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THE EFFECT OF FUEL QUALITY MONITORING AND INSPECTION ON THE QUALITY OF BRAZILIAN FUEL

Marcelo Meneses
Universidade de São Paulo (USP)
Romero Rocha
Universidade Federal do Rio de Janeiro (UFRJ)

This article estimates the effect of fuel quality monitoring and the inspection programs performed by the Brazilian National Agency of Petroleum (Agência Nacional do Petróleo – ANP) on the quality of fuel sold in Brazil. The research mainly uses microdata extracted from the Fuel Quality Monitoring Program (FQMP), which has characteristics of a random experiment, and also the Inspection Program, a typical example of command-and-control regulation. It is verified through an instrumental-variable estimation that monitoring and inspection activities employed by the ANP effectively reduce the likelihood that gas stations will commercialize non-compliance fuels. The results prove that either traditional or alternative deterrent methods can improve the engagement of economic agents concerning fuel quality, increasing the probability that a gas station sells fuels with less polluting potential.

Keywords: Applied Microeconomics, Policy Analysis, Instrumental Method, Experimental Methods, Economics of Regulation, Firm Behavior.

JEL Classification: C360, D22, H830, L510.

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Marcelo Meneses: mmeneses@usp.br
Romero Rocha: romero.rocha@ie.ufrj.br
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1. Introduction

Environmentalists, public managers, and citizens agree that burning fossil fuels is one of the leading causes of air pollution in large urban centers. When these fuels are put in thermal machines or automotive vehicles, a large amount of carbon dioxide is emitted into the atmosphere, along with other particles and gases that are harmful to human health. The World Health Organization reported that air pollution annually leads to 4.2 million deaths related to heart disease, stroke, lung cancer, and respiratory diseases (WHO, 2022). Moreover, if the emission level does not change, by 2050, air pollution will be the major death cause linked to the environment in the world (OECD, 2012).

Thus, improving fuel quality standards can reduce the emission of pollutants, minimizing the environmental damage caused by petroleum products. Nevertheless, it is not enough just to establish new quality rules to ensure that consumers have access to low-polluting fuels. A complex fuel monitoring system is required in order to ensure that commercialized fuels match the established specifications and that they are exempted from adulteration.

In Brazil, this job is carried out by the Brazilian National Agency of Petroleum (Agência Nacional de Petróleo – ANP), which controls the quality of fuel sold at gas stations through two programs. The first one is the Fuel Quality Monitoring Program (FQMP), a program primarily intended for informational purposes, which is performed by third-party companies that randomly choose gas stations to analyze their fuel. In parallel, the ANP also runs the Inspection Program, which uses the information produced by the monitoring program to effectively punish gas stations selling fuels that do not meet quality standards.

However, despite the robust monitoring system adopted in Brazil, the practice of selling low-quality fuels is still frequent. According to the Brazilian Statistical Yearbook of Petroleum, Natural Gas, and Biofuels of 2019, 3% of samples collected in the previous year through the fuel quality monitoring program did not meet Brazilian fuel quality standards. Moreover, irregularities were found in 25% of the inspection program actions. Therefore, by applying appropriate econometric tools, this work aims to measure the real effect of these two public policies on the quality of fuel sold in Brazil. In addition, the impact of one program on the other will also be measured, as well as the correlation of a series of explanatory variables on fuel quality.

The economics literature has extensively discussed the role of control over companies' compliance. A large number of studies have demonstrated that strict air control policies can reduce pollution, improves public health, and provides climate benefits (Yu & Morotomi, 2022; Li et al., 2020; Perera et al., 2019; Wang et al.,

2019; Marcus, 2017; Auffhammer & Kellogg, 2011). Others have revealed that robust monitoring implemented by regulatory agencies can improve the behavior of facilities, reducing industrial pollution, oil spills, and gas emissions (Stafford, 2012; Magat & Viscusi, 1990; Epple & Visscher, 1984). There is also literature that intends to understand whether alternative regulatory actions, for instance, inspections that do not generate penalties, can affect compliance (Haviland et al., 2012; Stafford, 2006; Gray and Mendeloff, 2005). Finally, new literature has tested the effect of monitoring technologies on deterring environmental crimes (Assunção et al., 2023).

Nevertheless, empirical evaluations of monitoring and control activities are still incipient due to econometric challenges. Therefore, this work can fill the gap and enrich the studies of evaluation of monitoring and control policies, as well as assessment of public policies in the energy sector. What is more important, the papers mentioned above use quasi-experimental methods. Thus, our article is the first one to measure the impact of two massive national compliance monitoring and control programs on an energy sector using experimental data. In addition, our research also contributes to the modern literature on alternative regulation methods by analyzing the effect of a monitoring program that does not generate immediate punishment. Moreover, the use of an experiment with a random selection feature combined with the application of an instrumental variable is an original aspect of this research.

Then, employing ordinary least squares (OLS) and two stages least squares (2SLS), this research reveals that the fuel quality monitoring and the inspection programs effectively reduce the probability that a gas station will sell fuels that do not meet the minimum quality parameters. It was also verified that the monitoring program has a significant role in defining the inspection program targets, allowing efficient control of the non-compliance hotspots. Furthermore, the results attested that the quality of fuels is not only related to the individual characteristics of gas stations but also to municipal attributes. Besides, a relationship between high-profit margins and a low coefficient of price variation with higher fuel quality standards has been demonstrated, indicating that competition between gas stations can also encourage companies to engage in unethical activities.

The rest of this article is presented as follows. Section 2 offers an overview of the Brazilian fuel market, explaining the role of the National Agency of Petroleum in controlling fuel quality. In section 3, the database and variables used are described. In section 4, a discussion of the economic theory is made, and the empirical model is specified. Section 5 presents the results of the econometric tests, assessing the causal effect of quality monitoring and inspection programs on fuel quality. In section 6, the robustness of the results is discussed. Finally, in section 7, the conclusions reached in this article are shown.

2. The Brazilian Fuel Market

Historically characterized by excessive government intervention, the Brazilian fuel market structure underwent profound changes in its operating dynamics from the 1990s onward. Such changes aimed to reduce state interference in the economy, strengthen the private initiative, increase efficiency, reduce the cost of services provided by the public sector, and improve users' satisfaction with public services. However, in order not to cause chaos, the Federal Government opted to open the fuel market in several stages, in a slow process that was only concluded in 2002. After that year, the government was legally prevented from intervening in fuel prices.

The changes were only possible after complex changes in the country's legal framework, which sought to attract private capital to the oil industry, one of the sectors most affected by the exhaustion of the State's capacity to invest in infrastructure. The most significant milestones of these transformation efforts were the approval of Constitutional Amendment no. 06/1995, which put an end to Petrobras's monopoly over several activities related to the oil and gas market, and the acceptance of Law no. 9478/1997, which created the National Agency of Petroleum (Agência Nacional do Petróelo - ANP), the regulatory body responsible for regulating and inspecting the economic activities of this industry.

The end of Petrobras's monopoly brought dynamism to the oil sector, introducing competition between companies that began to operate in this market. However, the entrance of new economic agents gave rise to several distortions, such as fuel adulteration, tax evasion, and other irregularities related to the safety of operations and the environment. Thus, to reverse this scenario, the ANP had to institute a complex fuel monitoring system to control the quality of fuel sold in Brazil.

2.1. *The Fuel Quality Monitoring Program*

The Fuel Quality Monitoring Program (FQMP) was instituted in 1998 by the National Agency of Petroleum (ANP), and one of its initial attempts was to guarantee the quality of fuels all over the national territory. The FQMP collects fuel samples to formulate quality indicators and identify non-compliance hotspots (Belisário, 2014). It is carried out monthly through simple stratified sampling (without replacement) based on establishing subpopulations (subareas) of gas stations. The collected samples are later sent to the laboratories and classified according to the fuel specifications described by the ANP.

The program is carried out by a third-party private institute hired by the ANP to run the analysis, and it is strictly non-punitive since the institute cannot apply sanctions to gas stations whose samples are non-compliant. Because several third-

party institutes are part of this program, it has a high capillarity, managing to reach municipalities far from large regional centers very quickly. Additionally, although the program's total cost is high, the cost per sample collected is meager, making it possible to analyze the quality of fuels at thousands of gas stations throughout the year. For example, between 2002 and 2018, more than 160,000 samples were collected for analysis yearly on average.

2.2. *The Inspection Program*

The National Agency of Petroleum (ANP) created the Fuel Supply Inspection Superintendence to plan and conduct inspection actions more systematically. This department analyzes the data produced by the Fuel Quality Monitoring Program (FQMP) for diagnosing non-compliance hotspots, making it possible to concentrate inspection efforts mainly in the places with the highest probability of irregularities (Brasil, 2015).

The companies considered suspicious are identified, and this information is sent to the regional inspection centers in the country's central municipalities that carry out an on-site inspection. Since there are only seven regional centers in a country as large as Brazil, the inspection actions of this program may not be fast enough to curb the practice of irregular activities. In addition, as this program's actions are punitive, complex coordination with local police is often required to ensure the safety of regulatory agency officials in charge of enforcement activities. This makes the cost of these enforcement actions very high, so the cost of action needs to be analyzed regarding its impact on improving the fuel market. For instance, between 2002 and 2018, an average of just over 20,000 inspection actions were carried out yearly in a universe of more than 120,000 economic agents.

3. Data Description

This study's primary data source is the microdata provided by the Fuel Quality Monitoring Program (FQMP), with samples collected from January 2002 to December 2014. It informs if a selection of each type of fuel (ethanol, diesel, and gasoline) gathered at a gas station is classified as "in compliance" or "in non-compliance" with ANP's standards. Besides, from this database, it is possible to get information such as the date of monitoring, the identification and address of the monitored gas station, the fuels collected, and the tests performed to verify the compliance of the samples and their results.

Additionally, three other databases belonging to the National Agency of Petroleum (ANP) were used complementary. The first one is the Product Movement Information System (PMIS). This database presents information about

the opening and closing dates of gas stations operating in Brazil, enabling one to identify which gas stations were authorized to work in a specific month. The database also informs the installed capacity of gas station's underground storage tanks (USTs), providing a good proxy for the size of the establishment and its importance in the market.

The Integrated Information Management System (IIMS) allows for accessing all information about the inspection actions conducted by the Fuel Supply Inspection Superintendence of ANP. Through the IIMS, it is possible to identify the National Registry of Legal Entities (NRLE) of gas stations inspected in a given period, the date on which the inspection was performed, the inspection document number (IDN) issued during the action, and the violations of the law verified in the examination.

Furthermore, through a weekly price survey, the ANP monitors the behavior of prices charged by distributors and gas stations. The Fuel Price and Marketing Margins Survey (FPMM) covers large Brazilian centers, showing weekly prices in 459 municipalities. This database provides the identification and location of the gas stations and the prices charged for each fuel type.

Besides the four databases elaborated by the National Agency of Petroleum (ANP), this research also uses data on the total population of municipalities provided by the Brazilian Institute of Geography and Statistics (IBGE) from 2002 to 2014.

4. The Economic Theory

Most authors who use Becker's model agree that people engage in illegal activity if the expected utility of doing this exceeds the utility they could obtain by using their time and other resources in another action. Moreover, when all variables are kept constant, increasing the probability of an individual being penalized for their actions reduces the number of crimes (offenses) committed by that individual (Becker, 1974).

By applying Becker's model to the case under analysis, we have that the gas station's profit maximization function indicates that this economic agent will only engage in an illicit activity when it verifies that the gains obtained in this way are more significant than the expected losses. Additionally, the likelihood of being punished is a function of the probability that a gas station receives an inspection action, which, in turn, is a function of the availability of data from fuel quality monitoring and other database sources.

The idea behind this statement is that when a gas station has its fuels collected by the monitoring team, this firm increases its perception of control by the

State, which raises its expectation of receiving an inspection action. Therefore, increasing monitoring activity can boost the likelihood of punishment perceived by the gas stations, even without an actual increase in the number of inspections.

4.1. *The Empirical Model*

Random assignment is the most reliable method to evaluate programs because it circumvents the most critical problems in empirical research: selection bias and omitted variable bias. The idea behind the random assignment is to allocate participants to different groups in an experiment through randomization to ensure that each participant has an equal chance of being placed in any group. Thus, the groups have, on average, similar observable and non-observable characteristics, and all differences in outcome can be safely attributed to the status assigned to each group, for example, treatment or control (Angrist & Pischke, 2009).

The empirical model formulated here is anchored in the fact that the Fuel Quality Monitoring Program (FQMP) selects gas stations to be visited randomly. Based on this, it is verified whether the activities carried out by the National Agency of Petroleum (ANP), such as the FQMP and the inspection activities, reduce the probability that gas stations sell fuel of poor quality. The initial procedures of this study begin with estimating two ordinary least squares (OLS) equations to define the causal effect of a previous monitoring action on the quality of samples collected in a subsequent quality monitoring activity. Thus, the first two equations can be described as follows:

$$compliance_{it} = \alpha + \beta_1 monitored_{i,t-x} + \beta_2 year_t + \beta_3 subarea_{it} + \mu_{it}, \quad (4.1)$$

$$compliance_{it} = \alpha + \beta_1 monitored_{i,t-x} + \beta_2 compliance_{i,t-w} + \beta_3 monitored_{i,t-x} * compliance_{i,t-w} + \beta_4 year_t + \beta_5 subarea_{it} + \mu_{it}. \quad (4.2)$$

where $compliance_{i,t}$ reports the fuel compliance analysis outcome of the gas station i, collected at month t, which is 1 if all the samples (ethanol, gasoline, and diesel) collected at this moment comply with the legislation, and 0 if at least one does not comply. In turn, $monitored_{i,t-x}$ is a dummy that indicates whether the gas station i was monitored in any month between $t - x$ and $t - 1$. To understand $monitored_{i,t-x}$, it is essential to realize that all observations used in the above equations have at least one previous monitoring. Thus, both the treatment and control groups have received a prior monitoring activity. Then, the treatment group is defined as the group of gas stations in which the previous monitoring activity happened between months $t - x$ and $t - 1$.

On the other hand, the control group is defined as the group of gas stations in which the previous activity occurred before month $t - x$. Character x represents the number of lagged months tested in each regression, and x can assume values 1, 3, or 6. For instance, if x takes the value 3, it will be verified whether there was one monitoring activity in months $t - 3$, $t - 2$ or $t - 1$, that is, the period between $t - 3$ and $t - 1$. Then, the variable $monitored_{i,t-x}$ is a dummy that takes value 1 if the fuel quality monitoring team has visited the gas station i within the interval between $t - x$ and $t - 1$.

Because of the randomness of the fuel quality monitoring program, coefficient β_1 informs the causal effect of the previous monitoring on the probability that new fuel samples collected at t will conform to the fuel quality standard. The variable $year_t$ identifies the year the samples were collected and absorbs any fuel quality time changes communal to all gas stations. Finally, $subarea_{i,t}$ represents the geographical place of the establishment i in month t , identifying the subpopulation used by the ANP to stratify the gas stations in the randomization process.

Equation 4.2 improves the formulation presented above by adding the compliance outcome of the gas station i in its previous monitoring. This procedure allows for analyzing how the compliance status in the last action monitoring impacts the probability of current compliance. The first innovation here is the introduction of the variable $compliance_{i,t-w}$, which is a dummy that informs the result of the fuel quality tests performed on the gas station i in the prior monitoring closest to month t. For those monitored in the period between t-x and t, compliance at t-w is the result of compliance in this monitoring. For those not observed in the period between t-x and t, compliance at t-w is the result of compliance in the last tracking that occurred at that gas station before t. So, w represents the smallest value necessary to reach the previous monitoring action at the gas station i, with $w \geq 1$. The dummy $compliance_{i,t-w}$ will take the value 1 if all the samples at the gas station i were following the ANP legislation in the previous monitoring.

In turn, the coefficient of $monitored_{i,t-x} * compliance_{i,t-w}$ informs the differential effect of having been monitored in previous months on compliance, taking into account the prior monitoring compliance status from a gas station. In other words, this coefficient measures whether the effect of the previous monitoring activity on the compliance status at the time t changes according to the compliance status verified during this last monitoring.

The second set of equations intends to analyze whether the Fuel Supply Inspection Superintendence of ANP accurately uses data acquired by the fuel quality monitoring program to determine which gas stations will receive a visit from the inspection team. Then, the following models are proposed:

$$inspected_{it} = \alpha + \beta_1 monitored_{i,t-x} +, \\ \beta_2 year_t + \beta_3 subarea_{it} + \mu_{it}. \tag{4.3}$$

$$inspected_{it} = \alpha + \beta_1 monitored_{i,t-x} + +\beta_2 compliance_{i,t-w} + \beta_3 monitored_{i,t-x} * compliance_{i,t-w} + \beta_4 year_t + \beta_5 subarea_{it} + \mu_{it} \tag{4.4}$$

where $inspected_{it}$ is a dummy indicating whether the gas station i was assessed by the inspection program during the month t. As in equations 4.1 and 4.2, the dummy $monitored_{i,t-x}$ informs whether a monitoring action was carried out at the gas station i in any month between $t - x$ and $t - 1$. One more time, x is the number of lagged months used in each test (1, 3, or 6 months). Likewise, $subarea_{it}$ designs the location of the gas station used for stratification in the randomization process of the FQMP, and $year_t$ identifies the inspection year.

In turn, equation 4.4 incorporates the gas station compliance status the previous time it was monitored. Here, the variables $monitored_{i,t-x}$, $compliance_{i,t-w}$ and $monitored_{i,t-x} * compliance_{i,t-w}$ assume the same meaning as that explained in equation 4.2. However, in this case, $monitored_{i,t-x} * compliance_{i,t-w}$ measures the differential effect that the compliance status in the previous monitoring has on the probability that a gas station will be inspected. In other words, the value of β_3 coefficient allows diagnosing whether a gas station previously monitored will have the probability of an inspection in the period t changed according to the result of the fuel samples analyzed in the monitoring action.

Finally, the third series of equations will evaluate whether the inspection program can improve the quality of fuel sold in Brazil. In other words, these equations measure the causal effect of inspection actions on the compliance of fuel samples analyzed in future monitoring actions. Thus, the model was initially formulated as follows:

$$compliance_{it} = \alpha + \lambda_1 inspected_{i,t-x} + \lambda_2 year_t + \lambda_3 subarea_{it} + \xi_{it}, \tag{4.5}$$

where $compliance_{it}$ represents a dummy that assumes value 1 if the gas station i monitored by the FQMP in month t was complying with the legislation; otherwise, it takes value zero. The variable $inspected_{i,t-x}$ is a dummy variable that determines whether the gas station i was inspected in any month between $t - x$ and $t - 1$. Then, $inspected_{i,t-x}$ would take the value of 1 if the previous inspection action happened during the interval $t - x$ and $t - 1$, and would be 0 otherwise. As before, x is a period arbitrarily selected that assumes the values of 1, 3, or 6 months.

Unfortunately, the model above might present endogeneity because $inspected_{i,t-x}$ is not defined randomly, which means that it is not possible to assure that $E(\xi_{i,t}|inspected_{i,t-x})=0$. This problem made finding an instrumental variable for the endogenous independent variable necessary. As already explained, the monitoring program information is one of the central sources used by the inspection program in choosing the gas stations to be analyzed. Thus, it can be assumed that the probability that a gas station will be inspected is greater if it had been previously monitored. This relationship between inspection and monitoring determines the first stage of the instrumental variables method and can be demonstrated as follows:

$$inspected_{i,t-x} = \alpha + \theta_1 monitored_{i,t-2x} + \theta_2 year_{t-x} + \theta_3 subarea_{i,t-x} + \varepsilon_{i,t-x}. \quad (4.6)$$

In the same way as equation 4.5, in equation 4.6 $inspected_{i,t-x}$ is a dummy variable that determines whether the gas station i was inspected in any month between $t-x$ and $t-1$. In addition, if there are one or more inspections in this period between $t-x$ and $t-1$, only the most recent inspection will be considered, and the month in which this fact occurred is named $t-k$. In other words, k takes the smallest possible value in the range $1 \leq k \leq x$. On the other hand, if there is no inspection, k equals x . In turn, the explanatory variable $monitored_{i,t-2x}$ informs whether the FQMP monitored the gas station i in a month between $t-2x$ and, $t-k-1$ which is the month immediately before $t-k$. Then, the variable $monitored_{i,t-2x}$ assume the value of 1 if the gas station was monitored between $t-2x$ and $t-k-1$, and 0 otherwise. One more time, x is the number of lagged months used in each test (1, 3, or 6 months).

The main advantage of using monitoring activity as an instrumental variable is that, by construction, the selection of gas stations to be visited by the FQMP is essentially random. Therefore, the exogeneity of $monitored_{i,t-2x}$ in equation 4.6 is assured, that is, $E(\varepsilon_{i,t-x}|monitored_{i,t-2x})=0$. Furthermore, this exogeneity ensures the lack of correlation between $monitored_{i,t-2x}$ and ξ_{it} of equation 4.5. Nonetheless, clarifying the roles of equations 4.5 and 4.6 on the instrumental variable's estimation is crucial. Using $inspected_{i,t-x}$ predicted by equation 4.6, equation 4.5 becomes the second-stage equation of a two-stage least square (2SLS) estimation. It measures the causal impact of an inspection that had occurred between $t-x$ and $t-1$ on the result of the monitoring activity ($compliance_{it}$) at gas station i in time t. In turn, regression 4.6 is the first stage of this system. It establishes the causal effect of being monitored between $t-2x$ and $t-k-1$ on the occurrence of an inspection activity ($inspected_{i,t-x}$).

The system presented above can be further extended by adding the variables $compliance_{i,t-w}$ and $monitored_{i,t-2x} * compliance_{i,t-w}$. The first of these variables, $compliance_{i,t-w}$ indicates the compliance status of the previous monitoring immediately before month $t - k$. Again, $t - k$ corresponds to the month of an inspection performed between $t - x$ and $t - 1$, in which k is the smallest possible value in the interval $1 \leq k \leq x$. On the other hand, k is equal to $t - x$ if there is no inspection between $t - x$ and $t - 1$. So, w represents the smallest value necessary to reach the previous monitoring action at the gas station i before the inspection analyzed, so that $w \geq k - 1$. In its turn, the second variable corresponds to the interaction between $compliance_{i,t-w}$ and $monitored_{i,t-2x}$. It informs the differential effect of monitoring on the probability of being inspected depending on the outcome of this monitoring. The extended system of equations, then, becomes:

$$compliance_{it} = \alpha + \lambda_1 inspected_{i,t-x} + \lambda_2 compliance_{i,t-w} + \lambda_3 year_t + \lambda_4 subarea_{it} + \xi_{it}, \quad (4.7)$$

$$inspected_{i,t-x} = \alpha + \theta_1 monitored_{i,t-2x} + \theta_2 compliance_{i,t-w} + \theta_3 monitored_{i,t-2x} * compliance_{i,t-w} + \theta_4 year_{t-x} + \theta_5 subarea_{i,t-x} + \varepsilon_{i,t-x}. \quad (4.8)$$

In addition to the three groups of regression presented above, this article also studied the relationship between fuel quality and some competitive indicators. In these tests, as the competitive indicators are not random, the results are interpreted as a correlation between them and fuel quality. Finally, this article investigates the relationship between population size in municipalities and the probability of selling non-specified fuels.

5. Results

This study's results reveal that the fuel quality monitoring and the inspection programs effectively reduce the probability of gas stations selling low-quality fuels. However, the effect of monitoring is heterogeneous based on the compliance status of gas stations at the previous monitoring. Indeed, monitoring increases compliance more in those facilities where compliance was already higher at the time of monitoring. In addition, it has confirmed the role of the monitoring program as an essential source of information for selecting the gas stations that will be inspected.

5.1. *The effect of monitoring on fuel compliance*

Confirming Becker's (1974) theoretical assumptions, the outcomes from the first group of regressions indicate that the fuel quality monitoring program has

a significant deterrent effect on gas stations. The statistical results are presented in Table 1. The gas stations not monitored in the previous month showed a degree of fuel sales within specifications of 55.1%. On the other hand, the gas stations watched one month before the current monitoring had a compliance rate of 3.5 percentage points higher. It implies that monitoring activity increases the probability of compliance in the following month by 6.3% (0.035/0.551). The estimated effect is statistically significant at a 1% level. This result has important theoretical implications, as it confirms that non-punitive monitoring actions, often with a reduced cost compared to punitive inspection, can generate significant benefits in terms of compliance.

However, when comparing the results of the first three columns of Table 1, it can be noticed that the deterrent effect caused by monitoring reduces over the months. While the probability of a gas station selling fuel within the specifications increased by 3.5% when the establishment was monitored just one month before the current monitoring, this effect was only 0.8% when the previous monitoring occurred three months before. Moreover, when the time range was extended to a gap of six months, the result was not statistically significant at the 10% level. These results suggest that monitoring generates a momentary perception that the State closely monitors the fuel market. Thus, when the following monitoring activity takes place in a shorter period, it is possible to verify that gas stations remain alert regarding the sale of fuel within specifications. Nevertheless, this feeling of vigilance disappears over time when the establishment is no longer monitored.

The results also show that the magnitude and sign of the monitoring effect on the probability of selling quality fuels depend on whether establishments were compliant in the last monitoring. Columns IV through VI of Table 1 explore the differences in compliance status in the previous monitoring. Contrary to expectations, the deterrent effect is considerably more significant at gas stations compliant during the last period than at non-compliant gas stations. More surprising is that the impact of deterrence on gas stations that were not previously compliant is negative. For instance, for the non-compliant gas stations, having been monitored at $t - 1$ reduces the probability of selling fuel within the specification in t by 5.5%. On the other hand, when the establishment was previously compliant, having been monitored in $t - 1$ increases the probability of selling good fuels in t by 21.6%. All results are statistically significant at 1%.

By analyzing the results above, it is possible to affirm that, in general, the quality monitoring program reduces the probability that a gas station will sell non-conforming fuel in the period following the monitoring visit. This effect is mainly seen in those gas stations already selling fuel within specifications. But for those gas stations selling non-conforming fuels, being monitored increases

the probability that these establishments will continue to sell such fuels in the following period. This result could be somewhat counterintuitive, but it is supported by several empirical researchers, such as Sullivan (2017).

TABLE 1

THE EFFECT OF MONITORING ON GAS STATION COMPLIANCE

compliance	I	II	III	IV	V	VI
	$x = 1$	$x = 3$	$x = 6$	$x = 1$	$x = 3$	$x = 6$
$monitored_{i,t-x}$	0.035***	0.008***	-0.000	-0.055***	-0.032***	-0.035***
	(0.003)	(0.001)	(0.001)	(0.006)	(0.002)	(0.002)
$monitored_{i,t-x*}$				0.132***	0.061***	0.055***
$compliance_{i,t-w}$				(0.007)	(0.002)	(0.003)
$compliance_{i,t-w}$				0.139***	0.123***	0.097***
				(0.001)	(0.001)	(0.002)
constant	0.551***	0.549***	0.552***	0.466***	0.475***	0.493***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Observations	843,322	843,322	843,322	843,322	843,322	843,322
R _ Squared	0.094	0.094	0.094	0.113	0.113	0.113
$subarea_{i,t}$	Yes	Yes	Yes	Yes	Yes	Yes
$year_t$	Yes	Yes	Yes	Yes	Yes	Yes
operating	Yes	Yes	Yes	Yes	Yes	Yes
previouslymonitored	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The coefficients are estimated with the use of a cross-sectional dataset covering the period from 2002 to 2014. The sample includes all gas stations with products collected by the Fuel Quality Monitoring Program (FQMP) from 2002 to 2014. The coefficients are estimated through the ordinary least squares (OLS) method. In columns I to III, the independent variable $compliance_{i,t}$, which indicates the compliance status of samples collected at establishment *i*, in month *t*, is regressed on the dummy $monitored_{i,t-x}$, which indicates if establishment *i* received a monitoring activity between $t - x$ and $t - 1$, in which *x* represents the number of months admitted for the period. In columns IV to VI, $compliance_{i,t}$ is regressed, once again, on $monitored_{i,t-x}$, in addition to the compliance status of the establishment in the previous monitoring ($compliance_{i,t-w}$) and the interaction between these two variables ($monitored_{i,t-x} * compliance_{i,t-w}$), in which *x*, again, represents the number of months admitted for the period. For all columns, controls are used for the year of observation ($year_t$) and the subarea where the gas station is located ($subarea_{i,t}$). Only samples collected during the period when the establishment was officially in operation (*operating*) were used. Finally, only the observations after the first fuel collection (*previously monitored*) by the monitoring team were considered. Standard errors in parentheses: *** p <0.01, ** p <0.05, * p <0.1.

One possible explanation is that the gas sellers erroneously understand that the monitoring and inspection programs are substitutes, not complements. Under this assumption, the probability of being inspected is reduced right after monitoring, even after finding fuel irregularities. Inspection data could support this interpretation: only 12.3% of non-compliant gas stations were inspected within two months after being monitored. Therefore, non-compliant gas stations feel even more confident to keep committing infractions after being watched since they believe they enjoy a subsequent period without inspections.

Another explanation is based on the real motivation for opening one gas station. Suppose there are gas stations with the primary objective of selling adulterated fuels. These businesses can intersperse the sale of non-compliant fuels with those within specifications in order to maximize their utility function. However, when identified as fraudsters by the FQMP, these gas stations understand that they will be quickly banned. Thus, the firm starts to sell the largest possible volume of adulterated fuels before the company is effectively closed. However, as the number of agents working in the inspection program, which is the program that can shut down a specific gas station, is small; so, in some cases, the fraudster gas station can be monitored again before receiving a visit from the inspection program. Thus, the probability of selling non-compliant fuel in period t tends to be greater for those who were monitored and were already irregular.

5.2. *The effect of monitoring on inspections*

This study also indicates that the fuel quality monitoring program appropriately supports the inspection program actions. As depicted in the first column of Table 2, gas stations that were not monitored in $t-1$ have a 3% probability of being inspected at t. However, if a gas station was observed in the previous month, the likelihood of receiving an inspection action in t is 0.004 percentage points higher. The estimated effect is statistically significant at a 1% level. This implies that the monitoring action increases the probability that a gas station will be inspected in the following month by 13.3% (0.004 / 0.030), which confirms that the monitoring program is an essential source of information used to define the inspected gas stations.

The results also show that the magnitude of the monitoring effect on the probability of inspection activity increases with time dilation. Being monitored by the FQMP within 1 month ($x = 1$ increases the likelihood of being inspected by 13.3%. However, this probability rises to 17.2% (0.005/0.029) and 22.2% (0.006/ 0.027) when x receives the values 3 and 6, respectively. These results infer that assimilating information from the FQMP by the Fuel Supply Inspection Superintendence is a lengthy process. Therefore, improving the speed of this department's internal processes may mean faster and more assertive inspection actions, favoring the quality of the fuel market.

TABLE 2

THE EFFECT OF MONITORING ON GAS STATION INSPECTION

Inspected	I	II	III	IV	V	VI
	$x = 1$	$x = 3$	$x = 6$	$x = 1$	$x = 3$	$x = 6$
$monitored_{i,t-x}$	0.004***	0.005***	0.006***	0.004***	0.007***	0.010***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$monitored_{i,t-x}$ *				-0.001**	-0.005***	-0.007***
$compliance_{i,t-x}$				(0.000)	(0.000)	(0.000)
$compliance_{i,t-x}$				-0.007***	-0.004***	-0.002***
				(0.000)	(0.000)	(0.000)
constant	0.030***	0.029***	0.027***	0.039***	0.035***	0.032***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	4,860,121	4,860,121	4,860,121	4,383,212	4,383,212	4,383,212
R _ Squared	0.023	0.023	0.023	0.024	0.024	0.024
$subarea_{it}$	Yes	Yes	Yes	Yes	Yes	Yes
$year_t$	Yes	Yes	Yes	Yes	Yes	Yes
operating	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The coefficients are estimated with the use of a cross-sectional dataset covering all months from January 2002 to December 2014. The sample includes all gas stations operating for at least one month. The coefficients are estimated through the ordinary least squares (OLS) method. In columns I to III, the independent variable $inspected_{it}$, which indicates whether establishment *i* received a fuel supply inspection in month *t*, is regressed on the dummy $monitored_{i,t-x}$, which indicates whether establishment *i* received a monitoring action in the period between *t-x* and *t*, in which *x* represents the number of months admitted for the period. In columns IV to VI, the dummy $inspected_{it}$ is regressed, once again, on $monitored_{i,t-x}$, in addition to the compliance status of the establishment verified in the previous monitoring activity ($compliance_{i,t-w}$) and the interaction between these two variables ($monitored_{i,t-x}$ * $compliance_{i,t-w}$), in which *x*, again, represents the number of months admitted for the period. For all columns, controls are used for the year of observation ($year_t$) and the subarea where the gas station is located ($subarea_{i,t}$). Only samples collected during the period when the establishment was officially in operation (*operating)* were used. Standard errors in parentheses: *** p <0.01, ** p <0.05, * p <0.1.

The results for the interaction of monitoring with compliance are even more relevant, as shown in Table 2, columns IV to VI. Column IV shows that establishments that were not in compliance in the previous monitoring and were monitored in the last month have a probability of 4.3% (0.039 + 0.004) of being inspected in *t*. In the case of a gas station with a positive compliance status monitored in the previous month, the inspection likelihood reduces to 3.5% (0.039 + 0.004 – 0.001 – 0.007), which corresponds to a reduction of about 20%. That is, the probability of a given gas station being inspected at time t is reduced if that establishment is monitored between t-1 and t-6, and it is found in this monitoring that the establishment follows fuel standards. This statement can be confirmed by analyzing the coefficient of the interaction variable in columns V and VI when *x* receives the values 3 and 6 (-0.005 and -0.007, respectively). All coefficients of interest tested were statistically significant at 5%.

In short, the coefficients depicted in Table 2 solidly attest to the hypothesis that the FQMP is an essential tool for the inspection program. Based on the information generated by the monitoring program, it is possible to identify establishments that sell high-quality fuels and require less coercion to comply with the law. Thus, the National Petroleum Agency can focus its limited resources on those most likely non-compliant establishments.

5.3. *The effect of inspection on fuel compliance*

Having shown that monitoring activities increase the probability of selling high-quality fuels and the likelihood that a gas station will be inspected by the National Agency of Petroleum (ANP), the effect of inspection on fuel quality is now assessed. The coefficients presented in Table 3 capture the impact of inspection actions on the probability that the fuels collected are within compliance standards. Columns I to III depict the results verified for equation 4.5. In this specification, a dummy that indicates whether a gas station was monitored before an inspection is used as the instrumental variable for inspection. Columns IV to VI refer to equation 4.7. In this second case, the interaction between being monitored and the conformity information is also used as an instrument. In both cases, the controls for the area of gas stations and the year of monitoring were maintained.

The results show that carrying out inspection actions in a specific month significantly reduces the probability that a gas station sells non-standard fuel in the subsequent period. The most significant effect occurs in inspections performed within one month, 10.4% (column I) and 6.3% (column IV). However, this effect is reduced to only 1.5% (column III) when the previous inspection was performed within six months, representing an 85% reduction in inspection power. This result indicates that the inspection program's ability to change economic agents' expectations dissipates over time, as previously demonstrated for the fuel quality monitoring program. However, the coercive power generated by a punitive action on the company's complicity is more significant than a monitoring action without the ability to generate fines.

As seen in Table 3, intensifying inspections today will have a strong deterrence effect on selling out-of-specification fuels up to a month ahead. This deterrence effect will be negligible when we consider up to 3 months (column II) and, finally, becomes a marginal effect when evaluated for up to six months (column III). This pattern of decreasing impact over time reinforces the need to maintain continuous enforcement actions in habitual infringing agents to effectively combat the trade of products that do not comply with regulations. Finally, the results presented in Table 3 are consistent in magnitude and significance, indicating that the findings are not motivated by the independent variable instrumentation chosen.

TABLE 3

THE EFFECT OF INSPECTION ON GAS STATION COMPLIANCE – SECOND STAGE

Compliance	I	II	III	IV	V	VI
	$x = 1$	$x = 3$	$x = 6$	$x = 1$	$x = 3$	$x = 6$
$inspected_{i,t-x}$	0.104***	0.022***	0.015***	0.063*	0.025***	0.017***
	(0.034)	(0.008)	(0.003)	(0.034)	(0.008)	(0.003)
$compliance_{i,t-w}$				0.139***	0.123***	0.110***
				(0.002)	(0.002)	(0.002)
constant	-0.088***	-0.072***	-0.072***	-0.057**	-0.062**	-0.086***
	(0.026)	(0.025)	(0.025)	(0.026)	(0.025)	(0.025)
Observations	362,689	362,689	362,689	362,624	361,948	360,675
R _ Squared	0.102	0.105	0.105	0.122	0.118	0.116
$subarea_{it}$	Yes	Yes	Yes	Yes	Yes	Yes
$year_t$	Yes	Yes	Yes	Yes	Yes	Yes
operating	Yes	Yes	Yes	Yes	Yes	Yes
previouslyinspected	Yes	Yes	Yes	Yes	Yes	Yes
previouslyinspected	Yes	Yes	Yes	Yes	Yes	Yes
First-stage F statistics	3,065.84	24,245.84	1.2e+05	1545.97	12,057.94	59,132.10
AR - Chi2	9.36	7.03	18.31	171.54	104.90	161.69
Prob > AR	0.0022	0.0080	0.0000	0.0000	0.0000	0.0000
SW - S – stat	9.36	7.03	18.31	171.46	104.87	161.61
Prob > SW	0.0022	0.0080	0.0000	0.0000	0.0000	0.0000

Notes: The coefficients are estimated with the use of a cross-sectional dataset covering the period from 2002 to 2014. The sample includes all gas stations with products collected by the Fuel Quality Monitoring Program (FQMP) during the sampling period. The coefficients are estimated using the two-stage least squares method (2SLS). In columns I to III, the dummy $compliance_{it}$, which indicates the compliance status of the samples collected at establishment *i*, in month *t*, is regressed on the dummy $inspected_{i,t-x}$, which indicates whether establishment *i* received a tracking of the inspection program in the period between *t-x* and *t* (specifically in month *t-k*), in which $1 \leq k \leq x$ and x represents the number of months admitted for the period. It is used as an instrumental variable $monitored_{i,t-2x}$, which indicates the existence of monitoring between *t-2x* and *t-k-1*. Again, *x* represents the number of months admitted for the period. In columns IV to VI, the dummy $compliance_{it}$ is regressed, once again, on $inspected_{i,t-x}$, in addition to the compliance status of the establishment in the previous monitoring immediately before month $t - k$ ($compliance_{i,t-w}$) , in which $monitored_{i,t-2x}$ and $monitored_{i,t-2x} * compliance_{it-w}$ are used as instrumental variables. For all columns, controls are used for the year of observation ($year_t$) and the subarea where the gas station is located ($subarea_{it}$). Only samples collected during the period when the establishment was officially in operation (*operating*) were used. Finally, only the observations after the first fuel monitoring (*previously monitored*) and the first inspection (*previously inspected*) were considered. Standard errors in parentheses: *** p <0.01, ** p <0.05, * p <0.1.

5.4. *The additional correlations with fuel compliance*

Other explanatory variables commonly used in empirical academic studies were also analyzed to verify their correlation with the quality of fuels sold in Brazil and if they influence the effect of being monitored. As shown in Table 4, column I, population and fuel quality are positively correlated. This means that fuels sold at gas stations in large cities are more likely to meet compliance standards than

those in small municipalities. The variable coefficient is statistically significant and practical since a 1% increase in the population is related to a 0.8% improvement in fuel quality. A possible explanation is that municipalities with larger populations are located close to regional inspection centers. Thus, gas stations in these areas are more likely to be inspected and punished if they commit irregularities.

TABLE 4

INFLUENCE OF THE ADDITIONAL VARIABLES ON THE EFFECT OF A PREVIOUS MONITORING

Compliance	I	II	III
$monitored_{i,t-1}$	0.071***	0.045**	0.003
	(0.020)	(0.018)	(0.009)
$population_t$	0.008***		
	(0.000)		
$monitored_{i,t-1}$ *	-0.003*		
$population_t$	(0.001)		
$sales\ margin_{it}$		0.107***	
		(0.010)	
$monitored_{i,t-1}$ * $sales\ margin_{it}$		-0.016	
		(0.049)	
$price\ variation_t$			-0.437***
			(0.065)
$monitored_{i,t-1}$ * price	0.547***		1.164***
$variation_t$			(0.301)
constant		0.547***	0.581***
	(0.003)	(0.005)	(0.004)
Observations	843,267	278,842	492,719
R _ Squared	0.094	0.082	0.084
$subarea_{it}$	Yes	Yes	Yes
$year_t$	Yes	Yes	Yes
operating	Yes	Yes	Yes
previously monitored	Yes	Yes	Yes

Notes: The coefficients are estimated with the use of a cross-sectional dataset covering the period from 2002 to 2014. The sample includes all gas stations with products collected by the Fuel Quality Monitoring Program (FQMP) during the sampling period. The coefficients are estimated through the ordinary least squares (OLS) method. In columns I to III, the dummy $compliance_{it}$ which indicates the compliance status of samples collected at facility *i*, in month *t*, is regressed on $monitored_{i,t-1}$, which indicates whether facility *i* received a monitoring activity during the period up to one month before the monitoring under analysis. Additionally, the dependent variable is regressed on the variables $population_t$ and $monitored_{i,t-1}$* $population_t$ (column I); $sales\ margin_{it}$ and $monitored_{i,t-1}$* $sales\ margin_{it}$ (column II); and $price\ variation_t$ and $monitored_{i,t-1}$* $price\ variation_{i,t-1}$ (column III). For all columns, controls are used for the year of observation ($year_t$) and the subarea where the gas station is located ($subarea_{it}$). Only samples collected during the period when the establishment was officially in operation (*operating*) were used. Finally, only the observations after the first fuel quality monitoring (*previously monitored*) were considered. Standard errors in parentheses: *** p <0.01, ** p <0.05, * p <0.1.

This result contradicts some studies in Social Sciences, such as Glaeser and Sacerdote (1999) and Oliveira (2005). They postulate that the larger the population, the lower the degree of social interaction in a locality, which favors criminal activity. According to these authors, with more gas stations and consumers, the relationship between seller and buyer would become more ephemeral, reducing the moral cost of an establishment selling fuel that does not comply with quality standards. Other studies, however, such as Guerrero (2012), did not find a statistically relevant correlation between population and probability of violation.

Still maintaining the focus on the analysis of the role of population, column I presents the differential effect of the variable "population" in the causal relationship between previous monitoring and the quality of fuels. The coefficient of the interaction variable $monitored_{i,t-1}$* $population_t$, which is statistically significant at 10%, allows us to infer that the smaller the population of the municipalities, the greater the effect of monitoring on the quality of the fuels collected. This result is predictable since small towns are less likely to receive a public inspection or monitoring agent, considering the smaller number of establishments. Thus, in these unusual moments of contact with a law enforcement agent, the feeling of being watched is fed, which improves the behavior of firms.

In its turn, columns II and III of Table 4 present significant findings for the academic studies about competition. Bennett et al. (2013) claim that competition between companies produces many benefits but can also encourage companies to engage in corrupt or unethical activities. This analysis is shared by Brasil (2015) and Dutra (2014), who confirm that price liberalization in the early 2000s intensified competition between gas stations. However, this increase in competition contributed to Brazil's fuel quality deterioration. The justification is that in municipalities with high competition, the gas stations compensate for the reduction in sale prices with the decrease in fuel quality. This compensation only becomes possible due to the consumer's difficulty to detect fraud.

This empirical research supports the above-mentioned theoretical statement. Column II in Table 4 presents the variable $sales\ margin_{it}$, which consists of the difference between the average purchase price of regular gasoline and its average sale price in a given month for each establishment. Its coefficient demonstrates a positive relationship between the profit margins of individual establishments and fuel quality. In turn, in column III, the variable $price\ variation_t$ presents an index of price variation of regular gasoline for each municipality. It reveals that the lower the coefficient of price variation in the cities, the greater the probability that the fuel will conform to specifications.

Thus, based on the analysis of the coefficients presented in Table 4, it is possible to infer a relationship between anticompetitive practices and fuel quality.

Municipalities with high-profit margins and low coefficient variation in fuel prices are correlated with fuel sales within quality parameters. Therefore, this result imposes a trade-off on the National Agency of Petroleum (ANP) actions. Protecting consumer interests concerning fuel prices can negatively affect fuel quality. In this way, low-quality products may take over the market if the effort to identify and dismantle cartels is not accompanied by more credible enforcement action aimed at curbing the sale of unspecified fuels.

Finally, it also can be seen from column III that the greater the coefficient of price variation, that is, the dispersion of the price of fuel sales in a municipality, the greater the effect of monitoring on the compliance status. This result corroborates the idea that the most competitive market structures (which present high price variation) are more prone to quality deviation. However, enforcement actions in competitive markets have a more significant effect since it conveys to the gas stations the feeling that the regulatory agency is committed to ensuring that commercial disputes occur without the deterioration of fuel quality.

6. Robustness Analysis

Although the findings in this study are consistent with the literature, several robustness tests were designed to prove that all gas stations were randomly selected within each subarea. In other words, that the observed characteristics of gas stations within the treatment and control groups are statistically similar. For robustness-checking purposes, the treatment group is any gas station monitored at t, and previously monitored between $t - x$ and $t - 1$. On the other hand, the control group comprises those who were also monitored at t, but were not monitored between $t - x$ and $t - 1$. Thus, it is possible to segregate the observations between the different groups in the experiment by measuring the time elapsed between any two monitoring activities at the same gas station.

TABLE 5

ROBUSTNESS TEST

Elapsed Time	I	II	III	IV
$compliance_{i,t-w}$	-0.010			
	(0.009)			
$tankage_{it}$		-0.000		
		(0.000)		
sales margin$_t$			0.090	
			(0.071)	
price variation$_t$				-0.567
				(0.526)
constant	3.116***	3.110***	2.949***	2.978***
	(0.025)	(0.025)	(0.037)	(0.036)
Observations	843,322	843,322	278,842	492,719
R _ Squared	0.073	0.073	0.066	0.061
$subarea_{it}$	Yes	Yes	Yes	Yes
$year_t$	Yes	Yes	Yes	Yes
operating	Yes	Yes	Yes	Yes
previously monitored	Yes	Yes	Yes	Yes

Notes: The coefficients are estimated with the use of a cross-sectional dataset covering the period from 2002 to 2014. The sample includes all gas stations with products collected by the Fuel Quality Monitoring Program (FQMP) during the sampling period. The coefficients are estimated through the ordinary least squares (OLS) method. In columns I to IV, the variable *elapsed time*$_{it}$, which indicates the gap period, in months, between the fuel collection at establishment *i*, in month *t*, and the immediately previous collection, is regressed on *price variation*$_t$ the variables $compliance_{i,t-w}$, $tankage_{it}$, *sales margin*$_t$ and , respectively. For all columns, controls are used for the year of observation ($year_t$) and the subarea where the gas station is located ($subarea_{i,t}$). Only samples collected during the period when the establishment was officially in operation (*operating*) were used. Finally, only the observations after the first fuel quality monitoring (*previously monitored*) were considered. Standard errors in parentheses: *** p <0.01, ** p <0.05, * p <0.1.

Table 5 presents a regression of the *elapsed time* between two monitoring activities (previous monitoring and current monitoring, which occurred in *t*) on various explanatory variables that characterize the gas stations and the municipalities they are located in. If ANP's random selection worked well, most of these characteristics would be uncorrelated with the time gap between two monitoring activities.

The first doubt that could be raised about randomization relates to the results obtained in the previous conformity tests. As one of the objectives of the fuel quality monitoring program is to provide subsidies for inspection, it would be rational to imagine that the probability of monitoring a gas station in time *t* increases when a gas station is found selling non-conforming fuels in the previous monitoring activity that happened in the period between $t - w$ and $t - 1$. However, this doubt can be eliminated based on the result presented in Table 5, column I. The relationship between the outcome of the fuel analysis in the previous monitoring and the time elapsed between this last monitoring activity and *t* is not statistically significant at 10%.

Column II tests the possibility that the gas station size interferes with the selection. The idea behind inspecting large establishments is that they offer their service to more consumers, putting more citizens at risk if they sell low-quality fuels. A good measure of the size of a gas station is its underground storage tanks (USTs). Thus, if there were any bias toward large establishments, we would expect to see a negative relationship between tankage and the elapsed time between two monitoring activities. Once again, the measured coefficient is not statistically significant at the 10% level.

In addition, the correlation between price formation and selection was investigated. The idea behind this investigation is that establishments that sell products at lower prices may have lower quality standards. And the lower the selling price, ceteris paribus, the lower the profit margin. Thus, the relationship between sales margin and monitoring would negatively correlate if the monitoring were targeted to low-margin gas stations. In addition, it could be assumed that there would be a greater tendency to deteriorate the quality of fuels in highly competitive markets, which generally have a higher coefficient of price variation. This tendency would happen because traders could reduce the quality of the product to compensate for the great competition, taking advantage of consumers' difficulty in detecting fuel quality. In this case, there would be an inverse correlation between the price variation coefficient and monitoring frequency. Fortunately, columns III and IV show, once again, that the variables are not significantly correlated at the 10% significance level.

The results presented above provide reassurance regarding a possible selection bias, allowing us to state that, controlling for the subarea, the randomization of the sample took place as expected, at random. However, once the concern about selection has been removed, a second question arises: is monitoring a valid instrument for inspection? This question has already been answered because it was proved that the selection of gas stations is carried out entirely at random. Moreover, it has been shown that there is a significant correlation between previous monitoring and subsequent inspection.

However, the parameters found in the instrument specification tests remain to be analyzed. The F statistic for the first stage, reported in Table 3, finally removes any concern regarding the instrument's strength. The regression presents an F-statistic greater than 10 in all columns, suggesting that it is a strong instrument (Stock et al., 2002). Thus, the coefficient of F corroborates the finding that inspections at gas stations have a significant deterrent effect on the sale of fuel that does not comply with the technical specification.

7. Conclusion

This work presents the first experimental analysis of the effect of the monitoring and inspection activities established by the National Agency of Petroleum (ANP) on the fuel market in Brazil. By using advanced econometric techniques and taking advantage of the random nature of the fuel monitoring quality program, it was possible to control the problems that commonly occur in studies that use observational data.

The study outcomes are robust and answer the questions proposed. The Fuel Quality Monitoring and the Inspection Programs effectively reduce the likelihood that a gas station will sell fuel that does not meet specifications. In addition, it was found that the fuel quality monitoring program fulfills its initially designed objective by serving as a source of information for inspection. Furthermore, the study provides empirical evidence that the characteristics of the municipalities where gas stations are established (such as population and price variation) interfere with individual behavior.

The differential effects produced by the variables price variation and population are also worth noting. When interacting with the previous monitoring, these variables could change the impact of the last tracking on current control activities. These results corroborate the recent literature on behavioral economics (Liu et al., 2018; Oliveira, 2005; Brock & Durlauf, 2001; Glaeser et al., 1996), which states that individual behavior is conditioned by the typical behavior of the population to which this individual belongs.

It was also found that the monitoring effect is heterogeneous and depends on the gas station's compliance status at the previous inspection. That is, the monitoring impact is only positive for those facilities that already were compliant. This fact suggests that firms have different degrees of commitment to compliance. Thus, for those establishments with an unfavorable history, it is essential to apply forceful enforcement actions to ensure compliance with the laws, reinforcing the idea of responsive regulation (Braithwaite, 2006).

Furthermore, the methodological rigor used in this study and the robustness with which the results are presented open some room for the practical interpretation of the coefficients in terms of public policy formulation. The evidence that alternative policies of coercion and deterrence (Stafford, 2012; Guerrero, 2012; Ferraz & Finan, 2008; Stafford, 2006) effectively achieve their objectives is of exceptional interest in a recurring context of public expenditures' contingency. In these situations, the need to identify and implement effective monitoring and enforcement policies that, in fact, reduce regulatory violations is highly emphasized.

Finally, this article presents a theme still underdeveloped in the literature related to environmental inspection. Most environmental studies discuss the

impact of monitoring on pollutant emissions carried out by industrial firms (Magat & Viscusi, 1990; Epple & Visscher, 1984). However, the present study involves a new theme of environmental monitoring, the right to access fuels with low polluting potential, and the role of the State in guiding society toward environmental development.

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ANNEX

TABLE A-1

STATISTICAL SUMMARY OF THE VARIABLES PRESENTED IN TABLE 1

Variable	Obs.	Mean	S.D.	Min.	Max.
compliance	905,395	0.6289575	0.4830841	0	1
monitored (t-1)	859,996	0.023392	0.151145	0	1
monitored (t-3)	859,996	0.3139247	0.4640865	0	1
monitored (t-6)	859,996	0.8105898	0.3918343	0	1
compliance (t-w)	859,996	0.6306436	0.4826308	0	1
monitored (t-1) compliance (t-w)*	859,996	0.0154408	0.1232979	0	1
monitored (t-3) compliance (t-w)*	859,996	0.1994788	0.3996088	0	1
monitored (t-6) compliance (t-w)*	859,996	0.5083268	0.499931	0	1
subarea	905,395	33651.34	8125.014	11,001	53,013
year	8,784,672	2008	3.741658	2,002	2,014
operating	8,784,672	0.5801009	0.4935422	0	1
previously monitored	4,705,005	1	0	1	1

TABLE A-2

STATISTICAL SUMMARY OF THE VARIABLES PRESENTED IN TABLE 2

Variable	Obs.	Mean	S.D.	Min.	Max.
Inspected	8,784,672	0.017298	0.1303793	0	1
monitored (t-1)	4,946,938	0.1779323	0.3824558	0	1
monitored (t-3)	4,946,938	0.487878	0.4998531	0	1
monitored (t-6)	4,946,938	0.7100972	0.4537171	0	1
compliance (t-w)	4,946,938	0.6257887	0.4839186	0	1
*monitored (t-1) * compliance (t-w)*	4,946,938	0.1117611	0.3150723	0	1
*monitored (t-3) * compliance (t-w)*	4,946,938	0.3046202	0.4602464	0	1
*monitored (t-6) * compliance (t-w)*	4,946,938	0.4452482	0.4969932	0	1
Subarea	905,395	33651.34	8125.014	11,001	53,013
Year	8,784,672	2008	3.741658	2,002	2,014
operating	8,784,672	0.5801009	0.4935422	0	1

TABLE A-3

STATISTICAL SUMMARY OF THE VARIABLES PRESENTED IN TABLE 3

Variable	Obs.	Mean	S.D.	Min.	Max.
compliance	905,395	0.6289575	0.4830841	0	1
inspected (t-1)	551,930	0.0537894	0.2256019	0	1
inspected (t-3)	551,930	0.1502691	0.3573353	0	1
inspected (t-6)	551,930	0.2667186	0.4422444	0	1
compliance (t-w)	544,603	0.6297009	0.4828852	0	1
monitored (t-4)	859,996	0.070184	0.2554571	0	1
monitored (t-6)	859,996	0.199123	0.399341	0	1
monitored (t-12)	859,996	0.2473558	0.4314755	0	1
monitored (t-4) compliance (t-w)*	544,603	0.0720506	0.258572	0	1
monitored (t-6) compliance (t-w)*	542,935	0.1966405	0.3974585	0	1
monitored (t-12) compliance (t-w)*	539,484	0.2445856	0.4298416	0	1
subarea	905,395	33651.34	8125.014	11,001	53,013
year	8,784,672	2008	3.741658	2,002	2,014
operating	8,784,672	0.5801009	0.4935422	0	1
previously monitored	4,705,005	1	0	1	1
previously inspected	2,197,592	1	0	1	1

TABLE A-4

STATISTICAL SUMMARY OF THE VARIABLES PRESENTED IN TABLE 4 AND TABLE 5

Variable	Obs.	Mean	S.D.	Min.	Max.
compliance	905,395	0.6289575	0.4830841	0	1
monitored (t-1)	859,996	0.023392	0.151145	0	1
population	8,783,112	917277.2	2510456	804	11,900,000
sales margin	1,394,694	0.3385741	0.1176285	-0.41	1.619
price variation	4,787,367	0.0262658	0.0148485	0	0.1709387
*monitored (t-1) * population*	859,928	20413.84	376431.3	0	11,900,000
*monitored (t-1) * price variation*	282,749	0.0083427	0.0561478	-0.035	0.857
*monitored (t-1) * price variation*	502,054	0.0006632	0.0046978	0	0.1055383
elapsed time	859,996	4.128644	4.07536	0	153
compliance (t-w)	859,996	0.6306436	0.4826308	0	1
Tankage	8,784,672	213.9416	3525.763	0	210,000
Subarea	905,395	33651.34	8125.014	11,001	53,013
Year	8,784,672	2008	3.741658	2,002	2,014
Operating	8,784,672	0.5801009	0.4935422	0	1
previously monitored	4,705,005	1	0	1	1