions of CO_2 (Panel A) and CO_2 equivalent (Panel B) from the growth of the NGV fleet in the Rio de Janeiro State. (1) assumes that all NGVs previously ran on gasoline only and that all flex-fuel cars run solely on gasoline. (2) differs from (1) by assuming that flex-fuel cars run only on ethanol. (3) assumes that all NGVs were previously flex-fuel vehicles and that all flex-fuel cars run solely on gasoline. Specification (4) differs from (3) by assuming that flex-fuel cars run only on ethanol. All values are in tonnes.

Changes in emissions of pollutants other than CO_2 are shown in Table 29. Even though the resuts in table 28 do not rule out that NGVs were cleaner in terms of CO_2 emissions than ethanol or gasoline, results in table 29 point to unambiguously higher emissions of

NO_x, aldehydes and CH_4. Emissions of non-methane hydrocarbons and particulate matter are unambiguously lower, while CO emissions are ambiguous.

Assuming the most recent official American government values of social cost of carbon, methane, and nitrous oxide deflated to 2008 American dollars White House (2021),[53] the cost of the greenhouse gases emissions was between US$ 23,607,776 and US$ 175,263,998 in 2008.

Our calculations go against the generally held view among policymakers and the public that NGVs are beneficial for the environment. We believe our estimates are lower bounds for the increased emissions by NGVs for three reasons. First, we only consider change in emissions from fuel price changes in the transportation sector. If these fuels are used in industrial activities, the effect may be even larger. Second, we do not consider leakage in the natural gas supply chain. This has been shown to be important in accounting for CNG environmental impacts elsewhere (Yuan et al., 2019). Third, we do not account for the fact that sugarcane ethanol is a renewable resource and CNG is not. Moreover, we do not calculate welfare implications of the expansion of the NGV fleet, since this would entail considering the environmental and local health effects from the emissions, the welfare changes by owners of NGVs and of ethanol/gasoline/flex vehicles (the latter due to changing fuel prices induced by the NGV fleet growth) in a single framework.

[53]We consider the average estimates assuming a 3% discount rate. The inflation rate between 2008-2020 in the US was of 20.21%.

Table 29: Emissions of Other Pollutants

Panel A - Scenario 1 (tonnes)

	(1) CO	(2) NO_x	(3) NMHC	(4) Aldehydes	(5) CH_4	(6) PM
Postulates 1 + 3	6,914	4,077	-453	412	3,466	-9
Postulates 1 + 4	3,052	3,292	-1,062	388	3,298	-17
Postulates 2 + 3	4,664	3,809	-671	399	3,424	-10
Postulates 2 + 4	803	3,024	-1,281	375	3,256	-18

Panel B - Scenario 2 (tonnes)

	(1) CO	(2) NO_x	(3) NMHC	(4) Aldehydes	(5) CH_4	(6) PM
Postulates 1 + 3	6,961	4,091	-347	493	3,467	-9
Postulates 1 + 4	3,099	3,306	-956	469	3,298	-17
Postulates 2 + 3	4,674	3,811	-657	409	3,424	-10
Postulates 2 + 4	813	3,026	-1,267	385	3,256	-18

Panel C - Scenario 3 (tonnes)

	(1) CO	(2) NO_x	(3) NMHC	(4) Aldehydes	(5) CH_4	(6) PM
Postulates 1 + 3	8,332	6,066	-560	568	4,807	-10
Postulates 1 + 4	-715	5,082	-1,777	520	4,473	-26
Postulates 2 + 3	6,082	5,798	-779	554	4,765	-11
Postulates 2 + 4	-2,964	4,814	-1,996	507	4,431	-27

Panel D - Scenario 4 (tonnes)

	(1) CO	(2) NO_x	(3) NMHC	(4) Aldehydes	(5) CH_4	(6) PM
Postulates 1 + 3	8,379	6,080	-454	649	4,808	-11
Postulates 1 + 4	-668	5,096	-1,671	601	4,473	-26
Postulates 2 + 3	6,092	5,800	-765	565	4,765	-11
Postulates 2 + 4	-2,954	4,817	-1,982	517	4,431	-27

* Non-Methane Hydrocarbons

** Particulate Matter

NOTES: Calculated increased emissions of various pollutants from the growth of the NGV fleet in the Rio de Janeiro State, namely: CO (Carbon Monoxide), NO_x (Nitrogen Oxides), NMHC (Non-Methane Hydrocarbons), Aldehydes, CH_4 (Methane) and PM (Particulate Matter). Panel A assumes that all NGVs previously ran on gasoline only and that all flex-fuel cars run solely on gasoline. Panel B differs from Panel A by assuming that flex-fuel cars run only on ethanol. Panel C assumes that all NGVs were previously flex-fuel vehicles and that all flex-fuel cars run solely on gasoline. Panel D differs from Panel C by assuming that flex-fuel cars run only on ethanol. All values are in tonnes.