UNIVERSITAT DE BARCELONA

Essays on Public Policies in Mexico: Pollution, Employment and Drug Crime

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PhD in Economics

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Essays on Public Policies in Mexico: Pollution, Employment and Drug Crime

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Advisor:

Germà Bel

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LIBERTAS PERFVNDET · OMNIA LVCE

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To my parents, Suzanne & Hans-Peter

Without evidence, we risk making decisions in the dark

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A PhD program is not a short sprint but rather like a long marathon. As we race towards ever more ambitious goals, having a good support network becomes vital for reaching those goals. The first section is dedicated to recognizing all the people that were a part of my PhD journey both inside and outside of the university walls.

Embarking on a PhD is a major challenge. PhD students go through an emotional rollercoaster. On this rollercoaster students face moments of excitement and motivation such as when a paper is accepted for publication or when our models work the way we intend them to. But that same rollercoaster has phases which confront students with moments of difficulties, such as, problems with our research, inconclusive results or uncertainty about the future after obtaining the PhD title.

During the program, PhD students are faced with a challenging environment in which they must produce original research papers. Such research also needs to have relevant contributions to their respective research fields, otherwise, 'what's the point?'. Such expectations can be testing at times. For that reason, having a good supervisor is essential. In my case, my supervisor was not only good, but he was great. And for that I would like to express my most sincere gratitude to my mentor on this journey: Germà Bel.

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Contents

Chapter 1

Introduction

1. Evaluation of Public Policies

For centuries, policy makers implemented public policies without any evidence that their programs would work. In general, little thought was given to the potential adverse effects of such policies and whether the results sought could be achieved more efficiently by other means. However, government representatives, funding agencies and the general public have begun to question whether their interventions actually achieve the desired goals (Gaarder and Briceño, 2010). The electorate, who in casting their vote implicitly expect elected officials to act in their interests, have begun to question whether their taxes are being well spent. In recent decades, public policy has come under greater scrutiny and the results of the evaluations conducted are now instrumental in shaping the political agenda.

Public policies can be defined as formal decisions or plans of action that have been undertaken by, or which involve, a state entity, e.g. a ministry or a state government (adapted from Richards and Smith, 2002). They often make up programs with specific goals that have been formalized in government documents. Ideally, subsequent policy evaluations are also "an integral part of the policy making process, in which policy formulation and evaluation are linked in an iterative process of policy evolution" (Bachtler et al., 2000, p.43).

With the increasing availability of data and broadening access to government data bases, applied economists have begun to look at other disciplines and have adopted causal evaluation methods that go beyond mere correlations. Some of these techniques, e.g. differences-in-differences or regression discontinuity designs, provide accurate impact evaluations and have become standard tools for empirical researchers. Technological advances have also contributed to this development and as computing power continues to increase, new methods are emerging for the analysis of big data.

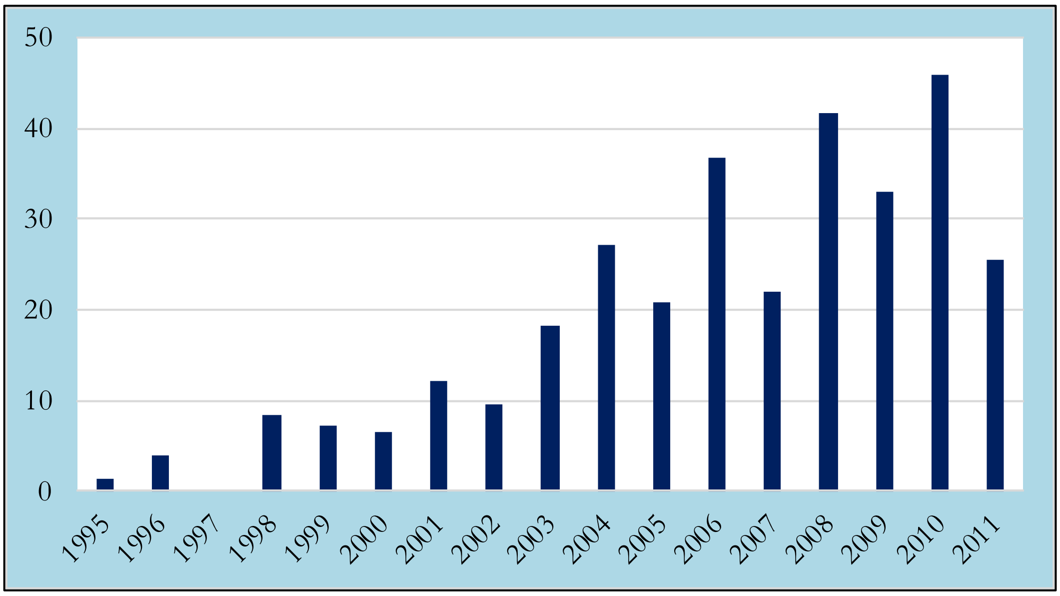
Specific policy evaluation studies, such as those presented in the chapters making up this thesis, analyze "whether the changes in well-being are indeed due to the program intervention and not to other factors" (Khandker et al., 2010, p. 7). To do so, most evaluation approaches rely on quantitative methods of analysis that consider periods before and after a policy or a program are introduced.

Policy analysis began in the late nineteenth century with a movement led by Woodrow Wilson, a Princeton scholar and U.S. President. The aim of this movement was to achieve positive net benefits from the implementation of government policies. However, it was not until the 1960s that policy analysis became a regular method for determining the effectiveness of US government programs (Bellinger, 2015). The good case practice of analyzing the effectiveness of government programs subsequently found recognition beyond U.S. borders and started to be adopted in many countries.

In Europe, policy evaluations have become an important element of policy culture at both national and regional levels. In the UK, Germany, Sweden and the Netherlands, there is an established tradition (dating back to the 1970s) of evaluating the effectiveness and efficiency of policies across different levels of government (Bachtler et al., 2000). According to Bel (2018), the countries of Northern Europe have followed an Aristotelian line of reasoning in the sense that "experience, the observation of nature, is the base upon which we build our ideas". As such, these countries have preferred to rely on the evidence derived from policy analyses rather than satisfying themselves with the simple intentions of policy makers. With the creation of the European Union and the requirements introduced by the European Structural Fund, other member countries have begun to evaluate policies in order to comply with established norms so that today the culture of policy evaluation has set down roots in most countries of Europe.

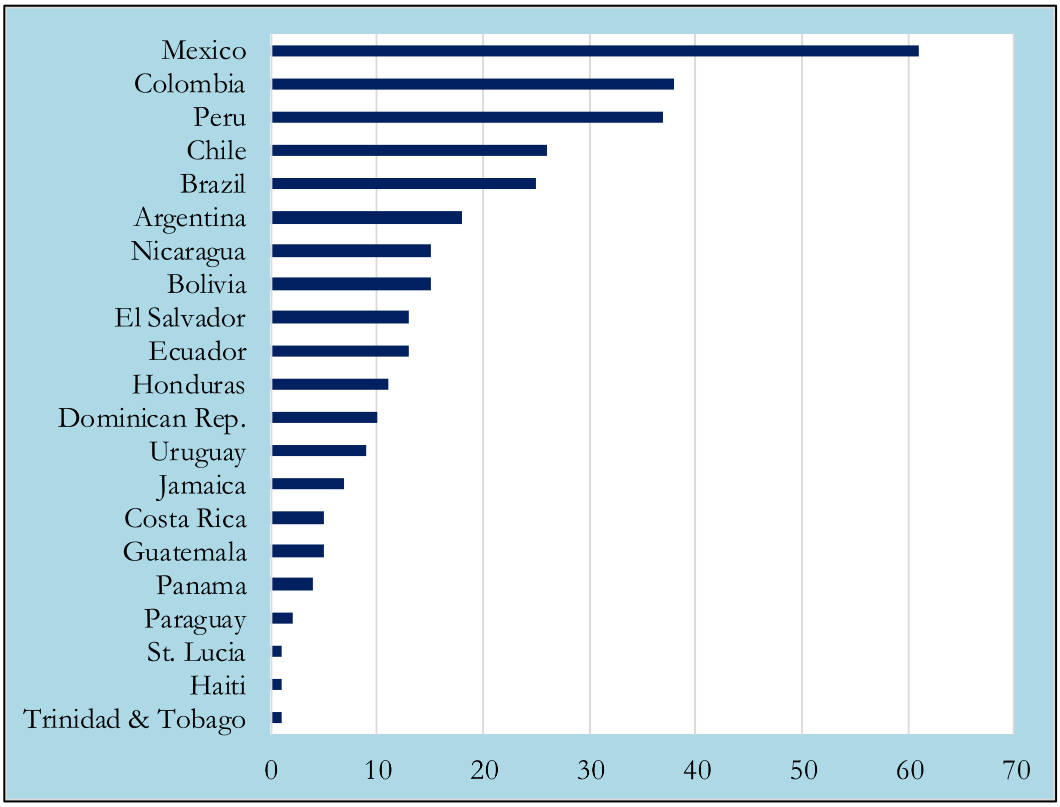
As Alzúa et al. (2013) report, impact evaluations have also found acceptance in Latin America with an increasing number of evaluations being conducted each year (see Figure 1.1). However, as Figure 1.2 shows, most policy evaluations using causal techniques have been concentrated in just a few countries: Mexico, Colombia, Chile, Brazil, Argentina, and Peru. Alzúa et al. (2013) highlight that most of these impact evaluations have been undertaken on social protection policies, followed by education, microfinance and active labor market policies.

Figure 1.1: Number of Impact Evaluations in Latin America, 1995-2011



Source: Based on data from Alzúa et al. (2013).

Figure 1.2: Number of Policy Evaluations by country during 1995-2011



Source: Based on data from Alzúa et al. (2013).

The role of public policy analyses and impact evaluations has grown in relevance in the 21st century. Having realized the importance of analyzing the efficacy and efficiency of government programs, developing countries have increased the number of evaluations they conduct, as they catch up in this regard with their more developed counterparts. However, the institutions that evaluate policies are still very much in the process of being created. For this reason, academic policy evaluations, such as those presented in the chapters making up this dissertation, remain of vital importance.

2. Why Public Policies in Mexico?

Mexico is a 1.23 trillion USD[1] economy with a population of 124 million people in 2016. According to data from the World Bank, the size of Mexico's economy (at constant U.S. Dollar and at purchasing power parity), places it 15th in the world rankings, just behind Spain, Australia and South Korea and ahead of such countries as Turkey, Indonesia and the Netherlands. Mexico has a privileged geographical location, lying south of the world's largest economy, and it enjoys access to both the Atlantic and Pacific oceans, providing it with excellent trading conditions. The country also has abundant natural resources, which are important for tourism, agricultural production, and oil and natural gas extraction.

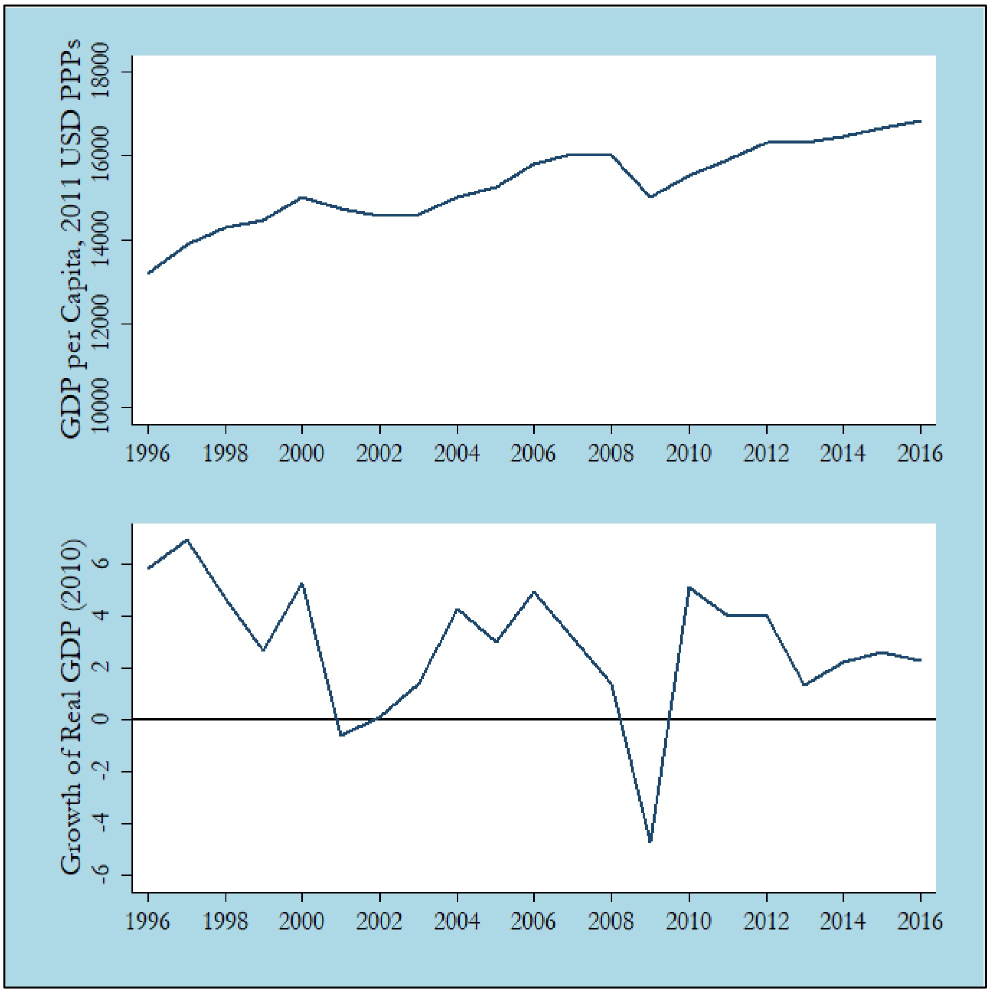
The country's economy is dominated by services (63.4% share), but its industrial sector remains important (32.2%) (CIA, 2017). After joining NAFTA, the Mexican manufacturing industries initiated a period of intense growth. Today, Mexico and Brazil are considered the two main economic engines of Latin America. Mexico has also been a member of the OECD since 1994.

Mexico ranks as the 13th largest exporting nation in the world. The country has taken advantage of its privileged geographical location and signed ten free-trade agreements with 45 countries (90% of its trade). It is also a member of the Trans-Pacific Partnership Agreement (TPP). Via these agreements, Mexico has access to a potential market of over one billion consumers and 60% of the world's GDP. Mexico's most important trading partner is the U.S., capturing around 81% of Mexican exports, followed by Canada (2.8%), China (1.4%) and Germany (1.1%).

[1] 2010 constant U.S. Dollar at Purchasing Power Parity

Over the years, Mexico has received praise for the reforms it has implemented, although key areas for further development, most notably security, remain (Friedman, 2016). For example, *The Economist* (2012) highlights Mexico's importance as a trading partner for the U.S., while drawing attention to continuing problems of security and violence in many areas of the country. Mexican industry has experienced significant growth and many car manufacturers have chosen the country as a location for their assembly plants (Economist, 2015). According to Goldman Sachs (2007), Mexico "appears to have both the potential and conditions to rival the current major economies". Given these economic trends and recent economic reforms, the professional services firm PWC expects Mexico to be among the 'Top 10' economies by 2050 (Hawksworth et al., 2017).

Figure 1.3: Evolution of Mexican GDP per capita (2010 at PPP) and real GDP growth, 1996-2016



Source: Based on data from the World Bank.

As Figure 1.3 shows, Mexico presents a positive trend in its GDP per capita. However, it also highlights the fact that the financial crisis of 2008-2009 led to a major economic setback. Although recovery was quick, various problems accentuated by the crisis remain: low wages, high underemployment, increased poverty and inequitable income distribution.

Despite the positive signs, Mexico remains a developing country with high poverty rates and low wages. In terms of poverty, the World Bank reports that Mexico has 3.8 million people living below the international poverty line, 1.90 USD per day, and around 15 million people living on 3.20 USD per day (figures in 2011 USD at PPP). In terms of inequality, the country has a Gini Index of 0.482 and the income share held by the highest 20% is about 53.5% (CIA, 2017).

Developing countries, inevitably, face similar problems and often share the economic characteristics presented by Mexico. However, it is these features that make Mexico such an interesting country in which to conduct public policy analyses and the Mexican case can also offer solutions to the problems that afflict other countries. The specific context in which the policies analyzed in this thesis have been implemented is the following:

1. Mexico City is one of the world's mega cities with an estimated population of about 20 million people in its metropolitan area (2010). Gentrification, and the fast pace at which the city is growing, means people have to commute over considerable distances each day and spend a considerable amount of time in doing so. The city has serious congestion problems exacerbating air pollution in the urban area. Congestion in the city is caused by the enormous number of private cars, a deteriorating fleet of public buses and the absence of any effective regulations. High pollution levels in major urban areas can affect the health of the inhabitants and can be hazardous, especially for children, the weak and the elderly. Survey reports show that 10.8% of urban inhabitants would be willing to switch from private to public transportation if public transportation was better (in terms of quality and availability) and 10.2% would consider a modal change if fuel prices continue to rise (CESOP, 2017a).

2. Mexico has also become a major drug-producing and transit nation. Estimated to be the world's third largest producer of opium and

marihuana, Mexico constitutes the main supply route for illicit drugs being transported from South America to the US (CIA, 2017). Major drug cartels, generically referred to as drug trafficking organizations (DTOs) control drug production, transport and distribution. At the end of 2006/beginning of 2007, the government sent federal police forces, the navy and the military to crack down on these drug criminals. Since then, the country has seen a marked rise in crime rates, including homicides, kidnappings, and robberies. DTOs have infiltrated local police forces and corrupted local and, on occasions, state politicians. Despite this wave of violence, Mexicans continue to believe (CESOP, 2016) that the navy and the military are among the most trusted government institutions, while most citizens express their approval of the continued use of military and navy forces to fight DTOs.

3. Minimum wages in Mexico have decreased in real terms over decades reaching a level at which these workers are unable to afford a minimum basket. Indeed, between 1980 and 2014, the value of the real minimum wage was eroded by almost 70%, leaving them considerably worse off. Not only is Mexico's minimum wage the lowest in the OECD, it is also the lowest among Latin American countries (Moreno-Brid, 2014). According to the Mexican Statistics Institute (INEGI), in 2015 about 7 million workers earned up to one minimum wage (about 0.90 USD per hour), and 13 million earned between one and two minimum wages. Moreover, Mexico, like many other developing countries has a split labor market, divided into formal and informal labor. The share of informal labor has been reported to reach up to 60%. CESOP (2017b) reports that 96% of citizens surveyed consider a minimum wage as being insufficient to live on, while 68% think it should be raised.

Mexico plays an important role in the world economy and expectations regarding its development are high. Conditions in the country with regard to transport, violence and wages, and the features it has in common with other developing countries, mean it is especially interesting to analyze the policies being implemented in Mexico.

3. Institutions and Policy Analysis in Mexico

As discussed, several Latin American countries have undertaken impact evaluations of the policies they implement. Indeed, institutions often perform different evaluations of the same policy but at different stages, e.g. a process evaluation and an impact evaluation (CAF, 2015, p.198).

As Jacob et al. (2015) explain, the degree of institutionalization of policy evaluation varies greatly across countries. However, these authors speak of the benefits of an evaluation culture that can foster openness, transparency and accountability among political actors and bureaucrats. Likewise, Julio Frenk, the former Mexican Health Minister, has highlighted the importance of an evaluation culture: "Both politically, in terms of being accountable to those who fund the system, and also ethically, in terms of making sure that you make the best use possible of available resources, evaluation is absolutely critical" (Oxman et al., 2010, p. 427).

Mexico's central government has extensive experience in public policy planning. The 1982 Planning Law (*Ley de Planeación*) requires that national objectives be outlined and its priorities be defined. The weakest feature of Mexico's policy planning scheme lies in the operative area, i.e. while national objectives are well defined, it is not clear how they should be achieved. While sectoral planning is usually determined for an administrative period, no annual objectives are fixed (García-López and García Moreno, 2010).

The strengths of Mexico's policy making lie in the fields of financial management, auditing and procurement, while the country's planning, monitoring and evaluation stages employ sound methodologies. However, planning and budgeting stages are not well coordinated with monitoring and evaluation stages. The weakest area is that of budget allocation based on the results and the efficacy of the policies implemented (García-López and García Moreno, 2010).

For some years now, Mexico has been engaged in a process of institutional construction that has facilitated good policy analysis. Created in 1983, the National Institute of Statistics and Geography (*Instituto Nacional de Estadística y Geografía,* INEGI) has been responsible for generating official statistics and in 2008 it became autonomous from the government.

In the early 2000s, during the presidency of Vicente Fox, a new information transparency law was passed. This law led to the creation of

Mexico's Freedom of Information Institute (*Instituto Federal de Acceso a la Información*, IFAI, later rebranded as INAI). Anybody can request information and data (assuming they exist) from this institution about all government offices. Later, in 2007, access to government information became a fundamental right for all Mexicans and was anchored in the constitution.

Mexico has a relatively short tradition of analyzing public policies compared to the longer experience of the U.S. and various European countries. While most policy analyses have been made at universities, the Mexican government has recognized the importance of independent evaluations of the efficacy of public interventions. In 2004, the General Social Development Law was passed, which recognized the need to "establish mechanisms for evaluation and monitoring of the programs and actions of national social development policies" (Article 1, Point VIII, General Social Development Law 2004).

With this law, the National Council for the Evaluation of Social Development Policies (*Consejo Nacional de Evaluación de la Política de Desarrollo Social,* CONEVAL) was created in 2004. Although this institution is coordinated by the Ministry of Social Development (*Sectretaría de Desarrollo Social,* SEDESOL), it reports to an executive board of independent academics and is responsible for the measurement of poverty, providing multidimensional analyses (Gaarder and Briceño, 2010). This multidimensional focus for policy evaluation covers all of the following stages: design, strategic planning, operation, coverage and targeting, perception of beneficiaries and results (CAF, 2015, p.198). The role of CONEVAL, however, is restricted to social development polices only.

More recently in 2015, the Center for Research and Teaching in Economics (*Centro de Investigación y Docencia Económicas,* CIDE), together with the National Council for Science and Technology (*Consejo Nacional de Ciencia y Tecnología,* CONACYT), founded the National Public Policy Laboratory (*Laboratorio Nacional de Políticas Públicas*, LNPP). This institution has been set up to simulate policy interventions and help in the evaluation of policies implemented in different parts of the country.

The creation of institutions to evaluate policies in Mexico is cause for optimism. However, the policy areas subject to such evaluation need to be widened beyond that of social programs. Indeed, there is still a marked absence of policy evaluations in fields beyond that of social development. In the hope of going some way to rectify this, the present dissertation undertakes an analysis of three different policies implemented in Mexico in the first years of the 21st century.

4. Dissertation Structure

This dissertation undertakes the analysis, in three separate chapters, of three specific public policies implemented in Mexico. Specifically, it comprises: (1) an impact evaluation of the introduction of the first bus rapid transit route on air pollution in Mexico City; (2) an assessment of the effects of the Mexican 'Drug War' on state economic growth; and (3) an analysis of how a territorial policy change in minimum wages affected employment in certain Mexican regions. The objective is to analyze each of these policies individually using modern econometric techniques and to determine the effects and consequences of these policies.

In chapter two, I analyze the introduction of the first route of the bus rapid transit (BRT) network in Mexico City in 2005. Given the congestion and pollution problems the city faced, the government introduced the BRT – naming it Metrobus – in an attempt to reduce congestion on one of the most heavily congested roads in the city. The impact of BRT on air pollution is believed to be positive, given the results of analyses that provide side-by-side comparisons of the old buses and new BRT units. However, these studies fail to consider the replacement effects of old buses and do not study specific pollutants at the molecular level. For this analysis, I use data from automatic air quality monitoring stations distributed across the metropolitan area and complement these with information from INEGI, the city's water systems commission CONAGUA, and the atmospheric monitoring network. The differences-in-differences approach I use for the analysis assigns monitoring stations into treatment and control groups based on their distance from the BRT corridor. The results show that the introduction of the BRT reduced the concentration of three out of the four pollutants analyzed: carbon monoxide (CO), nitrogen oxides (NO_x) and airborne particulate matter with aerodynamic diameter of 10 μm (PM_{10}). The results also show themselves to be robust to the use of a regression discontinuity design.

This chapter has been published as *Evaluation of the impact of Bus Rapid Transit on air pollution in Mexico City* in Transport Policy, 63, pp. 209-220.

In chapter three, I assess the economic effects of the policy commonly known as the Mexican 'Drug War' implemented by the federal government. The policy aimed at cracking down on the activities of drug trafficking organizations (DTOs) by employing the military, the navy and federal police forces. The effect of the public expenditure shock, in the form of an aggressive confrontation with the DTOs, had unintended consequences. The capture of high ranking drug lords upset the power equilibrium between the DTOs and a war broke out between drug cartels. This war, together with the battle waged with government forces, led to many casualties (with many civilians being caught in the cross-fire). To exacerbate matters, the DTOs diversified their criminal operations and became involved in kidnappings, extortion rackets, robberies, etc. Government policy, which involved increased military expenditure, as well as the unexpected increase in violence and crime, may have had unintentional effects on the economy that, to date, have not been explored in the literature. Using state-level data from INEGI and other sources, including the government's budget figures, I employ a dynamic panel data regression to analyze the effects that crime variables and military budgets had on state economic growth. The results show that crime had significant negative effects on economic growth, while military budgets show positive effects.

In chapter four, I investigate the employment effects of the 2012 minimum wage territorial policy change that reduced the number of minimum wage areas from three to just two. The minimum wage in the area that disappeared was increased to be on a par with that fixed for the area with the highest minimum wage. For my analysis, I use data from the INEGI's labor survey ENOE. The differences-in-differences analysis shows a negative and significant impact on employment. When disentangling formal and informal labor, the negative effects of the policy are apparent on formal employment but not on informal labor. The analysis also points to a marked impact of the minimum wage increase on male workers. Female workers, however, appear unaffected. For many years, the government has been undecided as to whether to increase minimum wages above inflation, fearing, among other effects, the consequences for employment. This chapter provides information to policy makers regarding how additional minimum wage increases are likely to affect employment in the short run.

The research reported here aims to obtain sufficient evidence of the impact of these three policies so that policy makers can be better informed of their consequences. The results presented in chapters two to four should also provide insights to other developing countries with similar economic characteristics and with similar problems to those in Mexico.

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Chapter 2

Evaluation of the Impact of Bus Rapid Transit on Air Pollution in Mexico City

Abstract

Mexico City's bus rapid transit (BRT) network, Metrobus, was introduced in an attempt to reduce congestion, increase city transport efficiency and cut air polluting emissions. In June 2005, the first BRT line in the metropolitan area began service. We use the differences-in-differences technique to make the first quantitative assessment of the policy impact of a BRT system on air polluting emissions. The air pollutants considered are carbon monoxide (CO), nitrogen oxides (NO_X), particulate matter of less than 10 μm (PM_{10}), and sulfur dioxide (SO_2). The ex-post analysis uses real field data from air quality monitoring stations for periods before and after BRT implementation. Results show that BRT constitutes an effective environmental policy, reducing emissions of CO, NO_X, and PM_{10}.

Keywords: Bus Rapid Transit, Differences-in-Differences, Environmental Policy Evaluation, Public Transport, Urban Air Pollution

JEL Codes: Q51, Q58, R41, R48

1. Introduction

In the literature of environmental and transport economics, road transport is widely considered one of the main sources of air pollution. More specifically, a large fraction of GHG emissions and air pollutants are recognized as being derived from road traffic: "In 2004, transport accounted for almost a quarter of carbon dioxide (CO_2) emissions from global energy use. Three-quarters of transport-related emissions are from road traffic" (Woodcock et al., 2009, p. 2).

The source of emissions coming from road transport is different depending on the area. While freight transport is an important source of polluting emissions in interurban areas, private vehicles are considered one of the main sources of emissions in urban areas. Moreover, pollution levels are particularly high in urban areas that suffer severe levels of traffic congestion such as the metropolitan area of Mexico City. Conventional road transport in metropolitan areas produces a series of pollutant emissions, which in high concentrations represent a hazard for the inhabitants. The most usual pollutants are particulate matter of different size fractions (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_X), and carbon dioxide (CO_2).

Urban road transit can be broken down into different sectors, with one of the most relevant being that of public transport. Urban buses emit relatively high levels of CO, NO_X, PM_{10}, and CO_2. However, due to the use of cleaner, better quality fuels and to stricter regulations on road traffic emissions, the net air quality impact of buses can be positive if vehicles are replaced periodically. This is particularly true if cities adopt electric vehicles and this energy is generated from renewable sources.

Public transport systems, such as subways and light rail networks, are emission friendly transport options (compared to private combustion engine vehicles) that are able to transport huge numbers of people on daily basis. The downside of these modes of transportation, however, is the enormous initial investment they require, the rigidity of their services and the GHG emissions generated by their electricity source. Most governments operate under considerable budget constraints so that building or expanding local public transport infrastructure requires massive investment, while construction is not always feasible owing to the nature of the local geography.

In the last few decades, governments have sought alternatives that are similarly effective but at the same time more affordable. One such option is the

Bus Rapid Transit (BRT) system, a high-quality bus service with a similar performance to that of a subway, but provided at a fraction of the construction cost (Cervero, 1998). Many countries around the world such as Brazil, China, South Africa and Turkey have adopted BRT systems. The main factors in their favor are the low initial investment costs (especially compared to a subway line), low maintenance costs, operating flexibility, and the fact that they provide a rapid, reliable service (Deng and Nelson, 2011). If a BRT line is unable to capture the projected transport demand, or if the usual route is under maintenance, the line can easily be rerouted.

The literature addressing the impact of BRT on air quality does not quantify the reduction in concentrations of the different pollutants. Most assessments are qualitative studies, computational simulations or take the form cost-benefit analyses that fail to provide details about individual pollutant levels. Our research seeks to address this gap in the literature. We study the impact of the BRT introduction in the Mexico City Metropolitan Area on the concentration of different air pollutants. The contributions of this paper are, as such, easily identifiable: a) to provide a rigorous quantification of the short-term impact on air quality of the introduction of a BRT network in the Metropolitan Area of Mexico City; b) to add to the few analyses to date that employ actual field data in their evaluations of public transport policy; and c) to employ the econometric-based method of differences-in-differences to analyze the environmental impact of a public transportation system like BRT.

2. Related Literature

2.1 Studies on Polluting Emission Reductions

Several studies have examined the impact of pollutants and report the potential effects for health. PM_{10} and $PM_{2.5}$ have been linked with a decrease in respiratory capacity, aggravating asthmatic conditions, and with severe heart and lung damage (WHO, 2001). Nitrogen oxides (NO_X) affect the respiratory system, Sulfur dioxide (SO_2) can worsen respiratory or cardiovascular diseases, and carbon monoxide (CO) is poisonous and in high concentrations can lead to unconsciousness and even death (Neidell, 2004; Schlenker and Walker, 2011). The effects of alleviating traffic congestion on infant health are analyzed in Currie and Walker (2011), who show that a reduction in congestion increases the health and development of infants (see also Kampa and Castanas, 2008; Wilhelm et al., 2008; and Lleras-Muney, 2010).

Many governments have introduced policies to reduce the emissions generated by their mobility services. Building up and expanding public transport infrastructure is a common strategy undertaken to reduce travel times, road congestion and polluting emissions. The study by Chen and Whalley (2012) looks at the introduction of Urban Rail Transit – the Metro – in Taipei and finds a reduction of between 5 and 15% in CO emissions. Topalovic et al. (2012) analyses the case of Hamilton in the US and points out that Light Rail Transit reduces emissions by displacing automobiles to alternative roads. An emission comparison between different transport modes, such as LRT and automobiles, is done by Shapiro et al. (2002), showing the benefits of public transport opposite to private car use. Similarly, Puchalsky (2005) also estimates lower emissions coming from electric forms of urban transport (LRT) compared to combustion engines such as the ones used by BRT units.

An alternative policy for abating emissions from road traffic is the introduction of maximum speed limits on highways or in certain metropolitan areas. Many studies have examined the impact of such policies by employing a vast range of analytical techniques. In this way, we find Gonçalves et al. (2008), who report modest reductions of polluting emissions in Barcelona; Keuken at al. (2010), who find a substantial reduction in polluting levels in the Netherlands; and, Keller at al. (2008), who estimate a 4% reduction in NO_X due to this policy in Switzerland. An alternative way of evaluating the impact of a policy on pollution levels is to measure the effect ex-post using field data. However, few studies of this type have been reported to date. Exceptions include Bel and Rosell (2013) and Bel et al. (2015) on the impact of an 80km/h speed limit and a variable speed limit policy in the metro-area of Barcelona. They report that a variable speed limit was much more effective, reducing NO_X and PM_{10} emissions by 7.7–17.1% and 14.5–17.3% respectively. This suggests that reducing congestion (for which variable speed limit is a useful tool) is more effective than enforcing a fixed maximum speed limit. Another study that uses field data is that by Van Benthem (2015), who analyses speed limits on the U.S. West Coast highways, and concludes that the optimal speed, considering costs and benefits, is about 88km/h (55 mph) and that increasing the speed would increase CO, NO_X, and O_2 levels.

2.2 Bus Rapid Transit and Air Pollution

Bus Rapid Transit –BRT– is a relatively new mode of public transportation that has found broad acceptance in developing countries since the early 1990s. By the end of 2016, 207 cities around the world had adopted some form of BRT. We find prominent examples in Bogotá, Curitiba, Guangzhou, Jakarta, and Istanbul. Latin America is seen as the epicenter of the global BRT movement (Cervero, 2013) with over 60 cities using BRT, moving about 20 million people each day; that is, 62% of the global demand for BRT services. Above all, cities in Brazil (34), Mexico (12) and Colombia (7) have led the rapid growth of BRT networks in the region. BRT has also developed in Europe and the U.S. Over 50 cities in Europe provide this service to an average of 2 million people daily. BRT systems exist in 18 cities in the US, transporting an average of almost half a million people daily (see http://brtdata.org/) for figures and statistics on BRT cities.

A key feature of BRT is that it acts not only as a transport policy, but also forms part of a country's environmental policy. In this latter regard, it needs to be borne in mind that old buses are being replaced by modern vehicles run on cleaner fuels, while the introduction of BRT lines should also reduce congestion. According to Cervero (2013, p. 19), BRT is 'likely' to have net benefits regarding emissions: "BRT generally emits less carbon dioxide than LRT [light rail train] vehicles due to the use of cleaner fuels". Cervero and Murakami (2010) consider that attracting former motorists to BRT can reduce vehicle kilometers traveled and thus polluting emissions. In addition, Bubeck et al. (2014) suggest that a better integrated public transport system would attract higher passenger volumes resulting in lower emissions.

The reduction in emission levels thanks to the introduction of BRT systems is noticeable. In Bogotá's TransMilenio, Hidalgo et al. (2013) estimate health-cost savings from reduced emissions following the completion of TransMilenio's first two phases at US$114 million over a 20-year period, based on a rough computation of data. They calculate that about 8% of total benefits can be attributed to air pollution and traffic accident savings (reductions in associated illnesses and deaths). However, the authors do not use real field data to quantify the pollution-reduction benefits. After the implementation of TransMilenio, the government of Bogotá reported a reduction of 43% in SO2 emissions, a reduction of 18% in NOx, and a 12% decline in particulate matter (Turner et. al. 2012). Indeed, in Bogotá, the buses displaced by the BRT were reallocated to the urban edge and smaller surrounding townships, leading

Echeverry et al. (2005) to argue that BRT may not have reduced the problem of polluting emissions but simply displaced it to other areas.

A study attempting to directly measure the air pollution impact of BRT is the one by Salehi et al. (2016), in which the authors study the development of different pollutants before and after the introduction of a BRT corridor in Tehran. Their measurements show a reduction of 5.8% for PM_{10}, 6.7% for CO, 6.7% for NO_x and 12.5% for SO_2. Their approach however does not consider the existence of a counterfactual, which would give their estimations broader validity. Using data from five air quality measuring stations during the time of the BRT introduction in Jakarta, Budi-Nugroho, et al. (2011) find a reduction of PM_{10} and Ozone levels and argue that this decline is linked to the modal shift of commuters from private modes of transport to the BRT. By comparing polluting emissions from light rail trains and BRT in the UK, Hodgson et al. (2013) find that BRT produces lower PM_{10} emissions, but higher NO_x emissions.

The analysis of historical trends of energy demand, air pollutants and GHG emissions attributable to passenger vehicles commuting in Mexico City's metro-area done by Chávez-Baeza and Sheinbaum-Pardo (2014), reported that the primary sources of small particle matter are road passenger transport vehicles. According to in-vehicle measurements by Shiohara et al. (2005), carcinogenic risks caused by micro-buses were much higher than those caused by buses and the metro. In a related study, Gómez-Perales et al. (2004) measured (in-vehicle) commuters' exposure to $PM_{2.5}$, CO and benzene in micro-buses, buses and the metro in Mexico City during morning and evening rush hours. They reported that pollution levels inside the micro-bus units presented the highest concentrations for all the pollutants during rush hours. Wöhrnschimmel et al. (2008) compared micro-bus, regular bus and BRT unit emissions in Mexico City. Based on in-vehicle emission measurements, they concluded that Metrobus units were the least polluting of the three options given that the buses are newer, more efficient and run on diesel instead of regular fuel.

The studies analyzing the impact of BRT on polluting emissions are scarce. In order to have a good overview of the methods used and the results obtained in these we summarize these aspect in Table 2.1, below. This paper contributes to the existing literature by providing a robust quantification of the short-term impact on air quality of the BRT network in the metropolitan area of Mexico City. We employ actual field data in our evaluation, and use the quasi-experimental method of differences-in-differences to analyze the environmental impact of the Bus Rapid Transit System in Mexico.

Table 2.1: Overview of studies analyzing the impact of Bus Rapid Transit on Polluting Emissions

Authors	Place and year	Method	Outcome
Wöhrnschimmel et al. (2008)	Mexico City (May - October 2005)	In-vehicle emission measurements	Reductions between 20% and 70% in commuters' exposure to CO, benzene and $PM_{2.5}$. No significant reductions in PM_{10}
Budi-Nugroho, et al. (2011)	Jakarta (April, May, September, and October 2005)	Structural equation model combined with an artificial neural network	Significant reduction in the concentration of PM_{10}
Hidalgo et al. (2013)	Bogotá (1998-2006)	Data computation for Cost-Benefit Analysis	Positive impact on health due to reduced emissions of air pollutants
Hodgson et al. (2013)	Reading, UK (2011)	Reading Urban Network System (Transit evaluation model)	Compared to Light Rail Trains, BRT has lower PM_{10} emissions, but NO_x emissions are higher
Chávez-Baeza and Sheinbaum-Pardo (2014)	Mexico City (1990-2008)	Estimation of historical trends using a Vehicle Emissions Scenario	Reduction of 7% for PM_{10}, 2.4% for CO, 15.4% NO_x.
Salehi et al. (2016)	Tehran (2011)	Measurement of emissions at BRT stations	Reduction of 5.8% for PM_{10}, 6.7% for CO, 6.7% for NO_x and 12.5% for SO_2

3. Bus Rapid Transit in Mexico City

3.1 The Metrobus Policy

The Mexico City Metropolitan Area is one of the most heavily populated metropolitan areas in the world. The estimated population in 2005 was 19.2 million inhabitants, growing to over 20 million by 2010 (population density was estimated at 2560 inhabitants/km^2). The city has a subtropical highland climate and lies in an elevated basin at 2,240 meters above sea level. The valley is confined on three sides by mountain ridges (east, south, and west). Diurnal temperatures oscillate between 10 and 22°C, and can easily climb above 30°C on hot days and fall to freezing on cold winter days. Rainfall is intense from June to October, but it is scarce from November to May. Pollution levels are much higher during the dry season. Wind speed plays a critical role in the city's weather and pollution levels: weak winds and the shape of the valley do not allow air pollutants to disperse.

It was only until the late 20th century that authorities recognized the Mexico City Metropolitan Area pollution problem and started to implement strategic measures to reduce polluting emissions. The measures implemented targeted industry emissions, vehicle emissions, commuter travel distances and travel times, and soil erosion. Although a downward trend was achieved, CO levels were above safety levels on 3% of the time, NO2 on 10%, and PM10 on 50% at least in some city areas between 1995 and 2000, while SO2 no longer surpassed official norm limits since 1993 (CAM, 2002).

The most known measure was the 'Hoy no circula' (today you do not circulate) program introduced in 1989. This program is coupled with an exhaust monitoring program (known as '*verificación*'), such that cars that do not fulfill emission criteria are not allowed on the road on one particular day during the week depending on the last number of their license plate. Analyzing the impact of this program with a regression discontinuity design, Davis (2008, p. 40) showed that this policy is not effective, but it also "led to an increase in the total number of vehicles in circulation as well as a change in the composition of vehicles toward high-emissions vehicles".

On 5 November 2002, the governor of Mexico City announced an ambitious program to deal with the worst cases of congestion. The aim was to reduce commuting times and to tackle the city's air quality problems, and several policies were implemented. In 2004 a few buses from the public network were renewed. In 2006-07 some parts of the 'second floor' of the inner-city highway *Anillo Periférico* were inaugurated. This helped reducing congestion in some areas, but the overall number of cars using both levels increased; so reduction of emissions was not significant. Other minor policies were introduced in 2007, such as a pilot project of a bicycle program. All in all, results obtained with these different programs and measures were modest.

At the heart of the 2002 program lay the introduction of a BRT ('Metrobus') system, designed to reduce traffic and air pollutant emissions. The intention was not to compete with existing public modes of transport; rather, BRT was seen as an alternative to existing options in order to reduce congestion. Note that, as found by Anderson (2014) for Los Angeles, congestion relief benefits alone may justify transit infrastructure investments. On March 2005, the *Secretaría de Mobilidad* (Mobility/Transport Secretariat, SEMOVI) oversaw the creation of the public entity Metrobus, with an initial operating budget of MXN 42.4 million pesos (USD 3.8 M in 2005). Metrobus was to be fully responsible for the BRT's operation planning and its control and administration.

The main idea underpinning the BRT system was to create an exclusive bus lane in which only authorized buses could operate subject to certain rules and criteria (schedule time, designated stops, physical dimensions of buses, and amount of emissions), to guarantee efficient operation. To promote the system, several stations had to be built to enable passengers to access the service. The project was implemented in 2005 with an initial investment of around USD $80 million to build up the infrastructure (Schipper et al., 2009). The investment included the construction of 37 BRT stations and exclusive bus lanes and the introduction of new articulated buses run on conventional diesel fuel. BRT was first opened on *Av. de los Insurgentes;* the initial fleet had a size of 80 units and the first line in this corridor was 19.6 km long (it was extended to 28.1 km in 2008 while the fleet grew to 98 units). BRT lanes reduced traffic congestion, as the measure eliminated overlapping of services with other bus lines. At the same time, flow in the car lanes was improved as traffic no longer had to stop whenever a bus or a micro-bus made a stop.

Following the introduction of the Metrobus, 90 buses where reallocated to other areas on the mountain side of the city[2], while 192 buses and micro-buses were completely destroyed. In general, Micro-buses are poorly maintained and produce serious amounts of health-threatening gases for people. In 2004, 61% of all minibuses in Mexico City ran on gasoline, 35% used Liquefied Petroleum Gas (LPG); the remaining ones ran on natural gas or diesel (GDF-SMA, 2006). The new BRT units used modern and certified diesel technology. Therefore, the substitution of the old units represented an important change in terms of the air quality conditions in the areas adjacent to the new Metrobus

[2] We have run the analysis excluding the air quality measuring stations close to this area, to avoid possible changes of our results. Coefficients remain unchanged in sign and significance. Results are available upon request.

route. One of the aims of the policy was to lower the air polluting emissions of public transportation, and the units operating the BRT network satisfy specific standards (Euro V emission standard).

While it seems intuitive that there is less pollution because of vehicle substitution, it is not clear whether pollution levels in the metropolitan area have also been reduced. Less congestion on a particular route may induce more people to use it. Hence, an increase in demand may even increase pollution levels in a given area if a sufficient number of commuters are attracted to use it. According to the Metrobus office, standard commuting times have fallen from 1 hour 30 minutes to 1 hour on the route, while passenger exposure to benzene, CO, and $PM_{2.5}$ has fallen by up to 50 percent, compared to the figures for the previous bus service operating in this corridor. However, the accuracy of this information is questionable as these outcomes are likely to be based on computations from in-vehicle emission changes, rather than real field data.

The Mexico City government monitors the air quality within its metropolitan area, by measuring levels of various pollutants within its network of automatic air quality monitoring stations distributed across the city. These stations have been operational during a number of years and the information is made publicly available. We use this information to measure the impact of the introduction of the Metrobus system on the concentrations of five pollutants.

3.2 Mexico City's Metrobus Network

The number of passengers using BRT has increased over the years (see Table 2.2) as has the size of the BRT-bus fleet. Since 2005 and the opening of the first line, the network has been expanded: line one was extended to the south in March 2008, and lines two (20 km) and three (17 km) came into operation in December 2008 and February 2011, respectively. At the same time, the overall size of the BRT fleet has grown to serve this expanding network, growing from 80 to 98 units (following the extension of line one), and subsequently to 167 (opening of line two) and 281 (opening of line three). In April 2012, line four (14 km) was inaugurated and, in November 2013, line five (10 km) was added. By which date the fleet had expanded to 396 units. In 2014, the Metrobus network transported a total of 254 million passengers, and with the expanding reach of the Metrobus network and the increasing number of buses required to operate each new line (which acts as a multiplier), passenger numbers continue to increase.

Table 2.2: Number of passengers using Mexico-City's Metrobus Network

Year	Line 1	Line 2	Line 3	Line 4	Line 5	Total
2005	34,720,301	0	0	0	0	34,720,301
2006	74,218,369	0	0	0	0	74,218,369
2007	77,652,339	0	0	0	0	77,652,053
2008	88,840,439	963,900	0	0	0	89,804,339
2009	93,381,006	33,753,903	0	0	0	127,134,909
2010	98,906,091	38,009,587	0	0	0	136,915,678
2011	112,322,116	43,192,375	31,668,509	0	0	187,183,000
2012	122,082,471	47,364,386	39,890,301	10,982,706	0	220,319,864
2013	124,717,045	48,005,198	40,476,438	13,586,594	3,157,914	229,943,189
2014	127,044,608	48,946,595	43,000,735	18,572,161	21,712,834	259,276,932

Source: Data from the Metrobus Public Information Office.

4. Empirical strategy

The first part of the analysis employs the differences-in-differences method to facilitate the measurement of the impact of the new BRT system on polluting emissions. By so doing, the intention is to estimate the atmospheric concentration of pollutants in Mexico City between 2003 and 2007 and to assess the impact of the introduction of the Metrobus.

The data panel used for this analysis is unbalanced. This characteristic of our panel comes from the fact that some stations were in operation from the beginning of the period of analysis, while other new ones were introduced at a later point in time, sometimes substituting older ones. On the other hand, most stations required maintenance at some point. The introduction or switching-off of the stations is exogenous and not correlated with the variables in the model.

In the absence of a randomized trial, the method we adopt is an extension of the differences-in-differences estimation procedure specified as a two-way fixed effects model. As stated in Wooldridge (2010: 828), "the usual fixed effects estimator on the unbalanced panel is consistent".

$$Y_{it} = \alpha + \beta X_{it} + \gamma Z_{it} + \theta_i + \delta_t + \varepsilon_{it} \qquad (1)$$

where Y_{it} is air pollutant concentration at station i for period t, α is a constant term, X_{it} is a vector of time-varying control covariates that include atmospheric characteristics, and Z_{it} is the BRT impact dummy variable to be evaluated. As usual in this kind of models, θ_i are station-specific fixed effects, δ_t are time-specific fixed effects and ε_{it} is the random error. Station fixed effects control for time-invariant station-specific omitted variables; time fixed effects control for trends around each monitoring station.

The key parameter in this differences-in-differences approach is γ, which measures the difference between the average change in air pollutant concentrations for the treatment group (stations within a radius of 10 kilometers around the Metrobus line) and average change in concentrations for the control group (stations located between 10 and 30 kilometers away from the area through which the Metrobus passes). Specifically,

$$\gamma = [E(Y_B|\, BRT = 1) - E(Y_A|\, BRT = 1)] \\ -[E(Y_B|\, BRT = 0) - E(Y_A|\, BRT = 0)] \quad (2)$$

where Y_B and Y_A denote the air pollutant concentrations before and after Metrobus came into operation. BRT=1 and BRT=0 denote treatment and control group observations respectively.

The equation for the dependent variables (CO, NO_X, PM_{10}, and SO_2) is:

$$Y_{it} = \alpha + \gamma_1 Metrobus_{it} + \beta_1 Pollutant\ Lag_{it} + \beta_2 Humidity_{it} \\ +\beta_3 Temperature_{it} + \beta_4 Wind\ Direction_{it} \\ +\beta_5 Wind\ Speed_{it} + \beta_6 Rainfall_{it} + \theta_i + \delta_t + \varepsilon_{it} \quad (3)$$

A basic assumption when using differences-in-differences is that the temporal trend in the two areas is the same in the absence of the intervention. If this were not the case, the impact being measured would be biased.

In conducting the analysis, the parallel trend assumption is first tested to determine whether the pollutant concentration trend was parallel in the period prior to treatment (i.e. before policy implementation). To conduct this test, the data were grouped by trimester. After testing and satisfying this assumption for all pollutants (with the exception of PM_{10}), we can verify that in the absence of intervention, the trend presented by the treated group is equal to that presented by the control. The evolution in pollutant levels over time is shown in graph form in Figure A2.1 in the Appendix. These graphs show how the treated and the non-treated pollutant levels behaved similarly during the pre-treatment period.

The failure to satisfy the parallel trend assumption in the case of PM_{10} leads to a biased impact evaluation for this particular pollutant. However, despite this slight upward bias, the PM_{10} analysis is included because of the importance of this pollutant. The impact evaluation of the remaining pollutants, however, is not biased since the parallel trends assumption is satisfied.

Furthermore, and as pointed out above, no major policy interventions took place during the period of study, giving the differences-in-differences analysis the required validity.

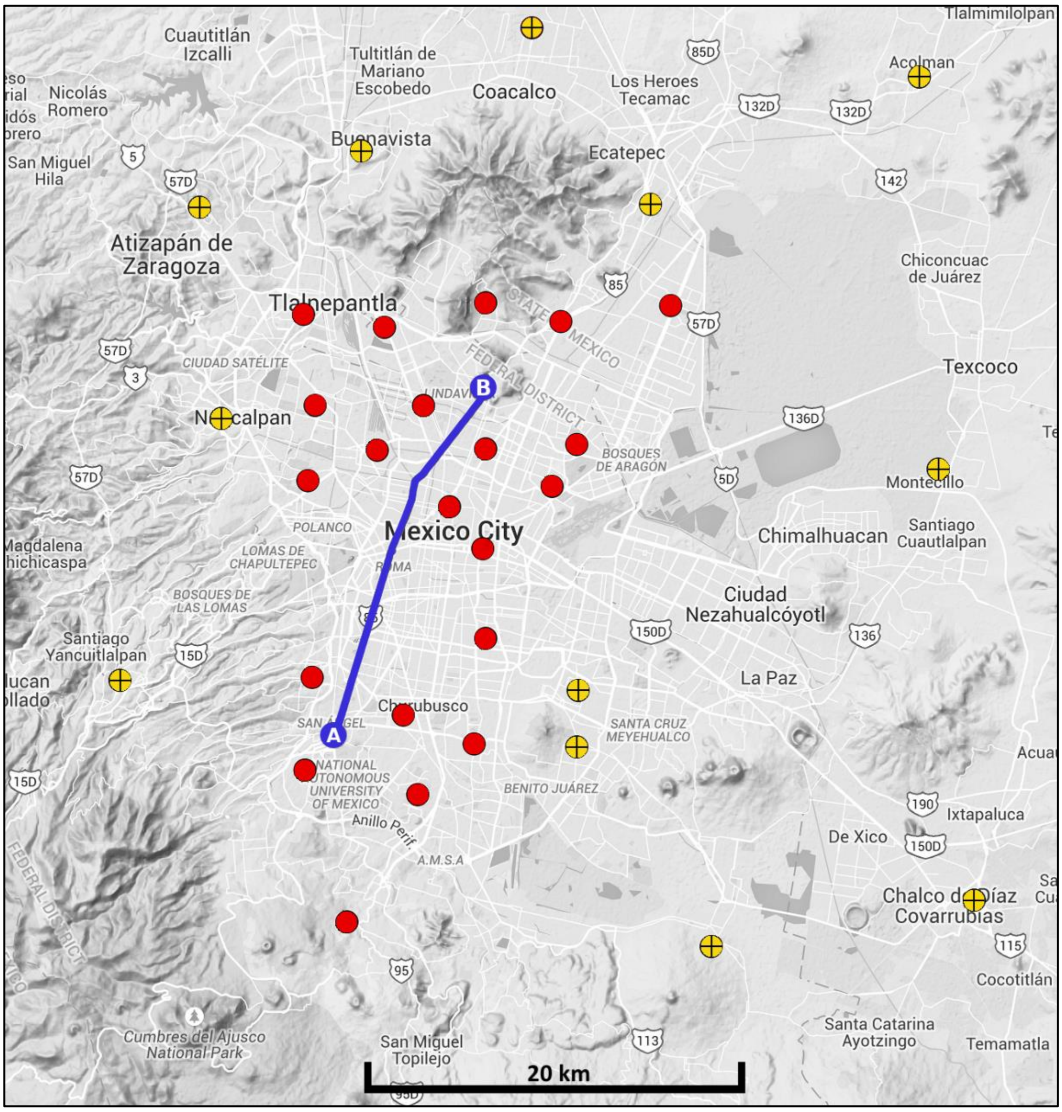
Endogeneity is a problem that can sometimes bias an impact evaluation. However, the great appeal of the differences-in-differences estimation "comes from its simplicity as well as its potential to circumvent many of the endogeneity problems that typically arise when making comparisons between heterogeneous individuals […]." (Bertrand et al., 2004, p. 250). Moreover, the implementation of this policy did not respond to a sudden deterioration in air quality, but rather to a longstanding and persistent congestion problem. As such, potential endogeneity issues are not likely to affect the present policy evaluation.

When using differences-in-differences in a panel data setting, regressions have to be undertaken with fixed effects: the correlation between the error components of station *i* and the explanatory variables should be different from zero. Closely related to this, an important assumption here is that unobservable variables and unobservable characteristics remain constant over time. By running the Hausman test and rejecting the null-hypothesis, we confirm the correct use of fixed effects in this panel. We test the model's basic assumptions (homoscedasticity, time dependence, spatial dependence and exogeneity of explanatory variables). To account for first order autocorrelation, we include a one-period lag of the respective pollutant in each regression. By using Driscoll-Kraay standard errors, the estimator is modified in such a way that it is robust to cross-section and time dependence. In this way, standard errors are also heteroscedasticity-consistent (Driscoll and Kraay, 1998).

For the analysis, we considered five different models, allowing the treatment group to change each time. This enables us to identify a distance band from the BRT corridor in which pollutant levels are affected by the introduction of the BRT. The control group remains the same for all five models: air quality monitoring stations in a radius of 10 to 30 kilometers around the Metrobus corridor (here we consider the shortest straight-line distance between stations and the closest point on the Metrobus route).

By focusing on different treatment groups, we are able to identify different patterns in the pollutant concentrations and in the dispersion of emissions. The distance bands around the BRT line are defined as follows: 0.0-2.5 km (6 stations), 2.6-5.0 km (4 stations), 5.1-10.0 km (11 stations) and 10.1-30.0 km (12 stations). These distance bands were defined based on the number of available air monitoring stations measuring each pollutant and their distance from the BRT corridor. Figure 2.1 shows a map with the BRT route, as well as the air quality monitoring stations in the treatment and control groups.

Figure 2.1: Map of the Metrobus line 1 (19.6 km) and location of the air quality monitoring stations



Source: Original Map from Google Maps. Own inclusion of the Metrobus line and air quality monitoring stations for all areas considered [0-2.5 km (6); 2.6-5.0 km (4); 5.1-10.0 km (11); 10.1-30.0 km (12)]. Treated stations are marked red and control stations are marked yellow.

Models 1-3 consider a treatment group of different sizes in the direct proximity of the Metrobus corridor: Model 1 uses the area in a 2.5-km radius around the Metrobus route, while Models 2 and 3 expand that radius to 5 and

10 km, respectively. It should be noted that Model 3 includes all available air quality monitoring stations. In contrast, models 4 and 5 do not consider direct proximity to the corridor, but focus instead on specific areas around the Metrobus route (2.6-5.0 km and 5.1-10.0 km, respectively). We expect to see the most marked changes in model 1, while models 2 and 3 should show weaker effects. The inclusion of Models 4 and 5 should help us identify more precisely the areas driving the results of Models 2 and 3. Intuitively, the effects in model 1 should be greater than those in models 4 and 5 (that is, if there are any noticeable effects). An illustrative scheme can be found in Figure A2.2 in the Appendix.

5. Data and variables

Pollution levels vary depending on a range of meteorological factors that have to be taken into consideration to capture this variation. Air contaminants are not static and so the average daily wind speed and average daily wind direction are included in the model. Wind direction is an important factor as a significant amount of pollution might be created in heavily industrial areas and then transported to other parts of the metropolitan area. Not only are pollutants transported, they also undergo a number of reaction processes. The rates of these reactions are influenced by temperature, so the average daily temperature needs to be considered. Water can result in a reactive change in the equilibrium or it may increase sedimentation; thus, relative humidity and daily rainfall are both included. Rainfall also reduces significantly the amount of pollutants in the air and so this meteorological variable has to be included. Note, however, that owing to data limitations, rainfall is calculated as the sum of daily rainfall amounts.

Data on air-related control variables (relative humidity, temperature, wind direction and wind speed) were obtained from Mexico City's Environment Secretary, which serves as the official monitoring entity. Data on air quality and amount of polluting emissions come from the Atmosphere Monitoring System (SIMAT), which comprises a network of around 40 monitoring points distributed across the Mexico City metro-area (see Table A2.1 in the Appendix for the exact location of the stations). The SIMAT network is divided into four monitoring subsystems, each measuring different atmospheric components and factors. The emission measurements takes place automatically every 10 minutes.

For the analysis of air pollutants, the RAMA (Automatic Network for Atmospheric Monitoring) subsystem serves as the source for all pollutant measurements. The RAMA network comprises 29 monitoring stations (their location is displayed in Figure A2.1 in the Appendix). The pollutants monitored are carbon monoxide (CO), nitrogen oxides (NO_X), sulfur dioxide (SO_2), particles of the order of 10 micrometers or less in aerodynamic diameter (PM_{10}). A few stations –only seven- also collect data for particles of the order of 2.5 micrometers or less ($PM_{2.5}$). Air quality monitoring stations are commonly installed on top of buildings, but not at street level directly. They are usually at a tree's height.[3]

Data on the meteorological parameters are obtained from the Meteorology and Solar Radiation Network subsystem (REDMET), which comprises 19 continuous monitoring stations that measure wind direction, wind speed, temperature, humidity, atmospheric pressure and solar radiation. Unfortunately, data on atmospheric pressure and solar radiation are not available after 2003, which is a limitation of the model presented below.

Further data on rainfall were provided by Mexico City's Water Systems office (SACM). This network of rainfall measuring stations comprises 78 monitoring stations distributed across the metropolitan area. Information on the exact location of the stations was denied for reasons of "national security", given that details regarding the city's waterworks infrastructure are restricted access only. However, the names of the stations were provided and as these typically include a reference to their location, it was possible with Google Maps to approximate the location of most of them. Of the stations, 70.5% were easy to locate, 16.7% were roughly approximated and 12.8% of the stations were impossible to locate based on their name. Rainfall data was obtained only by day, which led us to build the model based on daily averages as shown in Table 2.3.

Some of these variables are transformed into logarithms, such that relative changes can be interpreted more easily. The variables that are not transformed are relative humidity (which is already in percentage), temperature and wind direction (both of which follow an ordinal scale).

[3] Should the local government update its infrastructure, it would be useful to install new air quality monitoring stations at street level, such that future research can make a more detailed analysis.

Table 2.3: Description and Source of the model variables

Variable	Description	Source
CO	Carbon Monoxide daily average concentration (ppm)	RAMA
NO_X	Nitrogen oxides daily average concentration (ppm)	RAMA
PM_{10}	Airborne particulate matter with aerodynamic diameter of less than 10 μm daily average concentration (μg/m³)	RAMA
SO_2	Sulfur Dioxide daily average concentration (ppm)	RAMA
CO(-1), NO_X(-1), PM_{10}(-1), SO_2(-1)	One period lag (1 day) of the polluting variables	RAMA
Metrobus	Binary variable: 1 if the time period is after June 18, 2005, and the air quality measuring station lies within treatment area; 0 otherwise.	Metrobus Public Info. Office
Relative humidity	Daily average relative humidity (%)	REDMET
Temperature	Daily average temperature (°C)	REDMET
Wind Direction	Daily average wind direction (Azimuth Degrees)	REDMET
Wind speed	Daily average wind speed (m/s)	REDMET
Rainfall	Sum of the daily rainfall (mm)	SACM
Day Dummies	Binary variables for each day of the week (e.g. 1 if the day is Monday; 0 otherwise).	
Month Dummies	Binary variables for each month of the year (e.g. 1 if the month is January; 0 otherwise)	
Year Dummies	Binary variables for each year between 2003-2007	

Note: ppm = parts per million; μg/m³ = micrograms per cubic meter; m/s = meters per second; mm = millimeters.

As the air quality monitoring stations and rainfall measuring stations did not coincide, a matching was undertaken. Using the location of the air quality monitoring stations the closest rainfall station within a range of less than 10 km was selected. We assume that the weather conditions present at the air quality stations and at their closest respective rainfall stations do not differ. The rainfall stations that could not be located are not considered here given the impossibility of matching them to the air quality monitoring stations (the result of the station matching is available upon request).

Our analysis of Metrobus focuses solely on line 1 (opened on 19 June 2005). We measure its impact for the two-year period prior to its opening and the two-year post-operational period, i.e. from 19 June 2003 until 18 June 2007. Table 2.4 presents descriptive statistics of the variables.

Table 2.4: Descriptive statistics of the model variables (before Logarithms)

Variable	Mean	Std. Deviation	Min.	Max.	Obs.	Stations
CO	1.294	0.601	0.39	6.84	23,589	17
NO_X	59.444	30.011	3.75	241.65	24,139	17
PM_{10}	51.397	25.074	1.67	318.29	17,925	14
SO_2	9.928	9.928	0.86	115	29,935	23
Metrobus	0.5	0.5	0	1	1,461	-
Relative humidity	56.461	12.44	24.74	87.23	16,491	18
Temperature	16.194	2.406	7.45	23.57	15,469	18
Wind Direction	186.96	23.53	116.4	295.93	16,612	17
Wind speed	1.74	0.449	0.92	3.84	16,612	17
Rainfall	1.633	2.877	0	18.88	113,958	78

6. Results

Tables 2.5-2.9 present the results for the fixed effects regressions. The models for CO, NO_X, PM_{10}, and SO_2 are all jointly statistically significant at the 1% level. All estimations include year dummies, which capture time fixed effects (coefficients for year and holiday month dummies are not included in the outputs, and are available upon request). The within-R^2 values range between 0.62-0.64 for CO, 0.58-0.60 for NO_X, 0.56-0.57 for PM_{10}, and 0.34-0.36 for SO_2.

Table 2.5 presents the output for the fixed effects estimation of carbon monoxide. Results shows a downward trend in the relationship between the impact of the introduction of Metrobus on pollution and distance from the Metrobus route. In areas near the BRT line, the reduction in concentration was 7.17%, while in areas lying between 2.5 and 5 km and between 5 and 10 km from the route, the reduction was not significant. Comparing models 1-3 with models 4 and 5, we see that the area driving the significance of model 2 is the one lying between 0 and 2.5 km from the route.

Table 2.5: Estimation of the logarithm of Carbon Monoxide (CO) daily average concentration

Dep. Variable: Log(CO)	**(1)** 0.0-2.5 km	**(2)** 0.0-5.0 km	**(3)** 0.0-10.0 km	**(4)** 2.5-5.0 km	**(5)** 5.0-10.0 km
Metrobus	-0.0717**	-0.0546**	-0.0294	-0.00490	0.0330
	(0.0245)	(0.0225)	(0.0202)	(0.0294)	(0.0223)
Log(CO) (t-1)	0.560***	0.570***	0.554***	0.543***	0.522***
	(0.0220)	(0.0206)	(0.0177)	(0.0205)	(0.0173)
Humidity	0.00787***	0.00695***	0.00600***	0.00811***	0.00790***
	(0.00135)	(0.00127)	(0.00119)	(0.00147)	(0.00142)
Temperature	0.0159*	0.0152**	0.00514	0.0230**	0.00660
	(0.00698)	(0.00633)	(0.00631)	(0.00706)	(0.00739)
Wind Direction	-0.00049**	-0.000288*	-0.000203	-0.000241	-0.000357
	(0.000180)	(0.000151)	(0.000138)	(0.000180)	(0.000203)
Log(Wind Speed)	-0.414***	-0.411***	-0.432***	-0.417***	-0.448***
	(0.0296)	(0.0279)	(0.0280)	(0.0310)	(0.0324)
Log(Rainfall)	3.46e-06	0.000729	-0.00104	-0.00255	-0.00468
	(0.00412)	(0.00392)	(0.00361)	(0.00507)	(0.00441)
Constant	-0.369	-0.332	-0.152	-0.317	-0.153
	(0.264)	(0.272)	(0.252)	(0.216)	(0.201)
Number of Obs.	2,957	3,566	5,249	2,164	3,238
Within-R^2	0.638	0.632	0.629	0.616	0.624

The regressions include fixed effects for the air quality monitoring stations, the days of the week, the months of the year and for the years in the sample of analysis. Driscoll-Kraay standard errors in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

The results also identify the positive influence of the time lag on current levels of carbon monoxide, i.e., yesterday's CO-pollution levels largely determine today's pollution levels. A further factor playing a key role in the levels of CO in the air is the day of the week. Thus, pollutant levels are much higher during the week, when workers have to commute, than on the weekends. Environmental factors such as wind and humidity also play a marked role in air pollutant concentrations over the city, with both variables being significant.

The estimations of NO_X (Table 2.6) present a similar pattern to that presented by CO. Although the outcome is significant in all areas considered in the treatment group, the reduction in NO_X concentrations is greater in areas closest to the Metrobus route. The coefficient sign is negative, which is consistent with that of the other pollutants, and it presents values between 4.68 and 6.46%. The temporal lag plays an important role in the case of NO_X, as well as in all the areas defined around the Metrobus route. Higher wind speeds have a significant effect on the concentration levels, blowing the pollutant into other areas when the wind speed is high. Weekdays have a similar effect on pollutant concentrations as that described above for CO. For this pollutant, the year dummies are significant, capturing unobserved characteristics related to the time trend.

Table 2.6: Estimation of the logarithm of Nitrogen Oxides (NO_X) daily average concentration

Dep. Variable: Log(NOx)	**(1)** 0.0-2.5 km	**(2)** 0.0-5.0 km	**(3)** 0.0-10.0 km	**(4)** 2.5-5.0 km	**(5)** 5.0-10.0 km
Metrobus	-0.0646*	-0.0612**	-0.0546**	-0.0634*	-0.0468**
	(0.0285)	(0.0270)	(0.0226)	(0.0319)	(0.0206)
Log(NOx) (t-1)	0.460***	0.457***	0.433***	0.445***	0.421***
	(0.0210)	(0.0201)	(0.0191)	(0.0234)	(0.0221)
Humidity	0.00571***	0.00458***	0.00354***	0.00532***	0.00483***
	(0.00124)	(0.00114)	(0.000991)	(0.00131)	(0.00120)
Temperature	0.00917	0.00577	-0.00143	0.0164**	0.00583
	(0.00651)	(0.00594)	(0.00545)	(0.00673)	(0.00613)
Wind Direction	-0.00053**	-0.00035**	-0.000322**	-0.00043**	-0.00054***
	(0.000163)	(0.000125)	(0.000112)	(0.000155)	(0.000164)
Log(Wind Speed)	-0.415***	-0.404***	-0.429***	-0.412***	-0.451***
	(0.0281)	(0.0251)	(0.0233)	(0.0284)	(0.0279)
Log(Rainfall)	-0.00680	-0.00450	-0.00499	-0.00365	-0.00693
	(0.00404)	(0.00375)	(0.00332)	(0.00471)	(0.00409)
Constant	2.022***	2.169***	2.447***	2.172***	2.398***
	(0.230)	(0.224)	(0.166)	(0.202)	(0.167)
Number of Obs.	2,986	3,585	5,299	2,482	3,597
Within-R^2	0.598	0.590	0.603	0.575	0.603

The regressions include fixed effects for the air quality monitoring stations, the days of the week, the months of the year and for the years in the sample of analysis. Driscoll-Kraay standard errors in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

As noted, the results for PM_{10} present a slight upward bias and should be treated with caution. However, the reduction in concentrations was significant in all areas. In the area lying within a 2.5-km radius of the Metrobus route, the PM_{10} level fell by 7.65% following the opening of the line. The areas lying between 2.5 and 5 and between 5 and 10 km from the route experienced a reduction of 7.70 and 7.27% in their levels of PM_{10}, respectively (all reductions are statistically significant). Table 2.7 shows how the impact on this pollutant fell across all distances, unlike the patterns presented by NO_X and CO.

Humidity levels, wind speed, and temperature have a high statistically significant influence on PM_{10} concentration levels across all treatment groups. Higher humidity levels and higher wind speeds both reduce PM_{10} concentrations in the air, whereas rising temperatures increase concentration levels. The temporal lag of the endogenous variable indicates that past emission levels significantly affect today's concentration levels. Commuting to work or school at peak times during the week creates congestion within the city, which increases pollution levels in areas closest to these congested roads.

Table 2.7: Estimation of the logarithm of Particulate Matter with less than 10 μm (PM_{10}) daily average concentration

Dep. Variable: Log(PM_{10})	**(1)** 0.0-2.5 km	**(2)** 0.0-5.0 km	**(3)** 0.0-10.0 km	**(4)** 2.5-5.0 km	**(5)** 5.0-10.0 km
Metrobus	-0.0765**	-0.0884**	-0.0922***	-0.0770*	-0.0727**
	(0.0308)	(0.0292)	(0.0299)	(0.0314)	(0.0269)
Log(PM_{10}) (t-1)	0.442***	0.444***	0.434***	0.446***	0.434***
	(0.0280)	(0.0268)	(0.0256)	(0.0279)	(0.0260)
Humidity	-0.0112***	-0.0111***	-0.0114***	-0.0125***	-0.0130***
	(0.00173)	(0.00167)	(0.00160)	(0.00188)	(0.00175)
Temperature	0.0358***	0.0332***	0.0327***	0.0371***	0.0383***
	(0.00832)	(0.00812)	(0.00769)	(0.00885)	(0.00803)
Wind Direction	-0.000526*	-0.000395*	-0.000267	-0.000311	-0.000175
	(0.000231)	(0.000197)	(0.000165)	(0.000193)	(0.000170)
Log(Wind Speed)	-0.258***	-0.258***	-0.260***	-0.226***	-0.239***
	(0.0356)	(0.0328)	(0.0285)	(0.0328)	(0.0273)
Log(Rainfall)	0.0116*	0.0118**	0.0106**	0.0102	0.00839
	(0.00494)	(0.00445)	(0.00407)	(0.00525)	(0.00463)
Constant	2.720***	2.761***	2.768***	2.825***	2.765***
	(0.235)	(0.232)	(0.214)	(0.245)	(0.203)
Number of Obs.	2,054	2,658	3,697	1,611	2,046
Within-R^2	0.573	0.564	0.561	0.573	0.574

The regressions include fixed effects for the air quality monitoring stations, the days of the week, the months of the year and for the years in the sample of analysis. Driscoll-Kraay standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

When analyzing PM_{10} concentration levels, special attention should be paid to particle matter of 2.5 micrometers or less in diameter ($PM_{2.5}$). However, only seven of the air quality monitoring stations in the network collect data about this pollutant, which provided us with a considerably smaller number of observations. Despite this, we were able to calculate differences-in-differences estimates for the area lying in a 10-km radius of the Metrobus corridor (with almost 2,000 observations). Our results point to a significant reduction (17.9% at the 1% level) in pollutant concentration. The results of this estimation are available upon request.

Finally, our estimations of the SO_2 concentrations (Table 2.8) do not show any significant effect of the introduction of the Metrobus in any of the three areas defined around *Av. de los Insurgentes*. As expected, the signs of the coefficients are negative. The variation of the error term is too high to capture any significant impact from the Metrobus operation. Moreover, this higher variation of the error term is significantly larger than that of the estimations for CO, NOX and PM10, leading to a wider confidence interval. The SO2 concentration reduction caused by the BRT introduction falls therefore inside this larger confidence interval, and thus the non-significance. Interestingly, the model for this pollutant performs worse in terms of explanatory power, as the within-R^2 coefficient of determination is below that of the other pollutants.[4]

BRT units running on diesel came to replace Microbuses using Gasoline and Liquefied Petroleum Gas. The non-significance of the policy coefficient is likely to be this way because vehicles using gasoline produce less SO2 emissions than vehicles running on diesel. The main sources of SO2 emissions are a) factories using fossil fuels, coal, diesel and natural gas; b) processes such as oil refinement, the production of sulfuric acid and the smelting of zinc, copper and plumb; c) geothermic activity taking place in close by volcanos (e.g. the Popocatepetl volcano 72 km far away from Mexico City); d) vehicles using diesel, which in the case of the Mexico City Metro Area are mostly larger trucks. All of these sources of SO2 are normally not located in the area cover by the treatment stations, but further away from the BRT route.

[4] Our period of analysis overlaps with the PEMEX Magna gasoline with ultra-low Sulphur introduction in October 2006. Because of this overlapping, we restricted the period of analysis to September 30, 2006. The results, which are available upon request, remain unchanged in sign and significance. Ultra-low Sulphur versions of the PEMEX Premium gasoline and PEMEX Diesel were introduced after our period of analysis (2008-2009). For more information see NOM-086-SEMARNAT-SENER-SCFI-2005 (*Diario Oficial de la Federación*: 30/01/2006).

Table 2.8: Estimation of the logarithm of Sulfur Dioxide (SO_2) daily average concentration

Dep. Variable: Log(SO_2)	**(1)** 0.0-2.5 km	**(2)** 0.0-5.0 km	**(3)** 0.0-10.0 km	**(4)** 2.5-5.0 km	**(5)** 5.0-10.0 km
Metrobus	-0.0490	-0.0693	-0.0446	-0.102	-0.0168
	(0.0584)	(0.0550)	(0.0570)	(0.0669)	(0.0520)
Log(SO_2) (t-1)	0.456***	0.459***	0.447***	0.416***	0.411***
	(0.0270)	(0.0250)	(0.0240)	(0.0273)	(0.0269)
Humidity	-0.00127	-0.000469	-0.000548	-0.00369	-0.00277
	(0.00383)	(0.00349)	(0.00336)	(0.00350)	(0.00362)
Temperature	0.0472**	0.0501**	0.0466**	0.0514**	0.0473**
	(0.0193)	(0.0177)	(0.0168)	(0.0180)	(0.0182)
Wind Direction	0.00151**	0.00161***	0.00181***	0.00212***	0.00227***
	(0.000513)	(0.000437)	(0.000408)	(0.000454)	(0.000469)
Log(Wind Speed)	-0.384***	-0.413***	-0.414***	-0.432***	-0.420***
	(0.0837)	(0.0758)	(0.0657)	(0.0826)	(0.0700)
Log(Rainfall)	0.0158	0.0143	0.00501	0.0143	0.00243
	(0.0131)	(0.0116)	(0.0112)	(0.0145)	(0.0138)
Constant	0.309	0.318	0.244	0.593	0.294
	(0.474)	(0.433)	(0.413)	(0.412)	(0.422)
Number of Obs.	3,211	3,962	6,198	2,618	4,103
Within-R^2	0.338	0.355	0.343	0.342	0.315

The regressions include fixed effects for the air quality monitoring stations, the days of the week, the months of the year and for the years in the sample of analysis. Driscoll-Kraay standard errors in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

As above, however, the lagged value of the endogenous variable, and the wind and weekday variables have a significant influence on the concentration level of SO_2. Higher wind speeds reduce levels of concentration while the levels rise on days when commuters take to the roads.

The estimation outputs of the different pollutant molecules show that the introduction of the Metrobus had a marked impact on the concentration levels of most of the different pollutants in the areas defined. To appreciate better the impact of the Metrobus operation on air quality in the Mexico City metropolitan area, Table 2.9 summarizes this impact for all pollutants.

In the case of CO and NO_X, pollutant concentrations fall with distance from the Metrobus corridor; however, in the case of PM_{10}, the pattern is not clear. The fact that particulate matter can have both an anthropogenic and non-anthropogenic origin (WHO, 2013) may explain why a decreasing reduction with distance from the Metrobus route was not found for PM_{10}.

Table 2.9: Summary of the impact of the Metrobus implementation on the different pollutants

	(1)	(2)	(3)	(4)	(5)
	0.0-2.5 km	0.0-5.0 km	0.0-10.0 km	2.5-5.0 km	5.0-10.0 km
CO	-0.0717**	-0.0546**	-0.0294	-0.00490	0.0330
	(0.0245)	(0.0225)	(0.0202)	(0.0294)	(0.0223)
NOx	-0.0646*	-0.0612**	-0.0546**	-0.0634*	-0.0468**
	(0.0285)	(0.0270)	(0.0226)	(0.0319)	(0.0206)
PM_{10}	-0.0765**	-0.0884**	-0.0922***	-0.0770*	-0.0727**
	(0.0308)	(0.0292)	(0.0299)	(0.0314)	(0.0269)
SO_2	-0.0490	-0.0693	-0.0446	-0.102	-0.0168
	(0.0584)	(0.0550)	(0.0570)	(0.0669)	(0.0520)

Driscoll-Kraay standard errors in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

It should be stressed that the results reported herein are valid only for the short term. In the long term, the frequent improvement of existing public transport modes will be necessary in combination with "space–transport development strategies with the aim of increasing accessibility and reducing air pollution" (Ambarwati et al., 2016). To achieve abiding reductions, behavioral changes are needed and these are unlikely to occur unless middle/high income earners stop perceiving the metro and other modes of public transport as inferior goods (Crôtte et al., 2009).

6.1 Robustness Checks

In order to make sure that the empirical strategy is consistent, alternative approaches were employed to analyze the data.[5] First, the regressions were run again but dropping the year 2005 in order to account for the adoption time of the new transport mode. The signs and the significances remained unchanged, and the magnitudes did not present major differences. The reductions for the area lying within a 2.5-km radius of the BRT corridor were 11.5% for CO, 13.7% for NOx, and 8.7% for PM10.

Furthermore, we open the spectrum of analysis and use an alternative empirical method. Instead of employing a differences-in-differences approach, we resorted to a Regression Discontinuity Design (RDD) in order to identify the effects of the BRT introduction. For this approach, the Metrobus operation's start (19 of June 2005) is seen as the cutoff point around which the

[5] The results of all approaches used for the robustness checks are available upon request.

mean of observations before and after are expected to be significantly different. For this robustness check, different time bands on each side of the cutoff point – the Metrobus introduction – were considered: 2 years, 1 year and 6 months. This robustness analysis focuses solely on the area between 0 and 2.5 km around the Metrobus. The technical details of this procedure can be found in Hahn et al. (2001) or in Khandker et al. (2009). The results of the covariate-adjusted sharp regression discontinuity estimates can be found in Table A2.2 in the Appendix. We obtain similar results in terms of sign and significance, which supports the results obtained in the differences-in-differences estimation. However, we consider the differences-in-differences method to be more robust and therefore better suited for the Metrobus impact evaluation on air pollution.

7. Conclusions

This paper evaluates the short-term impact of the introduction of Bus Rapid Transit on pollution levels in Mexico City. The analysis is based on real field data obtained from automatic air quality monitoring stations and has focused specifically on four pollutants: CO, NO_X, PM_{10} and SO_2.

Results from the differences-in-differences analysis show a significant reduction in the concentrations of all the pollutants, except SO_2. Specifically, CO concentrations were reduced by between 5.5 and 7.2%, NO_X by between 4.7 and 6.5%, and PM_{10} by between 7.3 and 9.2%, depending on the city area. In the case of SO_2, our results are negative though not statistically significant. The estimation using Driscoll-Kraay standard errors failed to reveal any significant impact of the introduction of BRT.

It would be inappropriate to generalize the impact of BRT on air quality reported here to a longer time framework and to all cities, given that we have focused on evaluating short-term effects for the Mexico-City Metropolitan Area. Clearly, geographical and atmospheric traits will differ from one location to another. Moreover, further studies are needed in order to determine whether commuters show an enduring behavioral change (switching from private cars to BRT) and whether road congestion in the treated area was actually reduced. To date, the statistics indicate that the number of people using BRT continues to increase as the network expands. Future research would also benefit from comparing the reduction in emissions reported here with those detected in other metropolitan areas based on real field data, and from determining whether the latter are consistent with the findings herein.

For cities with similar characteristics to those of Mexico City, our results might encourage the expansion of their BRT networks, the regular introduction of cleaner BRT-units, and an increase in the size of their BRT fleets to provide a better standard of service, measures that should motivate more people to switch from private cars to public transport. It is important to recall, however, that the emission impact of each BRT line will be different for every corridor, and that other factors are likely to play a role.

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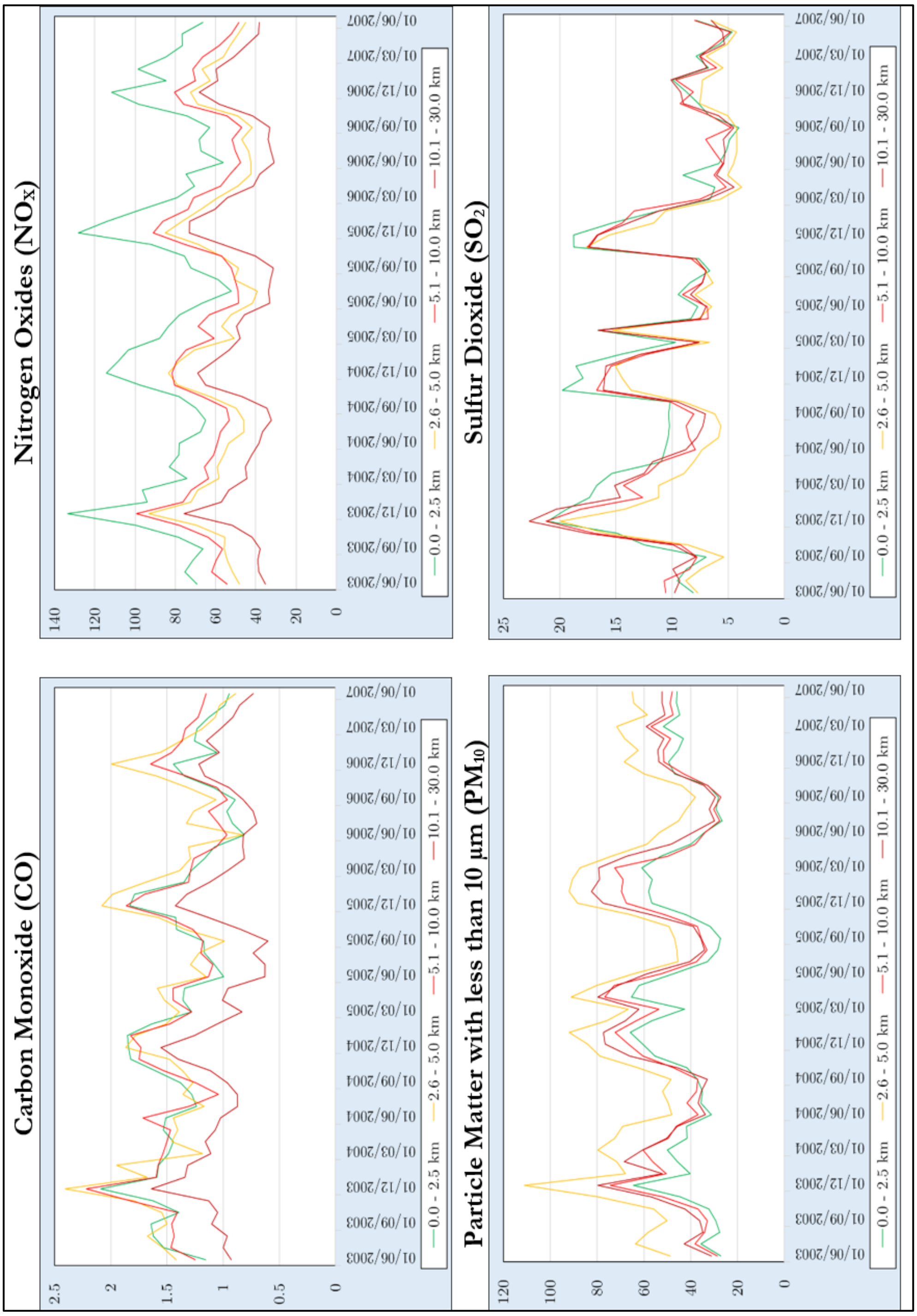
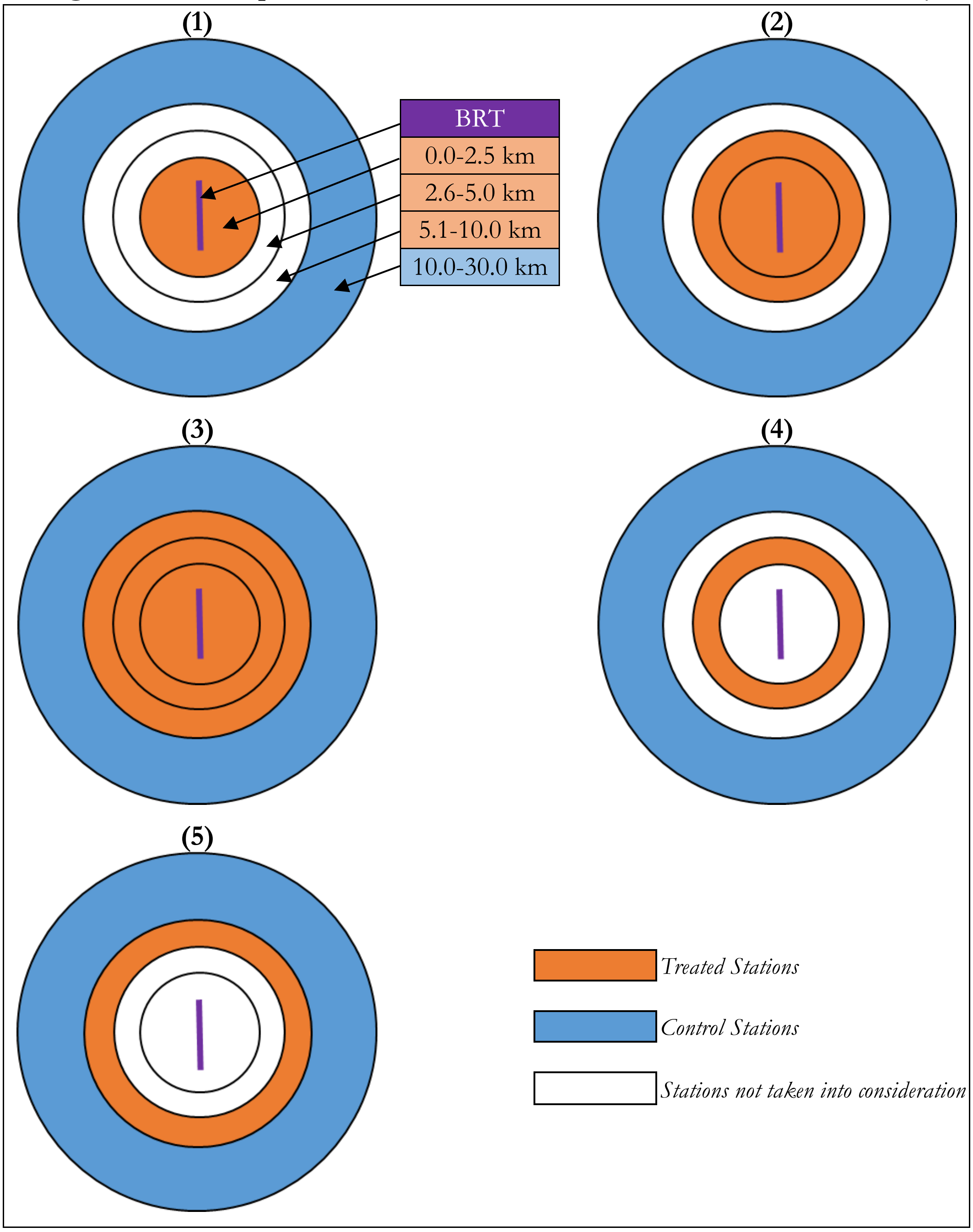
APPENDIX

Figure A2.1: Evolution of the different pollutant concentrations in the period June 2003 – June 2007



Source: Based on data from Mexico City's Environment Secretary (*Secretaría del Medio Ambiente,* SEDEMA).

Figure A2.2: Simplified scheme of the different models used in the analysis



Source: own elaboration.

Table A2.1: Coordinates of the automatic air quality measuring stations and distance to the Metrobus corridor

Code	Air Quality Measurement Station	Latitude	Longitude	Distance to BRT Corridor (in KM)
ACO	Acolman	19.635501	-98.912003	26.30
ARA	Aragón	19.471380	-99.074546	5.30
ATI	Atizapán	19.576963	-99.254133	16.70
AZC	Azcapotzalco	19.488893	-99.198653	6.22
CAM	Camarones	19.468404	-99.169794	2.41
CES	Cerro de la Estrella	19.335884	-99.074675	11.70
CHO	Chalco	19.266948	-98.886088	29.87
COY	Coyoacán	19.350258	-99.157101	2.95
CUA	Cuajimalpa	19.365313	-99.291705	10.90
FAC	FES Acatlán	19.482473	-99.243524	10.10
IMP	Instituto Mex. del Petróleo	19.488720	-99.147294	2.06
IZT	Iztacalco	19.384413	-99.117641	5.82
LAG	Lagunilla	19.443581	-99.135184	1.91
LLA	Los Laureles	19.578792	-99.039644	11.90
LPR	La Presa	19.534727	-99.117720	3.71
LVI	La Villa	19.469051	-99.117754	1.71
MER	Merced	19.424610	-99.119594	4.15
MON	Montecillo	19.460415	-98.902853	23.00
PED	Pedregal	19.325146	-99.204136	1.98
PLA	Plateros	19.367028	-99.200105	1.90
SAG	San Agustín	19.532968	-99.030324	9.83
SJA	San Juan de Aragón	19.452592	-99.086095	5.44
SUR	Santa Úrsula	19.314480	-99.149994	5.04
TAC	Tacuba	19.455068	-99.202453	5.19
TAH	Tláhuac	19.246459	-99.010564	21.60
TAX	Taxqueña	19.336841	-99.123203	6.77
TLA	Tlalnepantla	19.529077	-99.204597	9.59
TLI	Tultitlán	19.602542	-99.177173	12.80
TPN	Tlalpan	19.257041	-99.184177	9.10
UIZ	UAM Iztapalapa	19.360794	-99.073880	11.00
VAL	Vallejo	19.523598	-99.165702	5.55
VIF	Villa de las Flores	19.657671	-99.096307	17.60
XAL	Xalostoc	19.525995	-99.082400	4.62

Source: Mexico City's Environment Secretary (*Secretaría del Medio Ambiente,* SEDEMA).

Table A2.2: Results of the Regression Discontinuity Design

	(1) CO	**(2)** NOx	**(3)** PM10
2 years			
Coefficient	-0.295***	-0.247***	-0.149***
Standard Errors	(0.0293)	(0.0901)	(0.0299)
Observations	1,402	1,103	1,047
1 years			
Coefficient	-0.236***	-0.256***	-0.0144
Standard Errors	(0.0436)	(0.0854)	(0.0421)
Observations	692	551	556
6months			
Coefficient	-0.216***	-0.0623	0.0656*
Standard Errors	(0.0346)	(0.0465)	(0.0350)
Observations	256	216	224

Standard errors adjusted by station clustering in parentheses.
* $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Chapter 3

Assessing the Effects of the Mexican Drug War on Economic Growth: An Empirical Analysis

Abstract

Mexican President Felipe Calderón took office in December 2006. From the outset, his government deployed an aggressive security policy to fight drug trafficking organizations, in what became known as the 'Mexican Drug War'. The policy was to earn considerable criticism owing to the heavy number of unintended casualties resulting from the frontal assault waged against the drug cartels. In this article, we evaluate the economic effects of the Mexican Drug War policy. To do so, we study the effects of the rise in the homicide rate and changes in a state-level approximation of the military budget on economic growth. Using dynamic panel data econometrics, we find that while the growth in the number of homicides had negative and significant effects on state GDP growth, state military expenditure aimed at fighting drug trafficking had a positive and significant effect on the per capita economic growth rate.

Keywords: Drug Trafficking Organizations; Militarized disputes; Security policy; Homicides; Mexico; Drug War

JEL Codes: H56, K42, R11

1. Introduction

At the end of 2006, Felipe Calderón's government declared a war on drug trafficking organizations (DTOs),[6] and ordered the military to take strong action against the drug cartels. The military initiated a series of operations targeting the most dangerous drug criminals in Mexico. However, the criminals fought back, resulting in thousands of casualties (including, criminals, police, the military, and civil population). Indeed, the detention and eventual killing of the drug lords left a power vacuum that rival organizations sought to fill, which further increased the number of victims.

From the 1990s through to the mid-2000s, Mexico's homicide rate had fallen to an all-time low by 2007 of 8.1 homicides per 100,000 inhabitants (an absolute total of 8,861). Shirk and Wallman (2015) claim that if the fall had continued, the homicide rate would have eventually reached similar levels to those in the US (five homicides per 100,000 inhabitants). However, the homicide rate increased dramatically, reaching a high of 23.0 homicides per 100,000 inhabitants in 2011. The Mexican National Statistics Institute (INEGI) recorded 121,613 homicides in the country during Calderón's administration, while during Vicente Fox's preceding administration (2001-2006) the number of homicides was less than half (60,162). When Calderón left office, the homicide rate fell slightly for a time, but recently it has risen again. Indeed, since the end of Calderón's administration in 2012, the strategy to fight DTOs has not changed significantly.

Although there are barely any studies analyzing the impact of this spiraling violence on GDP, evidence suggests that foreign direct investment (FDI) experienced a setback in some industries (e.g. Mining and Oil Extraction) (Ashby and Ramos, 2013). However, this study analyzed all Mexican states together, regardless of whether they presented signs of DTO violence, and so the setback may be attributable to other factors. Yet, firms and individuals settled in dangerous regions have opted to move away to safer areas. According to NRC/IDMC (2010), 230,000 people are estimated to have fled their homes (up to 2010). Moreover, various countries have issued recommendations to their citizens not to visit certain areas of Mexico (Zapata, 2011). But whether these factors have affected the GDP growth rate has yet to be analyzed.

[6] The U.S. National Drug Threat Assessment defines DTOs as "complex organizations with highly defined command-and-control structures that produce, transport, and/or distribute large quantities of one or more illicit drugs." (DOJ, 2010, p.10).

Economic variables seem likely to be linked closely to the violence problem. Terrorist acts, such as those perpetrated in Spain, Turkey and Israel, have shown that economies suffer major setbacks from violence. While the terrorism-related literature can serve as a point of reference here, we cannot apply its findings to the case of DTO violence in Mexico, as terrorism and drug trafficking are very different in nature.

Based on the number of victims during Mexico's recent drug crusade and the opportunity costs of government spending on its fight against DTOs, it is reasonable to expect that Mexico's economy was affected by DTO activities. A society that experiences violent acts faces not only the costs suffered by those directly and indirectly affected, but also the political and institutional costs. Acemoglu et al. (2013) point out that when the relationship between the actors controlling institutions and criminals reaches certain levels, a symbiotic relationship may emerge and non-state actors are able to influence policy decisions. Events in Italy illustrate how criminal organizations like the Mafias have poisoned and corrupted government at the highest levels (Alesina et al., 2016), while Colombia faced the same problem up until the end of the 20th century, when the drug cartels of Medellin and Cali were particularly strong.

A number of studies have analyzed the economic effects of drug-related violence, but what we do in this article is to assess the specific impact of President Calderón's policy aimed at fighting DTOs and drug-related violence. To do so, we analyze the effects of increases in drug-related violence (based on homicide rates) and a state-level approximation of the military budget on the growth of state GDP per capita. For this purpose, we work in a well-known growth setting, using the β-convergence framework, while also considering the possibility of spatial effects between states. The objective of this paper is to assess not only how violence deterred economic activity, but more importantly how government action in the form of military expenditure affected state economic growth.

To analyze the impact of military expenditure, we approximate state-level military budgets, and weight them by crime variables associated with the drug cartels and the fight against DTOs.

Thus, we make several contributions to the literature: 1) we undertake an economic analysis of the 'Drug War' policy and how it impacted economic growth in the Mexican states. Although the effects of the violence escalated, we focus on the actions implemented by the central government, specifically in the form of military expenditure, to tackle the problem of DTOs in the territory. To the best of our knowledge, the impact of state-level military spending on the per capita GDP growth rate, against the backdrop of the Mexican Drug War, has never been analyzed before. 2) By using the β-convergence framework, as developed within economic theory, and by employing dynamic panel data, for the empirical analysis, we build upon existing efforts to assess the effects of violence generated by the presence of DTOs and government attempts to fight drug criminals. In so doing, we link the empirical analysis of national security policy with economic theory in a more effective way than previous studies examining violence and economic growth in Mexican states that fail to consider the dynamic nature of the data. 3) Our approach captures the violence generated by the presence of DTOs by employing a range of different variables. We also make several approximations of military spending at the state level, given that such information is not publicly available in Mexico. To overcome this limitation, we develop a new method to estimate military expenditure at the state level in a developing country. By using a range of options for both variables, we are able to endow our analysis with greater robustness.

2. Literature Review

2.1 Economic Growth in Mexico

The analysis we undertake of the effects of homicides and military expenditure on economic growth is based on a growth model, and several studies in the literature are of particular relevance to the case we present. The speed of convergence of an economy does not always remain the same. There will be periods in which convergence accelerates and others in which it slows down. Similarly, regional economies within a country may grow at different speeds, leading to convergence or divergence.

Chiquiar (2005), in a study of income convergence across Mexican states, suggests that the divergence pattern that emerged in the mid-1980s was not reversed with the signing of NAFTA, and that Mexican regions became more sensitive to new sources of growth. Likewise, for this same period, Rodríguez-Oreggia (2005) contends that differences in growth across states can be attributed to disparities in human capital, with northern and central states boasting higher skilled workers than those found in Mexico's southern states. Carrion-i-Silvestre and German-Soto (2007) took a time series from 1940-2001 and found evidence of convergence after controlling for structural breaks. In a more recent study, Cabral and Mollick (2012), using dynamic panel data techniques, found positive rates of output convergence across Mexican regions: 9.4% for the period 1996 to 2006.

All these studies analyzed periods of time prior to the Mexican Drug War, which was initiated in 2007. It is our conjecture that the speed of convergence might have changed for those Mexican states that were most affected by the policy outcomes (i.e. drastic increase in the homicide rate).

2.2 Drug Trafficking Organizations

A difficulty when fighting DTOs is that the actions undertaken by governments often just shift the problem to another location. The spatial competition model developed by Rasmussen et al. (1993) suggests that higher drug enforcement in one jurisdiction simply moves the drug problem to neighboring jurisdictions, resulting in higher violent crime rates. Their analysis concludes that "Drug enforcement increases violent crime due to the disruption of spatial equilibria in drug markets" (Rasmussen et al., 1993, pp. 229-230).

In countries facing insurgency movements, governments seek to fight the insurgents by military means and by providing services to incentivize the community to share information. Berman et al. (2011) examined the case of Iraq and found that regional spending on public goods is violence-reducing. However, Andreas (2004, p. 650) argues that "[m]ilitary success on the battlefield can significantly depend on entrepreneurial success in the illicit economy […]".

The economic literature on DTOs is scarce. Several scholars have opted to place the violent acts happening in Mexico in the same category as terrorist or counter-insurgency acts. As Williams (2012) explains, this characterization is wrong, since the killings in Mexico are not motivated by politics, ideology or religion and he stresses that while there is some evidence of 'careless' violence (some civilians have been erroneously executed or caught in the crossfire), the violence in Mexico has been quite selective.

The reasons for violence in Mexico are diverse. Variables such as the poverty rate, unemployment and weak institutions all play an important role. For example, Levitt and Venkatesh (2000) find that criminal organizations are more successful at recruiting people with lower incomes. In Mexico, where DTOs have been active for decades, the reasons for the rise in the homicide rate appear to be more closely associated with the increase in reprisal killings, the wars waged between rival DTOs and clashes with the armed forces. Rios (2013) claims that the violence is driven by two mechanisms: 1) the competition between DTOs to expand their drug trafficking turf, and 2) government action in the form of police and military operations to apprehend drug cartel members. These two mechanisms are obviously interconnected, since when the leaders of a dominant DTO are arrested, its competitors see an opportunity to expand into their territory, with a resulting escalation in violence.

A recent study investigating violence and the effects of DTOs in Mexico (Dell, 2015) shows that drug-related violence increases substantially after closely fought mayoral elections involving a change in the ruling party.[7] This result is in line with the findings of Snyder and Duran-Martinez (2009), Astorga and Shirk (2010) and Chabat (2010). A wave of violence following a change in the ruling party at the municipal level seems to indicate that the previous incumbent had entered into agreements with DTOs. Following the elections, these agreements are no longer binding and, as the police and military forces seek to capture the drug lords, violence breaks out. The Italian mafia display a similar pattern of behavior: "regions with a greater presence of criminal organizations are characterized by abnormal increases in homicides during the year before elections" (Alesina et al., 2016, p.2).

2.3 Economic Effects of Drug Violence

Several studies have looked at economic variables and how the presence of organized crime affects them. For instance, Cabral et al. (2016) report that a rise in crime has negative effects on labor productivity. Ashby and Ramos (2013) find that organized crime in Mexico deters FDI in financial services, commerce and agriculture. In terms of human capital accumulation, Marquez-Padilla et al. (2015) report barely any effect on total enrollment in schools. In their analysis of income inequality, Enamorado et al. (2016) estimate that a one-point increase in the Gini coefficient increases the number of drug-related homicides by 36%. Finally, Orozco-Aleman and Gonzalez-Lozano (2017) study migration flows

[7] Our analysis also included a test of political changes at the state level. Several dummy variables were used to test whether states governed by PRI or by PAN showed abnormal increases in their crime variables after state elections. None of the results was significant. Results are available upon request.

and find that migration decisions are sensitive to both local violence and transit (on route) violence.

However, other studies conclude that the presence of DTOs could have various "positive" effects for the local economy. In their bid to expand their influence, DTOs need to infiltrate the social structure and attract members of the local community into the ranks that make up what is a labor-intensive drug production chain (Rios, 2008). Having a DTO in town can lead to higher rates of employment and higher wages for those involved in production, transport and distribution. Fernández-Menéndez and Ronquillo (2006) report that farmers involved in marijuana and poppy production can earn wages that are several times higher than normal, in addition to receiving a generous lump-sum payment. Likewise, anecdotal evidence suggests that DTOs can have a positive economic impact: "The narcoeconomy ushered certain forms of consumption into an otherwise stagnant, marginal community; it brought money back into the community in various forms of legal reinvestment activities, such as farms and businesses; and it provided many people with all manner of jobs." (McDonald, 2005, p. 121).

A further consequence of a town's being under the influence of a DTO might be that corrupt government agents work for the benefit of the DTO, accepting bribes and sabotaging police operations. Meanwhile, these corrupt agents have to launder their bribe money without raising suspicions. Moreover, by focusing federal police or military operations within a specific state means that federal police forces and soldiers have to be relocated to that state, with the resulting additional expenditure for the government.

To the best of our knowledge, the effects of the Mexican Drugs War on the country's GDP and income growth have been examined primarily in three studies. First, Robles et al. (2013) use electricity bills as a GDP proxy to estimate the impact of violence on GDP and unemployment using IV and Synthetic Control methods. They find that an increase of 10 homicides per 100,000 habitants results in an increase of around 1.5% in the rate of unemployment, a 0.4% reduction in the proportion of business owners, and a 1.2% reduction in average income. In addition, they use a synthetic control to estimate that electricity consumed per capita fell in the first 2 years after a conflict involving two DTOs.

Second, Pan et al. (2012) use a spatial model to estimate the impact of violence on GDP between 2005 and 2009. They find that while GDP growth is positively related to crime within a specific state in the previous year, it is negatively related to crime in its surrounding states. An interesting aspect of this study is the introduction of an aggregate variable of federal grants (education, public security, health services, and social infrastructure). The model specification features an aggregate crime variable, which includes fraud, rape, assault, property damage, homicide, and other crimes.

Third, Enamorado et al. (2014) employ the β-convergence framework to estimate the impact of drug-related homicides on real income growth in Mexico. They find evidence of a negative impact of drug-related homicides on income growth in Mexican municipalities between 2005 and 2010. Their model considers aggregate figures of public expenditure at the local level, which are found to be significant. When comparing the effects of drug-related homicides with those of non-drug-related homicides, they obtain negative and significant results for the drug-related homicide rate. The model recognizes some form of spatial interaction since it clusters the standard errors by state.

These last two studies are particularly relevant to the case we deal with here as both approaches seek to link their empirical models to the growth literature in a similar way to the method we adopt here. However, our analysis differs from these two studies in various ways. We seek to undertake a more comprehensive analysis of the Drug War in Mexico by including an approximation of military expenditure instead of using federal grants (Pan et al., 2012) and municipal government expenditure (Enamorado et al., 2014). The expenditure figures used by these two studies are not earmarked to fight DTOs, while a key feature of our study is that we explicitly model the Mexican government's policy to fight DTOs by including military expenditure.

Other differences concern choices regarding the empirical methodology and data employed. Enamorado et al. (2014) opt for ordinary least squares and two-stage least squares in conducting their cross-sectional analysis, whereas Pan et al. (2012) use a spatial model with panel data. Neither of these models is dynamic. Here, by employing a difference-generalized method of moments (GMM) model, we take into account the dynamic nature of the data, and control for autocorrelation. The range of our data is also greater than that drawn on in these two previous studies. By considering data from 2003 to 2013 we cover all of Calderón's presidency (and several years before).

In the absence of the policy implemented by Calderón's administration, it is likely that the homicide rate, in common with other crime indicators, would have followed the downward trend and eventually abated. However, the violence of this period was generated by a) the confrontation between government officials and DTO members; b) the struggles that broke out between DTO lieutenants as they fought to take power following the beheading of a DTO; and c) the expansion of turf boundaries by a DTO and the ensuing struggle for power with a competing DTO.

To enhance the measurement of crime indicators related to DTOs, we gave individual consideration to a range of high-impact crime variables. Indeed, these were the variables used by the government to assess progress during the Drug War. Government expenditure on the fight against crime is central to our model, since we wish to identify the effect of this spending on the state economy. Therefore, we concentrate on an approximation of state-level military budgets.

3. The Policy

During the last decade of the 20th century, the number of DTOs increased as a result of cartel fragmentation, an increase in political competition, and anti-corruption reforms (Snyder and Duran-Martinez, 2009, p. 270). The growth of DTOs across the country weakened the government's position, even had they wanted to strike a new deal with the drug lords.

Towards the end of Fox's administration (2001-2006), DTO-related homicides rose significantly, from 9,329 in 2004 to 10,452 in 2006. Unsurprisingly, one of the main pillars of Calderón's campaign was to strengthen the rule of law, given that to continue tolerating DTOs would have represented too high a political cost (Chabat, 2010). In December 2006, Calderón launched the 2007-2012 Directive for the Integral Fight against Drug Trafficking (*Directiva para el Combate Integral al Narcotráfico 2007-2012*).

While the Mexican military had played some role in fighting the DTOs for some time, the Directive introduced new and more aggressive guidelines against drug trafficking. It identified four strategies to support its national security policy: 1) Improve operation schemes to eradicate local cultivations, intercept illegal drug trafficking, and fight DTOs; 2) Contribute to activities organized by public security institutions to guarantee a safe social environment; 3) Help maintain the rule of law by fighting armed criminal organizations; 4) Strengthen army and air force capacities to enforce laws against firearms and explosives. This fourth point aimed at identifying and stopping the illegal firearm flows coming from the U.S.

With the new Directive, "[t]he federal government […] deployed thousands of federal troops to man checkpoints, establish street patrols, and oversee other domestic law enforcement functions in high drug violence states" (Shirk, 2012, p. 10). In addition, the military inspected hangars, deposits, mail delivery companies, and bus and train stations. The military also cooperated with police forces to stop criminals. During Calderón's administration, the Defense Department reported the detention of 9 high-ranking drug lords and 149 cartel lieutenants (Defense Department's activities reports, 2007-2012).

Figure 3.1: Evolution of the real military spending and the homicide rate per 100,000 habitants, 2000-2013

Source: Based on data from INEGI and PEF.

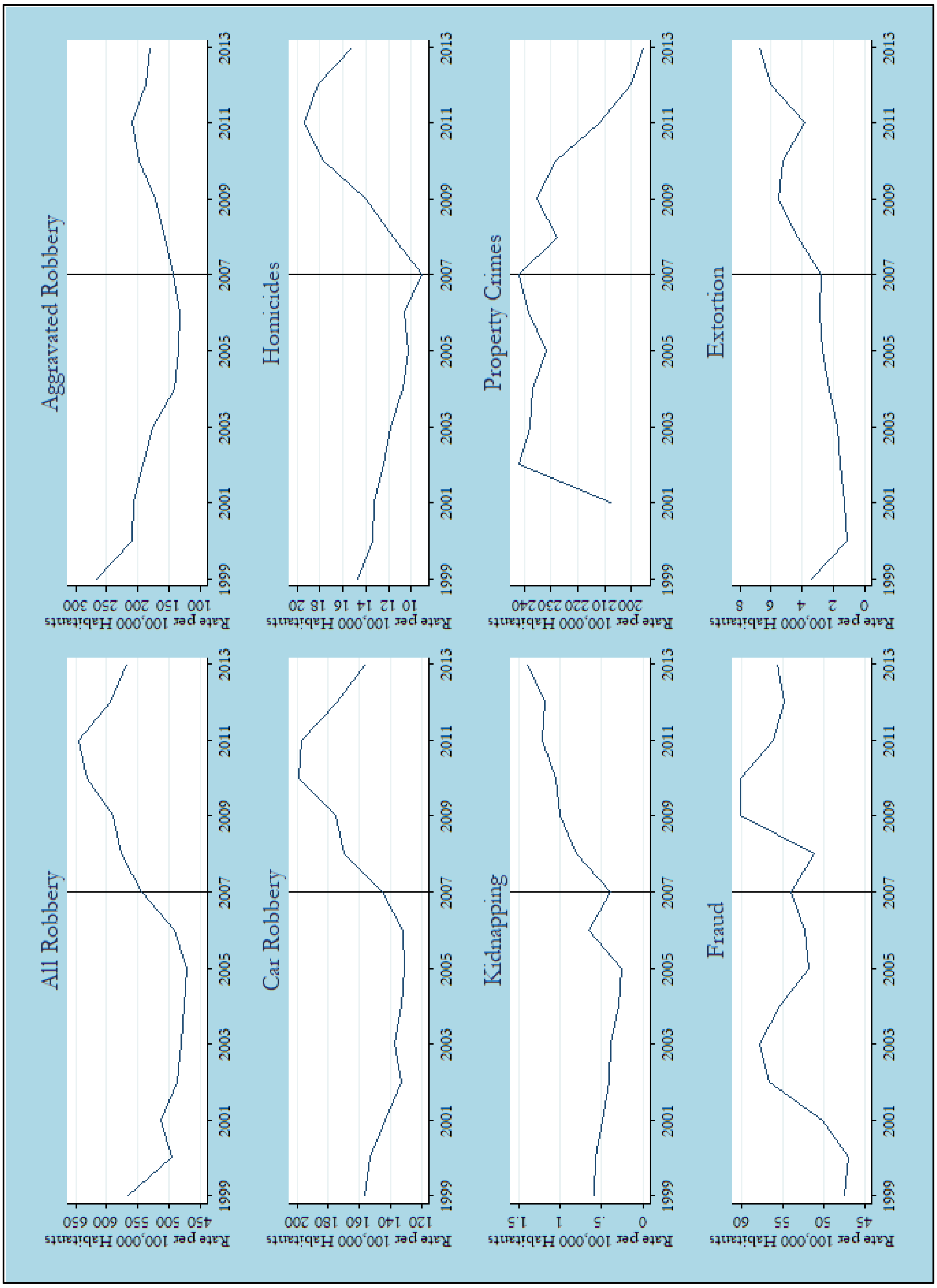
The fight against the drug cartels was not conducted by the military forces alone. In fact, Calderón deployed the army, navy, and federal police forces, which reflected the lack of capacity or integrity (or both) of local police (Shirk and Wallman, 2015). The role played by the navy is particularly interesting; according to Camp (2010), the navy tends to be more transparent than the army, and more willing to cooperate internationally. If we compare the respective forces, we find that in 2012 the navy numbered 53,505 sailors, while the army totaled 209,716 soldiers. Figure A3.1 in the Appendix compares the evolution in the two forces' budgets during the Drug War.

Military operations are costly, and indeed the government increased the Defense Department's budget over real GDP from 0.24% in 2006 to 0.47% by 2012. If we consider total military expenditure as a percentage of GDP, then it rose from 0.4 to 0.6% between 2006 and 2012, according to World Bank data. Similarly, expenditure increased in all Mexico's military regions, but regions III, IV, V and VI (where the Drug War waged was particularly intense) recorded larger increases in several years, and an increase well above the average for the period. Figure A3.2 in the Appendix shows the budget increases for all military regions in the period 2006-2012.

Calderón's determination to fight the drug cartels won the support of the U.S. government. On 30 June 2008, the Merida Initiative was passed by the U.S. congress. As a result of this initiative, the U.S. government offered to support the Mexican government with a three-year, $1.4 billion U.S. Dollar aid package to be used for judicial reform, institution-building, human rights and rule-of-law issues (Shirk, 2010). In addition, the Mexican military acquired helicopters and surveillance aircrafts. Despite Calderón's policy (or, perhaps, because of it), the number of homicides in the country rose markedly during the administration. In fact, all criminal activities related to DTOs experienced a significant increase: drug trafficking, homicides, kidnappings, the armed robbery of vehicles, etc.

Figure 3.1 shows the evolution in military spending and the homicide rate per 100,000 habitants, while Figure 3.2 shows that crime increased substantially during the period 2006-2012. The largest increases were recorded in extortion (113%), kidnapping (79%), homicides (70%), and aggravated robbery (41%).

Figure 3.2: Rate of crime variables associated to DTOs per 100,000 habitants in Mexico, 1999-2013



Source: Based on data from INEGI and SNSP.

4. Empirical Strategy

We use a simple Cobb-Douglas production function, in line with that proposed in Mankiw et al. (1992), and adapt it to the regional β-convergence hypothesis, as discussed in Barro et al. (1991). β-convergence refers to the negative relationship between the rate of growth of a particular variable (here GDP per capita) and the initial level of that variable. Furthermore, we model violence and the efforts to fight this violence by introducing a deterrent variable. The development of the theoretical model is presented in Appendix A and B. For our empirical strategy, we introduce the following econometric specification of the dynamic panel data model used herein:

$$y_{it} = \alpha + (1+\beta_1)y_{it-1} + \beta_2 k_{it} + \beta_3 h_{it} + \beta_3 n_{it} + \delta_1 Fin.Crisis_t + \delta_2 HR_{it} + \delta_3 MB_{it} + \varepsilon_{it} \quad (1)$$

where y_{it} is the logarithm of real state GDP in per capita terms, α is the intercept, y_{it-1} is the logarithm of initial state GDP per capita and $\beta_1 = -(1 - e^{-\beta_0 T})$, which informs us about the speed of convergence. This becomes evident if we transform equation (1) into first differences, as proposed by Arellano and Bond (1991), to eliminate state-specific effects:

$$y_{it} - y_{it-1} = \alpha - \left(1 - e^{-\beta_0 T}\right)y_{it-1} + \beta_2 \Delta k_{it} + \beta_3 \Delta h_{it} + \beta_3 \Delta n_{it} + \delta_1 \Delta Fin.Crisis_t + \delta_2 \Delta HR_{it} + \delta_3 \Delta MB_{it} + \Delta\varepsilon_{it} \quad (2)$$

In this specification, real state GDP is expressed in per capita terms. In addition to fitting the theoretical model, the per capita adjustment of real GDP helps to control for population size and migration. This variable selection is in line with that employed in similar studies, including Abadie and Gardeazabal (2003), Bilgel and Karahasan (2015) and Pinotti (2014).

Furthermore, k_{it} and h_{it} are the variables that approximate physical and human capital (in logarithms), respectively, and n_{it} is the population growth rate. We also introduce a dummy for the 2008-2009 financial crisis, the logarithm of the homicide rate per 100,000 inhabitants (HR_{it}), and the logarithm of the approximation of state military spending in per capita terms (MB_{it}). Finally, ε_{it} is a stochastic error term.

To ensure that our model is correctly specified, we ran several diagnostic tests to check that no important assumptions of our spatial model are violated.

With variance inflection factors between 1.02 and 1.19 for all variables, we can rule out the presence of multicollinearity. To control for heteroscedasticity, we used robust standard errors. Furthermore, we included a one-period time lag of the dependent variable to account for the time autocorrelation.

Overall, we expect positive signs for the lagged absolute value of real GDP per capita, physical capital and human capital, whereas the 2008-2009 financial crisis should have a negative impact on the economy of the states. We also expect the homicide rate to negatively affect the economy. In the case of the government expenditure variable in the form of military spending, we expect a positive sign, given that the Drug War does not destroy physical assets and that government spending enters the GDP equation positively from the demand side.

5. Data

For our estimations, we draw on balanced panel data for all 32 Mexican states (the *Distrito Federal*, the capital, is considered a contiguous state) for the period 2001-2013. The state-level is the smallest spatial unit for which all the variables considered here were available. During this period, a political change took place at the presidential level. With this, an important shift was recorded in homeland security policy. This period also coincides with the 2007-2012 Directive for the Integral Fight against Drug Trafficking, or 'Drug War'.

We obtained population data for each state from the National Population Council (CONAPO), the institution responsible for overseeing the national census. The last census was conducted in 2010. We also use CONAPO's population forecasts for 2010-2013. These population data are used to compute per capita figures and violence rates. The time series for real state GDP by state were obtained from INEGI. Figure A3.3 in the Appendix shows cross-sectional maps of GDP per capita growth from 2004-2013.

In the absence of official capital stock data, we use the figures presented in German-Soto (2015), which are a computation of the capital stock data described in German-Soto (2008). Data for human capital are also scarce. The regional science literature circumvents this problem by using the regional share of population with tertiary education. However, this information is not available for the whole period. Therefore, we opted to use state averages of years of schooling instead.

Both INEGI and the Interior Department publish homicide statistics. INEGI uses administrative registers from the National Health Information System (SINAIS), which follow the classification recommended by the WHO, whereas the Interior Department compiles its data from police investigation files. Although INEGI is unable to identify a homicide as being related to a drug crime, we opted for this source for several reasons. First, INEGI is a more trustworthy source than the Interior Ministry due to its autonomy (working as it does independently of any law-enforcement agency). Second, there have been newspaper reports about police forces failing to investigate murders in some northern states due to the great volume of homicides. According to Shirk and Wallman (2015), less than 25 percent of crimes are reported, and only 20 percent of these are investigated. And, third, it has been suggested that the government might manipulate data to improve its approval ratings and to support its security strategy.

Information about military and navy budgets is not publicly available at the state level. We undertook searches of government records and budgets but were unable to find state budgets for either military or navy spending. We followed this up with a formal information request, but were informed that this information was only available at the regional level. We managed to obtain regional military budgets for the 12 regions that are made available in the Federation's Expenditure Budget (*Presupuesto de Egresos de la Federación*, PEF) for each year. This subdivision into regions was only available for the military, but not for the navy or federal police. For that reason, we focus on the military budget only.

The budget contains information on a wide range of subjects including the funding destined to each of the 12 military regions. Each region can comprise up to five states. Figure 3.3 describes which states make up each military region.

Due to the lack of data on military budgets by state, we approximate them by weighting the regional budget with variables that are good indicators of military involvement in the 'Drug War'. First, we took the number of homicides in each state. Moreover, when conducting the robustness checks, we also considered the number of people detained during operations targeting DTO activities, the number of vehicles seized either in operations targeting drug criminals or when conducting searches at specific check-points, and the number of investigation files opened. Using these variables only (and not any other crime variables) to weight military budgets adheres to the intuition that military budgets are assigned to those areas (states) where the activity of the DTOs is most intense. Most military regions comprise either two or three states, which means the error associated with the weighting of the variables is limited. Dividing a national budget by the 32 states would, on the other hand, contain a large error.

Figure 3.3: Mexican Military Regions

Note: The Mexican Military Regions comprise the following federal states:

Military Region I:	Distrito Federal; Hidalgo; State of Mexico; Morelos
Military Region II:	Baja California; Baja California Sur; Sonora
Military Region III:	Sinaloa; Durango
Military Region IV:	Nuevo León; San Luis Potosí; Tamaulipas
Military Region V:	Aguascalientes; Colima; Jalisco; Nayarit; Zacatecas
Military Region VI:	Puebla; Tlaxcala; Veracruz
Military Region VII:	Chiapas; Tabasco
Military Region VIII:	Oaxaca
Military Region IX:	Guerrero
Military Region X:	Campeche; Quintana Roo; Yucatán
Military Region XI:	Chihuahua; Coahuila
Military Region XII:	Guanajuato; Michoacán; Querétaro

Source: Based on data form the Defense Secretary (*Secretaría de la Defensa*, SEDENA)

The variables selected for weighting the regional military budgets during the period considered are well suited because: a) they show temporal and spatial variation, and b) they are closely related to the Drug War strategy initiated by Calderón. For example, if a region comprises two states, one in which DTOs are highly active and one with little DTO activity, we can expect a higher share of the budget during the Drug War to be allocated to the state in which DTOs are more active. All four variables are reported by INEGI in its *Anuario Estadístico y Geográfico por Entidad Federativa* and are computed specifically for the 'Drug War'. However, they do not refer solely to the actions taken by the military, and include also the efforts of the navy as well as those of the federal and local police. To show some of the characteristics of these weighting variables, we report their descriptive statistics in Table A3.1 in the Appendix.

Table 3.1 describes the variables used in our econometric specification of the model. Table 3.2 presents the descriptive statistics for these variables. The rates of kidnapping, extortion, property crimes and fraud include fewer observations because some states did not report occurrences in some years.

Table 3.1: Description of Variables

Variable	Description	Source
GDP p.c.	Logarithm of the real State GDP per capita (in $MXN of 2008)	INEGI
Physical Capital	Stock of physical capital per capita by State (in logarithms)	Germán-Soto (2015)
Human Capital	Average years of schooling of the general population aged 15 and more per State (in logarithms)	INEGI
Population Growth	Population growth rate in %	CONAPO
Financial Crisis	Binary variable: 1 for the years 2008-2009; 0 otherwise	-
Homicides	Homicides rate per 100,000 habitants (in logarithms)	INEGI
Kidnappings	Kidnapping rate per 100,000 habitants (in logarithms)	SNSP
Extortions	Extortion rate per 100,000 habitants (in logarithms)	SNSP
Car Robbery	Car Robbery rate with and without violence per 100,000 habitants (in logarithms)	SNSP
All Robbery	Robbery rate per 100,000 habitants (in logarithms). This robbery rate includes all type of robbery	SNSP
Aggravated Rob.	Aggravated robbery rate per 100,000 habitants (in logarithms)	SNSP
Property Crimes	Property Crimes rate per 100,000 habitants (in logarithms)	SNSP
Fraud	Fraud rate per 100,000 habitants (in logarithms)	SNSP
MB (Homicides)	Military budget per capita (in $MXN of 2008) weighted by the number of homicides (in logarithms)	PEF / INEGI
MB (Detained People)	Military budget per capita (in $MXN of 2008) weighted by the number of detained people during drug war operations (in logarithms)	PEF / INEGI
MB (Investigations)	Military budget per capita (in $MXN of 2008) weighted by the number of investigations opened (in logarithms)	PEF / INEGI
MB (Seized Vehicles)	Military budget per capita (in $MXN of 2008) weighted by the number of seized vehicles during drug war operations (in logarithms)	PEF / INEGI

Table 3.2: Descriptive Statistics of the Model

Variable	Mean	Std. Deviation	Min.	Max.	Obs.
Log of GDP p.c.	11.4737	0.5723	10.5101	13.9922	320
Log of Physical Capital	-2.9863	0.8156	-4.6369	-0.6614	320
Log of Human Capital	2.1253	0.1110	1.7846	2.3780	320
Population Growth Rate	0.0145	0.0072	-0.0020	0.0388	320
Financial Crisis	0.2000	0.4006	0.0000	1.0000	320
Log of Homicide Rate	2.3315	0.8578	0.5403	5.2048	320
Log of Kidnapping Rate	-0.6922	1.1867	-3.9120	3.6014	284
Log of Extortion Rate	1.2401	1.0675	-2.9957	3.5888	263
Log of Car Robbery	4.4647	1.0642	0.7696	7.0108	320
Log of All Robbery	6.1015	0.7147	3.8497	7.7904	320
Log of Aggravated Robbery	4.4099	1.0635	0.0091	7.1547	320
Log of Property Crimes	5.2891	0.7036	2.4360	6.5503	319
Log of Fraud	3.8444	0.8208	-1.4819	5.021314	318
Log of MB (Homicides)	19.6775	1.2100	16.8678	23.3175	320
Log of MB (Detained People)	19.6575	1.2211	15.8109	23.3908	320
Log of MB (Investigations)	19.6900	1.1514	17.1934	23.4032	320
Log of MB (Seized Vehicles)	19.7143	1.2000	16.1260	23.1624	320

6. Results

The results of our policy analysis of the 'Mexican Drug War' are reported in Table 3.3. Here, various econometric specifications are presented: first, to generate some intuition about the variables, we introduce a restricted version of the model using a fixed effects estimation (columns 1-4). This specification is common for regions for which physical capital and human capital variables are unavailable. Then, we refine the accuracy of our estimates by introducing physical and human capital stocks (columns 2-4). In column 2 we introduce the homicide rate provided by INEGI as a proxy for violence and in column 3 we use the homicide rate weighted by the military budget. Column 4 includes both these variables.

As mentioned, equations 1-4 are estimated with fixed effects so as to generate some intuition and to show our variables of interest have a certain level of robustness. However, fixed effects regressions are biased because they do not account for the dynamic nature of the model. Neglecting to do so leads to consistency issues as described in detail by Nickell (1981). To overcome this, we use the difference-GMM panel data specification developed by Arellano and Bond (1991) in columns 5-8. This method takes into account the dynamic nature of the lagged dependent variable, by differentiating with one-period lagged values correcting for the bias. Because of this, the estimation reports 288 observations instead of 320.

Table 3.3: Estimation Results (Dep. variable: Log of GDP p.c.)

Dep. Variable: Log of GDP p.c.	(1) Fixed Effects	(2) Fixed Effects	(3) Fixed Effects	(4) Fixed Effects	(5) Difference GMM	(6) Difference GMM	(7) Difference GMM	(8) Difference GMM
Log of GDP p.c. (t-1)	0.824***	0.611***	0.616***	0.602***	0.986***	0.701***	0.718***	0.707***
	(0.0317)	(0.0360)	(0.0357)	(0.0361)	(0.0502)	(0.169)	(0.148)	(0.149)
Log of Physical Capital		0.215***	0.215***	0.220***		0.467***	0.386***	0.410***
		(0.0228)	(0.0229)	(0.0229)		(0.0743)	(0.0379)	(0.0646)
Log of Human Capital		0.0403	0.136**	0.0641		-1.625***	-0.995***	-1.357***
		(0.0707)	(0.0616)	(0.0716)		(0.441)	(0.289)	(0.276)
Population Growth	2.630**	1.347	1.131	1.094	7.704**	-11.16***	-6.829**	-0.428
	(1.101)	(0.957)	(0.968)	(0.962)	(3.021)	(4.309)	(3.231)	(3.110)
Financial Crisis	-0.0514***	-0.0377***	-0.0375***	-0.0365***	-0.115***	-0.0494**	-0.0675***	-0.0631***
	(0.00460)	(0.00423)	(0.00426)	(0.00427)	(0.00968)	(0.0200)	(0.0177)	(0.0149)
Log of Homicide Rate	-0.00276		-0.00361	-0.00835*	-0.0727***		-0.0284***	-0.0390***
	(0.00519)		(0.00387)	(0.00455)	(0.0145)		(0.00868)	(0.0111)
Log of weighted MB	0.00375	0.00577		0.0116*	-0.0564***	0.0545*		0.0762***
	(0.00577)	(0.00503)		(0.00592)	(0.0200)	(0.0317)		(0.0204)
Observations	288	288	288	288	288	288	288	288
R-squared	0.783	0.840	0.840	0.842				
Number of States	32	32	32	32	32	32	32	32
Chi^2 of the Wald test					1467***	420.2***	638.1***	1527***
AR(1)					-3.332***	-1.213	-2.113**	-3.493***
AR(2)					0.885	1.781*	0.967	1.624
Hansen test p-value					0.111	0.478	0.269	0.283

Note: Weighted MB is the military budget weighted by the number of homicides. Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

From the performance statistics provided at the bottom of Table 3.3, we can see that the GMM estimations fit the model well because the chi^2-statistic of the Wald test strongly rejects (at the 1% level) the null hypothesis of the joint statistical insignificance of the covariates. Due to the inclusion of the lagged value of the dependent variable as a covariate (which is highly significant in the fixed effects estimations), first-order serial correlation in the first-differenced errors is expected. We then reject the existence of second-order serial correlation in the first- differenced errors. With these results for the different tests we can affirm that our model is correctly specified and that the moment conditions are valid.

Difference-GMM panel data estimations rely on a series of lagged variables that are then differenced and used as instruments. The Hansen test checks that the over-identifying restrictions are valid. The inclusion of all possible instruments in a small sample size would result in too many over-identifying restrictions and consequently the specification would perform poorly. To overcome this, we restrict the number of instruments in each equation so that the Hansen over-identification test is not rejected.

In all our estimations, we use the same dependent variable: i.e. the logarithm of real state GDP per capita. The logarithm of the lagged value of GDP per capita (interpreted as the initial level) is positive and highly significant for all specifications. Bearing in mind that $\beta_1 = -(1 - e^{-\beta_0 T})$, the results are intuitive and in line with economic theory. Richer economies tend to have low GDP growth rates while poorer economies tend to have higher rates.

The variable for the per capita physical capital stock performs well, being positive and highly significant. For the human capital variable proxied by average schooling years, the coefficient is significant and negative. This negative sign is found in other studies that undertake panel data analyses in an augmented Solow Model framework (Benhabib and Spiegel, 1994; Islam, 1995), and is attributed to a lack of variability in the education averages once jurisdiction-specific heterogeneity (state-specific fixed effects) is accounted for.

The 2008-2009 financial crisis had a marked impact on Mexican states. As expected, the estimates are negative and highly significant for all specifications. The descriptive map (Figure A3.3 in the Appendix) shows that in 2008 signs of the crisis began to emerge, but that it was not until 2009 that all 32 states reported negative growth rates in their per capita output. Hence, the magnitude and the negative sign of the coefficient of this two-year dummy seems reasonable.

In the approach reported here, we measure growth in the homicide rate, i.e., we focus on the flow but not on the stock of homicides. We obtain negative and highly significant coefficients. A negative sign is clearly intuitive if we consider the wave of violence affecting Mexico to be a deterrent to the states' economic performance. Thus, not only do drug-related homicides seem to affect state economic growth, but the increase in violence in terms of homicides seems to have negative and highly significant marginal effects.

Our results for this DTO-associated crime variable are in line with results in Enamorado et al. (2014) for the drug-related homicide rate (measured in levels). The coefficients indicate a negative association with state GDP per capita. In Pan et al. (2012), the aggregate crime variable has a positive and significant sign, resulting from the fact that their variable is an aggregation of crimes which may have opposite signs.

Here, the military budget weighted by the number of homicides in each state is positive and highly significant for the full model specification reported in column 8. In keeping with our claim that the weighted military budget should be a good indicator of where the Drug War strategy was implemented most intensely, this positive association indicates that military spending had a positive effect on state GDP per capita growth.

To address potential issues of reverse causation, we check for the possibility that states with high growth rates demand or receive greater military intervention. To do this, we focus on the correlations of our variables (Table A3.2 in the Appendix) and the auxiliary difference-GMM regression between the growth rate of state GDP per capita and the weighted military budget options. From this analysis, we find that the correlations are minimal while the regression indicates no significant effects. The results of this auxiliary regression can be found in Table A3.3 in the Appendix.

6.1 Weighting Alternatives for Military Expenditure

Weighted military expenditure is our main variable of interest. For this reason, we consider it both pertinent and necessary to show that the budget is robust to different ways of weighting it. Thus, we tested additional weight variables associated with the fight waged by the Mexican military against DTOs.

In the category of crimes catalogued as crimes against society, the number of detentions is specifically related to "crimes against health", including such crimes as drug trafficking, terrorist acts, human organ trafficking and trafficking of other illegal products. Here, INEGI reports the number of people detained during such crimes and the number of vehicles seized. Additionally, it is evident that most criminal investigations (per capita) are conducted in those states that are being disputed by DTOs. We chose investigations because it is often the case that the authorities initiate inquiries into shootings between DTOs or they find mass graves in a DTO territory.

Table 3.4: Estimation with alternative weight variables for state level military expenditure (Dep. variable: Log of GDP p.c.)

Dep. Variable: Log of GDP p.c.	(1) Difference GMM	(2) Difference GMM	(3) Difference GMM	(4) Difference GMM
Log of GDP p.c. (t-1)	0.707***	0.405***	0.393***	0.608***
	(0.149)	(0.0523)	(0.0455)	(0.0918)
Log of Physical Capital	0.410***	0.241***	0.270***	0.225***
	(0.0646)	(0.0274)	(0.0343)	(0.0462)
Log of Human Capital	-1.357***	0.373***	0.457***	-0.177
	(0.276)	(0.144)	(0.122)	(0.243)
Population Growth Rate	-0.428	2.878*	3.049***	0.969
	(3.110)	(1.518)	(0.843)	(2.323)
Financial Crisis	-0.0631***	-0.0534***	-0.0542***	-0.0666***
	(0.0149)	(0.00584)	(0.00454)	(0.00925)
Log of Homicide Rate	-0.0390***	-0.00925***	-0.00551***	-0.0156*
	(0.0111)	(0.00233)	(0.00182)	(0.00880)
Log of MB (Homicides)	0.0762***			
	(0.0204)			
Log of MB (Detained People)		0.0109***		
		(0.00301)		
Log of MB (Investigations)			0.00503**	
			(0.00208)	
Log of MB (Seized Vehicles)				0.0215***
				(0.00660)
Observations	288	288	288	288
Number of States	32	32	32	32
Chi^2 of the Wald-Test	1,527***	46,175***	107,492***	2,463***
AR(1)	-3.493***	-3.746***	-3.414***	-3.896***
AR(2)	1.624	1.211	0.501	1.146
Hansen Test p-value	0.283	0.958	0.977	0.151

Note: MB stands for the military budget weighted by the indicator in parentheses. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

The results in Table 3.4 show that the estimates are positive, highly significant, and range from 0.0109 to 0.0762. Recall that caution is needed when interpreting the magnitude of this variable, because it is a state approximation for data that are available only at regional level.

The results for these variables present the opposite sign to that reported by Enamorado et al. (2014) and Pan et al. (2012). However, in their models, the public expenditure variables are overly generic, since they target neither the improvement in public security, in general, nor the fight against DTOs, in particular.

The war waged against DTOs is unlike any other. While typical wars target strategic physical assets such as transport, energy and communication infrastructure, a drug war is waged differently. Ongoing military operations to fight drug criminals bring with them the need for increased government spending, especially to sponsor field operations conducted by military troops (mainly infantry). Thus, rather than facing the widespread destruction of physical assets, the drug war results in increased government expenditure. The extraordinarily high level of military spending by Mexican standards is positively associated with the growth rate of real state per capita GDP.[8] Mexico presents an annual average increase of 8.33% between 2006 and 2012 in its real military expenditure, which is much higher than that recorded in the other major countries (population > 20M) of Latin America: Brazil (5.24%), Colombia (4.92%), Argentina (2.10%), Peru (5.87%) and Venezuela (6.31%) [Data taken from Stockholm International Peace Research Institute (SIPRI)].

6.2 Robustness of Violence

To show the robustness of our estimates for the violence variable, we present the estimation results obtained when using alternative proxies for crime and violence. These include rates of kidnapping, extortion, car robbery, overall robbery, aggravated robbery, property crimes and fraud. These criminal activities are often associated with the diversification of DTOs (Rios, 2008; Shirk, 2012; Calderón et al., 2015). The results are presented in Table 3.5.

[8] It is logical to believe that the drug lords will have increased their expenditure on arms, vehicles, personnel (*sicarios*), and other means to fight increasing government action, thus boosting demand in a state's economy. However, for obvious reasons, we cannot empirically address this assumption.

Comparing the estimates of the violence proxies, we see that all coefficients present a similar magnitude and are highly significant. Hence, our results are in line with the findings (also negative and significant) reported by Enamorado et al. (2014) for drug-related homicides.

Table 3.5: Estimation with different variables describing violence in Mexican States (Dep. variable: Log of GDP p.c.)

Dep. Variable: Log of GDP p.c.	(1) Difference GMM	(2) Difference GMM	(3) Difference GMM	(4) Difference GMM	(5) Difference GMM	(6) Difference GMM	(7) Difference GMM	(8) Difference GMM
Log of GDP p.c. (t-1)	0.707***	0.320***	0.339***	0.509***	0.440***	0.482***	0.445***	0.503***
	(0.149)	(0.0705)	(0.0604)	(0.0735)	(0.0841)	(0.0542)	(0.0425)	(0.0508)
Log of Physical Capital	0.410***	0.602***	0.237***	0.245***	0.569***	0.514***	0.464***	0.235***
	(0.0646)	(0.0381)	(0.0244)	(0.0366)	(0.0448)	(0.0255)	(0.0237)	(0.0286)
Log of Human Capital	-1.357***	-0.0826	0.608***	-0.292***	-0.965***	-0.841***	-0.660***	0.0998
	(0.276)	(0.168)	(0.170)	(0.103)	(0.218)	(0.130)	(0.0855)	(0.0961)
Population Growth Rate	-0.428	1.668	4.600***	-2.578***	-6.717**	-9.775***	-5.730***	0.466
	(3.110)	(1.045)	(0.857)	(0.779)	(2.774)	(1.746)	(1.490)	(0.574)
Financial Crisis	-0.0631***	-0.0267***	-0.0504***	-0.0578***	-0.0418***	-0.0341***	-0.0343***	-0.0582***
	(0.0149)	(0.00812)	(0.00535)	(0.00829)	(0.0103)	(0.00484)	(0.00453)	(0.00553)
Log of weighted MB	0.0762***	0.0342**	0.00676*	0.0150*	0.0429**	0.0333***	0.0186***	0.0110**
	(0.0204)	(0.0145)	(0.00364)	(0.00818)	(0.0180)	(0.00620)	(0.00480)	(0.00440)
Log of Homicide	-0.0390***							
	(0.0111)							
Log of Kidnapping		-0.0147***						
		(0.00295)						
Log of Extortion			-0.00197**					
			(0.000919)					
Log of Car Robbery				-0.00906***				
				(0.00215)				
Log of Robbery					-0.0724***			
					(0.0212)			
Log of Aggravated Robb.						-0.0130**		
						(0.00517)		
Log of Property Crimes							-0.0218***	
							(0.00436)	
Log of Fraud Rate								-0.00360**
								(0.00158)
Observations	288	241	230	288	288	288	286	284
Number of State	32	31	31	32	32	32	32	32
Chi^2 of the Wald Test	1527***	977.0***	151197***	139491***	499.4***	2307***	7652***	12974***
AR(1)	-3.493***	-2.131**	-3.458***	-3.620***	-0.950	-1.110	-2.059**	-4.823***
AR(2)	1.624	-0.517	0.830	1.521	0.827	0.835	0.500	1.489
Hansen test p-value	0.283	0.648	0.982	0.359	0.297	0.971	0.858	0.948

Note: Weighted MB is the military budget weighted by the number of homicides. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

6.3 Spatial Effects

Although most actions undertaken by the states to fight DTOs (i.e. operations conducted by local and state police) are limited by individual state jurisdictions, military action and drug trafficking activities are not. For this reason, we study the existence of spatial effects in neighboring states. Table A3.4 in the Appendix shows the results of the estimation output for the spatial model. The signs of the coefficients are consistent with those obtained in the difference- GMM model described above. Likewise, the coefficients of the approximated state military spending are positive and in almost all cases highly significant. Thus, our weighted military budget approximation is robust to the inclusion of a spatial component. Finally, all the crime variables used here are negative; however, not all remain significant.[9]

7. Conclusions

This paper has analyzed the Mexican government's policy in its fight against DTOs and drug-related violence. Moreover, it has studied the effects of this policy on state GDP per capita using a panel data GMM model developed within the theoretical framework of regional convergence.

We focus our attention on the effects of the policy implemented by the government to fight DTOs as approximated by state-level military spending. As only regional military budgets are available, we propose a state-level approximation of the military budget. We detect two different effects of the 'Drug War' policy on economic growth: on the one hand, the escalation in violence since the adoption of the 'Drug War' strategy has resulted in significant negative effects on economic growth, regardless of the crime variable employed; on the other hand, military expenditure at state level presents a positive and significant effect on state economic growth. Our results indicate that an increase of 1 percentage point in the military budget (weighted by the number of people detained) is associated with an increase of 0.011 to 0.076 percent in the state GDP per capita growth rate.

[9] The coefficient for the spatial variable (the W-matrix multiplied by the spatially lagged value of state GDP p.c. included in the model) is positive and significant. We perform a standard test to ensure that the spatial coefficient is different from zero. Based on the significance of the values reported in the table, we reject the hypothesis of the spatial coefficient ϱ_1 being equal to 0.

DTOs constitute a serious problem for Mexico, and for other countries on the continent. However, the war waged against these criminal organizations is having several unintended and unforeseen consequences, with particular effects on economic activity. While we have analyzed some of these effects during president Calderón's administration, much more research is needed if we are to gain a better understanding of the problem and of how to address it. To conduct this research, the Mexican authorities need to make more and better data available to researchers, so that different dimensions of this complex public policy problem can be better analyzed.

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APPENDIX

A. Theoretical Framework

We work with a regional economy growth model, where in region i during time t the economy uses labor (L_{it}), physical (K_{it}) and human (H_{it}) capital stocks, as well as the state of technology (A_{it}) to produce its output (Y_{it}). In addition, we introduce an output deterrent variable (Z_{it}), which in our context will be a violence function $Z_{it} = f(V_{it}, S_{it}) \leq 1$, with V_{it} being the loss due to violence in our economy and S_{it} is some form of State intervention to fight the levels of violence. If $Z_{it} = 1$, our economy is not affected by violence problems. On the other hand, if $Z_{it} = 0$, our economy will not be able to function properly. The average labor productivity (y_{it}) is a function of the average levels of physical and human capital stocks:

$$y_{it} = A_{it} Z_{it} {k_{it}}^{\alpha} {h_{it}}^{\beta} \quad (1)$$

where $\alpha > 0$ and $\beta > 0$ are the internal rates of return for physical and human capital stocks respectively. We also assume that $\alpha + \beta < 1$. Technology is assumed to grow exogenously and equally for all economies. The spillovers of neighboring economies are defined by γ, which is the spillover intensity. If $\gamma = 0$, neighboring economies do not affect our incumbent economy, while if $\gamma = 1$, our economy will be affected for good or for worse. When the neighboring economies are bigger than the incumbent is, the influence is likely to be higher. For simplicity, we assume all economies to have the same influence on their neighbors. The factors $k_{\rho it}$ and $h_{\rho it}$ are the per capita ratios of physical, and human capital. $Z_{\rho it}$ denotes the violence function affecting the neighboring economies.

$$y_{it} = Z_{it}\Delta_{it}{k_{it}}^{\alpha}{h_{it}}^{\beta}(Z_{\rho it}{k_{\rho it}}^{\alpha}{h_{\rho it}}^{\beta})^{\gamma} \tag{2}$$

With these neighboring effects, when physical and human capital increase, the rate of return will be $(\alpha + \beta)(1 + \gamma)$. The spillover effects grow as the returns to capital and human capital grow. Consequently, the growth rate of y_{it} can be expressed as

$$g_y = g_Z + \alpha g_k + \beta g_h + \gamma\left(g_{\rho Z} + \alpha g_{\rho k} + \beta g_{\rho h}\right) \tag{3}$$

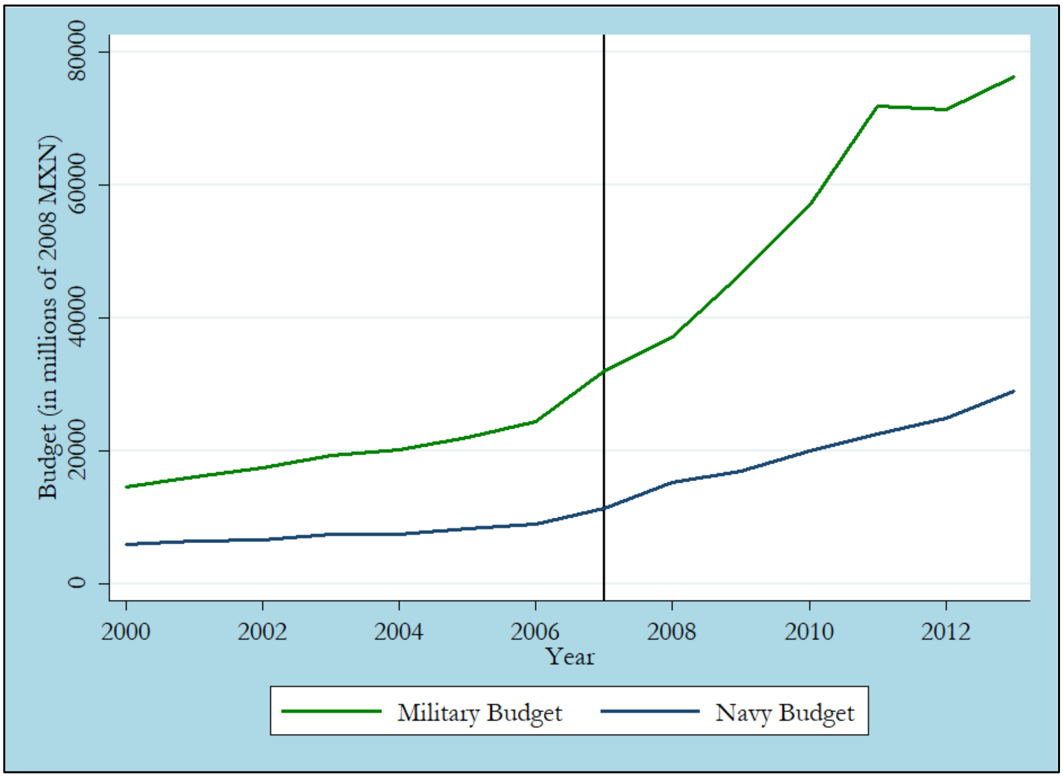
B. Spatial Analysis

To justify the inclusion of the spatial component in the model, i.e. if one region shows an influence of neighboring regions, we run the Global Moran's I test, the Global Geary's C test, the Global Getis and Ord's G test and the Pesaran test for cross-sectional dependency. They all reject the null hypothesis of absence of spatial autocorrelation, such that we can confirm the presence of spatial dependency. To determine the type of spatial dependency, we run the Lagrange Multiplier (LM) tests as well as further Wald tests and conclude that the spatial component is given by a spatial lag of the dependent variable. This leaves us with a Spatial Lag Model.

The spatial component is introduced by a W-matrix which is a binary contiguity weight matrix which is then multiplied with to state GDP per capita in surrounding states (y_{jt}) to the incumbent. The elements of the W-matrix are $w_{ij} = 1$ when two states share a common border and $w_{ij} = 0$ otherwise. This matrix is then standardized as is the usual case in the literature, such that the sum of each row of the matrix equals to 1.

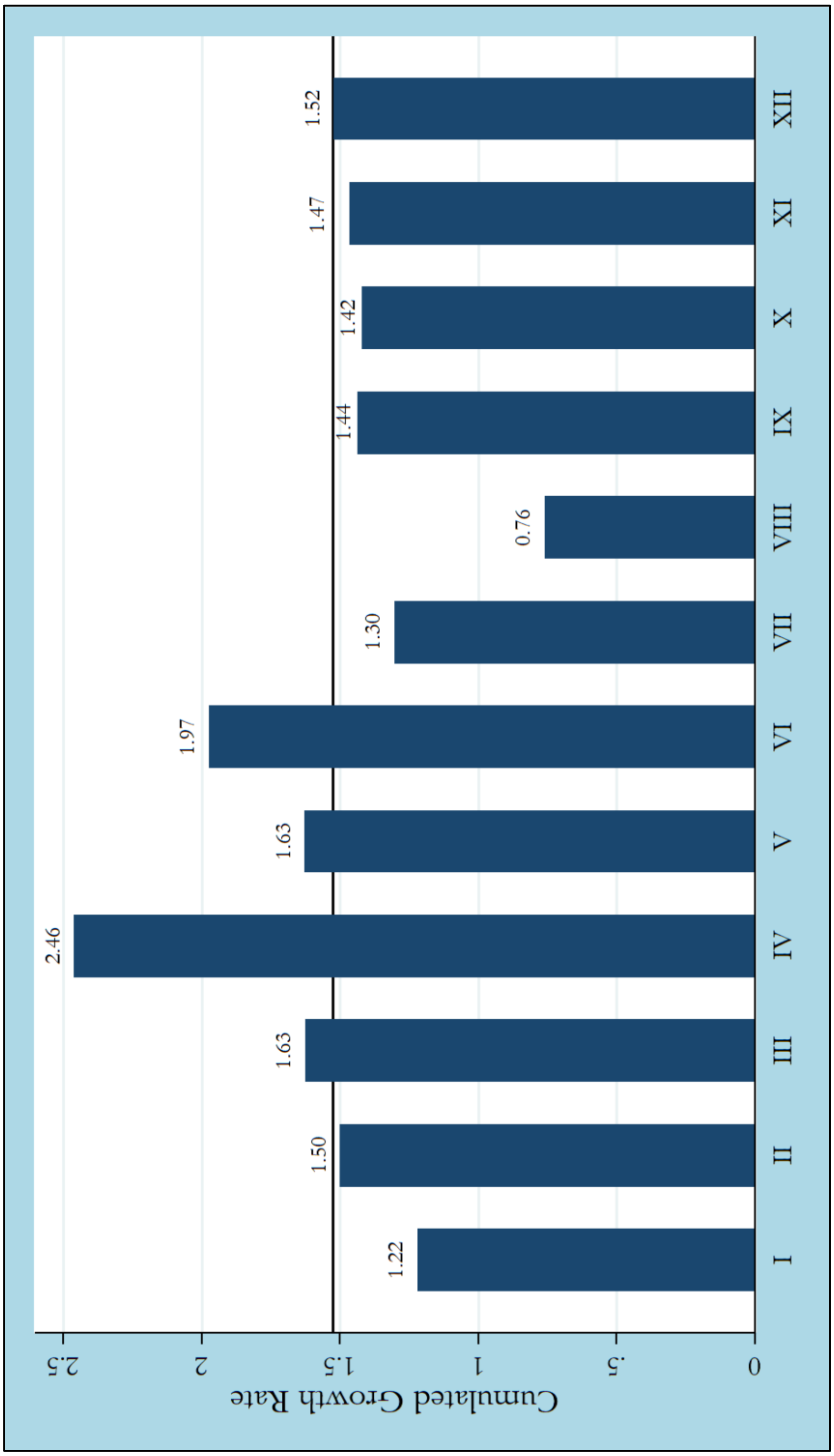
The results of the spatial analysis can be found in Table A3.4.

Figure A3.1: Evolution of the Military and Navy budgets, 2000-2013



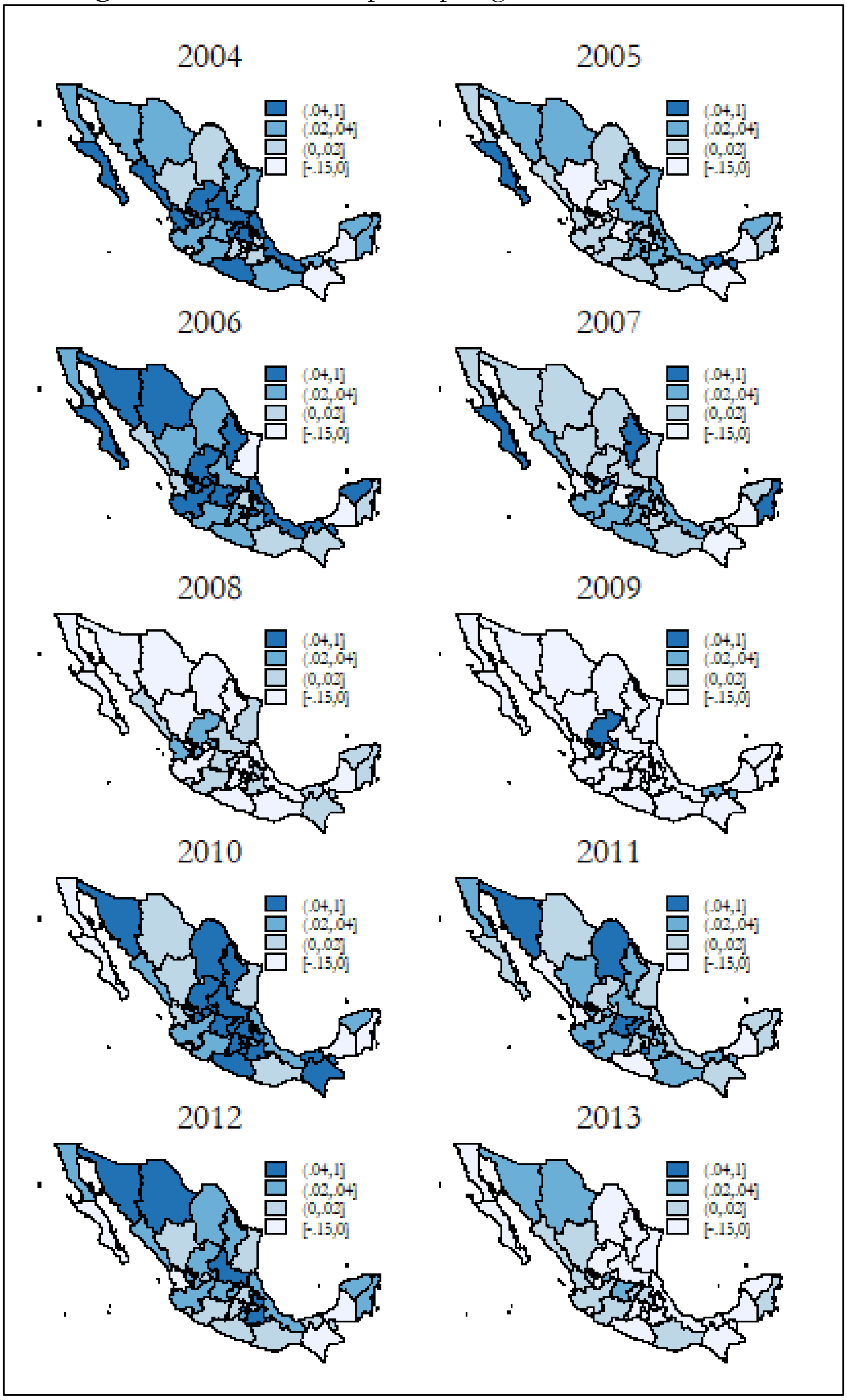
Source: Based on data from PEF.

Figure A3.2: Cumulated growth rate of the real military budget for all military regions for the period 2006-2012



Note: The horizontal line marks the average growth rate of all military regions (152%) during the period. Source: Based on data from PEF.

Figure A3.3: Real GDP per capita growth rates, 2004-2013



Source: Based on data from INEGI and CONAPO.

Table A3.1: Descriptive Statistics of the weight variables for the Military Budget

Variable	Mean	Std. Dev.	Min	Max	Obs
Homicides	544.8531	726.9028	21	6421	320
Detained People	892.3875	1313.887	5	9483	320
Previous Investigations	4534.222	6037.466	491	37025	320
Seized Vehicles	413.6062	667.4658	1	4563	320

Table A3.2: Correlation Matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1) Log of State GDP p.c.	1.000																
(2) Log of Physical Capital	0.397	1.000															
(3) Log of Human Capital	0.569	0.326	1.000														
(4) Population Growth Rate	0.239	-0.095	0.310	1.000													
(5) Financial Crisis	-0.014	-0.015	-0.001	0.145	1.000												
(6) Log of Homicide Rate	0.011	-0.260	0.052	-0.105	-0.027	1.000											
(7) Log of Kidnapping Rate	0.043	-0.074	0.101	-0.091	0.100	0.564	1.000										
(8) Log of Extortion Rate	0.089	-0.215	0.107	-0.067	0.062	0.096	0.350	1.000									
(9) Log of Car Robbery	0.325	0.041	0.451	0.085	0.061	0.536	0.467	0.163	1.000								
(10) Log of All Robbery	0.502	-0.062	0.448	0.337	0.023	0.259	0.372	0.313	0.763	1.000							
(11) Log of Aggravated Robbery	0.340	0.099	0.509	0.034	-0.039	0.405	0.446	0.251	0.515	0.562	1.000						
(12) Log of Property Offences	0.149	-0.326	0.027	0.299	0.021	-0.196	0.018	0.335	0.187	0.610	0.206	1.000					
(13) Log of Fraud	-0.044	-0.266	0.080	0.187	-0.008	-0.165	0.020	0.235	0.179	0.501	0.239	0.815	1.000				
(14) Log of MB (Homicides)	-0.054	-0.084	0.029	-0.438	-0.058	0.300	0.288	0.256	0.115	0.058	0.173	-0.058	-0.048	1.000			
(15) Log of MB (Detained People)	0.163	0.108	0.193	-0.381	-0.025	0.302	0.341	0.275	0.218	0.120	0.348	-0.101	-0.087	0.793	1.000		
(16) Log of MB (Investigations)	0.063	-0.011	0.149	-0.424	-0.068	0.277	0.284	0.345	0.168	0.111	0.354	0.006	0.005	0.868	0.848	1.000	
(17) Log of MB (Seized Vehicles)	0.044	-0.028	0.079	-0.418	-0.030	0.273	0.318	0.281	0.164	0.080	0.249	-0.041	-0.007	0.864	0.873	0.807	1.000

Note: MB stands for the military budget weighted by the indicator in parentheses.

Table A3.3: Auxiliary estimation using difference GMM (Dependent variable: weighted Military Budget)

Dep variable: Log of weighted MB	(1) Log of MB (Homicides)	(2) Log of MB (Detained People)	(3) Log of MB (Investigations)	(4) Log of MB (Seized Vehicles)
Log of GDP p.c.	-3.391	3.122	-4.618	4.892
	(2.552)	(4.956)	(3.808)	(7.092)
Log of GDP p.c. (t-1)	2.597	1.942	-6.650	3.914
	(2.866)	(9.428)	(4.135)	(7.989)
Log of GDP p.c. (t-2)	0.955	-3.134	10.18*	-6.524
	(2.548)	(8.076)	(5.268)	(8.910)
Observations	256	256	256	256
Number of States	32	32	32	32
Chi^2 of the Wald test	8.219**	0.447	5.421	0.906
AR(1)	-0.920	-0.633	2.272**	-1.081
AR(2)	0.787	1.819*	0.337	0.977
Hansen Test p-value	0.816	0.368	0.243	0.298

Note: MB is the military budget weighted by the number of homicides. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table A3.4: Results for the Spatial autoregressive difference GMM panel data estimation

Dep. variable: Log of GDP p.c.	(1) SAR Difference GMM	(2) SAR Difference GMM	(3) SAR Difference GMM
Log of GDP p.c. (t-1)	0.544***	0.532***	0.537***
	(0.0325)	(0.0331)	(0.0331)
Log of Physical Capital	0.235***	0.242***	0.242***
	(0.0214)	(0.0214)	(0.0215)
Log of Human Capital	-0.0139	-0.109*	-0.0955
	(0.0613)	(0.0636)	(0.0665)
Population Growth	1.541*	1.601*	1.411*
	(0.839)	(0.831)	(0.829)
Financial Crisis	-0.0313***	-0.0306***	-0.0305***
	(0.00367)	(0.00366)	(0.00369)
Log of Homicide	-0.000587		-0.00351
	(0.00360)		(0.00419)
Log of MB		0.00855*	0.0111**
		(0.00458)	(0.00545)
W * Log of GDP p.c. (i-1)	0.244***	0.246***	0.231***
	(0.0373)	(0.0359)	(0.0377)
Observations	288	288	288
States	32	32	32
Chi^2 of the Wald test	1766.9***	1841.2***	1826.8***

Note: MB is the military budget weighted by the number of homicides. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Chapter 4

Effects on employment of reducing minimum wage areas in a developing country with high informality

Abstract

At the end of 2012, in an effort to increase the value of the country's real minimum wages, which had eroded over the preceding decades, the Mexican government reformed its minimum wage territorial policy and reduced the previous three minimum wage areas to two. The minimum wage in the area that disappeared was increased to be on a par with that fixed for the area with the highest minimum wage. It is the effects of this natural experiment that this study analyzes. The results from the differences-in-differences analysis show that the increase in the minimum wage in these territories resulted in a reduction in employment, above all among male workers employed in the formal labor market. The impact on the number of informal workers was not significant.

Keywords: Minimum Wage; Employment; Informality; Mexico

JEL Codes: J08, J21, J46

1. Introduction

Minimum wages have been in place for decades in many countries of the western world. Yet, the consensus about the impact of minimum wages and minimum wage increases was broken in the mid-1990s when Card and Krueger (1994) reported finding no employment effects following a minimum wage update. Since this first study, a large body of empirical literature has emerged questioning the effects long attributed to minimum wages by economic theory.

Decision makers are particularly cautious about the impact of the minimum wage. The caution (or even open refusal) expressed by governments to increase the minimum wage significantly above inflation appears to be based on the fear of the possible consequences of such an action on employment, poverty, productivity, informal labor, wage distribution, etc.

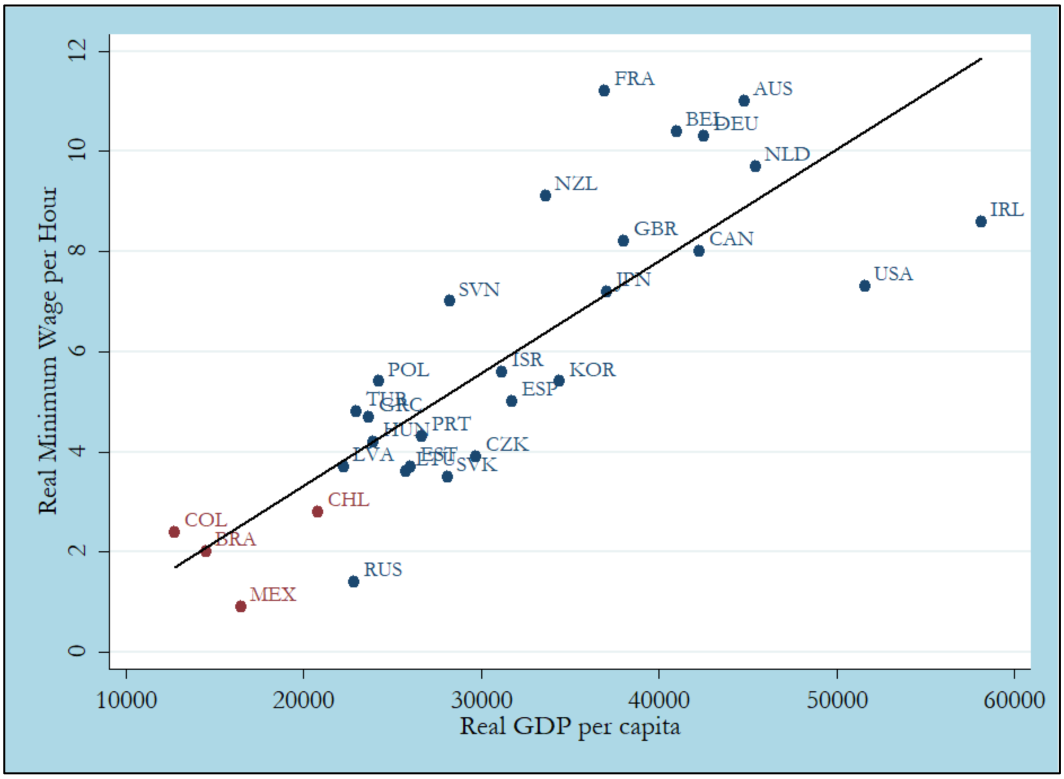
In developing countries, minimum wages, which are supposed to guarantee the most basic living standard, are sometimes too low to acquire the minimum basket of goods. The case of various Latin American countries is notorious in this regard. During much of the late twentieth century, when many of these countries suffered high inflation, more than one government chose to reduce minimum wages in real terms, in attempt, among other things, to bring inflation under control.

Many studies have analyzed the effects of minimum wages, typically focusing on the impact of their introduction or increase on inflation and employment. In determining their effect on prices, Lemos (2008), in an evaluation of thirty empirical studies, calculates that a 10% minimum wage increase raises overall prices by 0.4% in the US and by less than 0.3% in Brazil. In the case of Colombia, Lasso-Valderrama (2010) estimates a price increase of 0.6% following a 10% increase of minimum wages.

Many empirical analyses of the impact on employment have been undertaken in the wake of Card and Krueger's (1994) seminal study. The debate has been ongoing for more than two decades, but there is little consensus as to whether minimum wage increases have negative effects on employment or not, and if so, which segment of the labor force is affected. Most of these studies have focused primarily on the situation in developed countries, that is, the US and Europe, while the number of studies focusing on Latin American countries is small. Yet, given the heterogeneity of labor markets and economic structures across countries it would not be surprising if developing economies did not present more marked results than those presented by developed countries.

Figure 4.1 compares the relationship between minimum wages and GDP per capita of OECD countries and a few non-OECD countries. Latin American countries appear in the lower left area of this figure, with Mexico at the very bottom in terms of real minimum wages per hour and below the level predicted by the simple regression line.

Figure 4.1: Comparison of real Minimum Wages per hour and real GDP per capita across countries, wages in 2015 US Dollars at PPPs

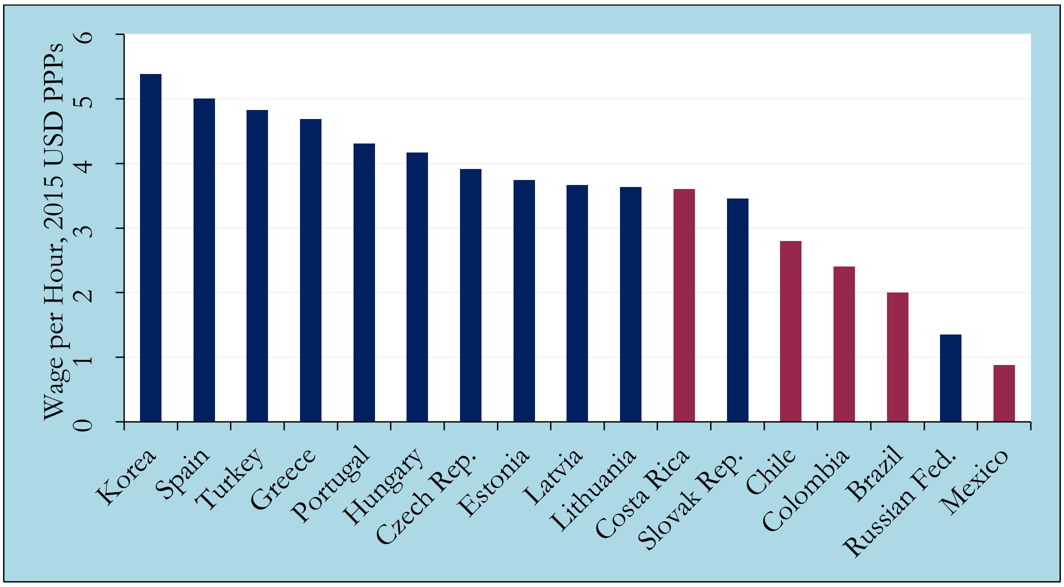


Source: Based on data from the OECD

With an average real GDP growth rate of 2.84% since 1990, Mexico is the second largest economy in Latin America (after Brazil). Inflation in the country was brought under control following the 1995 Peso crisis and since 2000 Mexico has reported one-digit annual inflation rates. For this reason, it is somewhat surprising that Mexico has one of the lowest minimum wages, not only among OECD countries, but also among Latin American countries (see Figure 4.2).

Mexico, in common with other Latin American countries, has a large informal labor market, estimated at 50-60% of the working population. This makes it difficult to anticipate just how a minimum wage increase would affect both formal and informal employment.

Figure 4.2: Real minimum wages per hour in 2015 for selected countries, wages in 2015 US Dollars at PPPs



Source: Based on data from the OECD

Since the early 2000s, civil society, worker unions, and even some business sectors have been lobbying strongly to increase minimum wages. In Mexico, some 6.4 million people[10], or 13.1% of the working population, earn up to one minimum wage or less. The government of Mexico City has proposed increasing the minimum wage to a rate that is 15.7% above inflation until the real minimum wage level recovers the value it had in the 1980s. Pressure to increase wages has also comes from outside Mexican borders. During the 2017 NAFTA renegotiation talks, Canada and the US pushed Mexico to increase (minimum) wages arguing that Mexico keeps wages low in order to attract investment that values low labor costs.

While some countries operate a national minimum wage, others introduce a territorial differentiation at the sub-national level, e.g. in the US, the States can set minimum wages that are higher than the federal minimum. In Mexico, a differentiation is made based on living standards across the nation, with the country being divided into minimum wage areas. Until 2012, three such areas were in operation; however, following a policy change in that year, they

[10] Campos-Vázquez (2016) reports 6.46 million people earning up to one minimum wage, 11.99 million earning between one and two minimum wages, and 11.09 million earning between two and three minimum wages (Data from the Mexican labor force survey ENOE, first quarter of 2014)

were reduced to just two. Such policy changes are rare events, but present an excellent opportunity to analyze how economic variables react to minimum wage changes.

This study therefore examines the effect of a minimum wage increase on employment in Mexico. The contributions of this study can be simply stated: 1) using causal techniques, evidence is found that minimum wage increases have negative effects on employment and, more specifically, on formal employment; 2) by drawing a distinction between formal and informal labor markets, the analysis is able to determine the labor force movement between the formal and informal sectors of employment after a minimum wage increase; 3) gender differences are found for the impact of minimum wages, with male workers being more affected than female workers; 4) given the negative impact of the policy on employment, and in line with theoretical considerations, the Mexican labor market for low-wage workers is closer to a scenario of perfect competition than one of monopsony.

2. Theoretical and Empirical Background

2.1 Theory

The effects of minimum wage policies have been analyzed exhaustively over the years. Various theoretical models have emerged that seek to explain the mechanics linking labor supply and labor demand, and the resulting effects on wages and employment when the minimum wage is raised. Most models can be grouped in one of three categories: a) that of perfect competition, b) that of monopsony, in which a single company demands all labor available in the labor market, and c) that of monopsonistic competition, a situation that lies between these two extreme scenarios.

In recent decades, the monopsony and monopsonistic competition models have found greater acceptance among researchers due to their closer resemblance to reality. The extreme monopsony model assumes the presence of a sole company that concentrates all market power and which maximizes its profits when its marginal costs equal the marginal productivity of labor. Since the model assumes that workers have no choice regarding their workplace, the company sets salaries below the equilibrium level provided by the model of perfect competition. In this scenario, an increase in the minimum wage level could lead to an increase in employment since the profit-maximizing company might absorb the wage increase and keep its demand for workers unchanged. It might even be the case, albeit unlikely, that the monopsonist takes on more workers to produce more and so offset the increased labor costs.[11]

Monopsonistic competition provides for the existence of several companies demanding labor, allowing oligopsonies to emerge. These oligopsonies pay wages between the monopsony wage and the perfect competition wage. By increasing the number of companies in a market, conditions converge towards the perfect competition scenario. When increasing the minimum wage, employment can either increase (when the market approaches a monopsony), decrease (when the market approaches perfect competition) or remain ambiguous. However, if the minimum wage increase is considerable and close to the companies' marginal cost, it may force some companies to exit the market.

Various studies, including Bhaskar et al. (2002), have criticized policy decisions based on the neoclassical model on the grounds that perfect competition is a rather rare scenario and wages can vary significantly even within short distances.

Based on the predictions of these models and the results of the empirical analysis reported below, this study is able to pin down which scenario best fits the Mexican labor market, thus providing policy makers with more information about the labor market.

2.2 Methodology for Analyzing Minimum Wages and Employment

The controversy concerning the effects of minimum wages on employment and just how these effects should be analyzed is by no means new. The debate first ignited in the 1990s following the publication of Card and Krueger's (1994) study, which, contrary to theoretical predictions and previous empirical studies, found no significant effects of a minimum wage increase in the fast food industry on employment numbers. Their experimental approach based on the use of treatment and control groups to analyze minimum wages rapidly spread and many studies have subsequently tried to find causal evidence to support their findings. Studies that analyze the fast food industry following the experimental approach developed by Card and Krueger include Dube et al. (2007), Hoffman and Trace (2009), and Dube et al. (2010). These causal studies focus on low-wage workers in the fast food sector and involve a refinement of

[11] See Boeri and Van Ours (2008) for a more detailed description of such a case.

Card and Krueger's original approach. While Hoffman and Trace (2009) find significant negative effects, Dube et al. (2007, 2010) do not. One aspect Dube et al. (2010) deem it important to control for is state-specific labor market trends.

County-specific labor trends are examined in Addison et al. (2015), who report very low minimum-wage elasticities. While in their extensive comparison of minimum wages and related institutions across the European Union, Arpaia et al. (2017) include country-specific employment trends and find that minimum wages have negative but non-significant effects on employment.

A different strand of the literature has focused its attention on the use of models with fixed effects as opposed to market trends. Neumark and Wascher (1992) control for state-level fixed effects and estimate that a minimum wage increase of 10% reduced employment among young workers by 1.5-2.0%. Neumark and Wascher (1998, 2000) and Neumark (2001) refined the approach and included individual fixed effects. Later, Neumark and Wascher (2007) carried out an analysis of 102 minimum wage studies finding negative effects on low-wage workers. Dube et al. (2016) use a regression discontinuity design and claim that given their empirical design local trends are meaningless.

In the debate concerning the most appropriate methodology for analyzing minimum wage effects, Meer and West (2015) and Neumark et al. (2014) are critical of most studies that employ state-specific time trends. They claim that in so doing the authors have "thrown out so much useful and potentially valid identifying information that their estimates are uninformative or invalid" (Neumark et al., 2014, p. 644).

In this longstanding discussion on how best to analyze minimum wage policies, several authors have tried to combine approaches. For instance, Allegretto et al. (2011) include both fixed effects and state-specific labor market trends. They find very little to no effect on employment numbers.

Another possible method that allows both approaches to be combined involves using a dynamic model. Dolton et al. (2015) employ such a model to analyze the impact of the national minimum wage in the UK and find no discernible effects on employment. A recent study finding small effects is Allegretto et al. (2017). They estimate their model using first differences, which is similar to a dynamic approach. Dube and Zipperer (2015) find no reduction in employment effects and highlight the relevance of lagged effects, especially, in minimum wage studies.

2.3 Minimum Wages and Employment in Mexico

Although this study specifically analyzes the effects of minimum wage increases in Mexico, it is clearly beneficial to be able to compare the outcomes with countries presenting similar labor market characteristics (in terms, that is, of their informal labor market, low minimum wages, etc.).

In common with other countries in the region, Brazil has a sizeable share of its working population operating in the informal labor market (45-55%). Lemos (2004), in a review of the existing literature, reports that a 10% increase in the Brazilian minimum wage would lead to a decrease in the employment figures of up to 5%. For Colombia, Bell (1997) reports that a 10% increase in the minimum wage level reduced the employment of low-wage workers by 2 to 12%.

To the best of my knowledge, the effects of minimum wage increases on employment in Mexico have been examined primarily in three studies. First, Bell (1997), in undertaking a regression analysis of firm-level data from large manufacturing firms, while controlling for fixed effects, is unable to find any significant employment effects after minimum wage increases. Second, Feliciano (1998) analyses the employment-to-population ratios between 1970 and 1990 using regional minimum wages and finds that large minimum wage reductions increased the employment of female workers but reduced the employment of males aged 55 to 64. Minimum wages did not affect the employment levels of young males, while for females the study reported negative effects. Third, Campos-Vázquez et al. (2015) analyze the effects of minimum wage increases following the reduction of the minimum wage area in 2012. The authors focus primarily on individual wages, but they also analyze employment levels. More specifically, their study uses an experimental design to estimate the extent to which the probability of being employed was affected by the minimum wage area reduction. Their results show negative but non-significant effects of the minimum wage increase on the probability of being employed.

This last study is particularly relevant to the case dealt with herein, as it analyzes the effects of the same policy. However, a key difference between the two studies is that here the approach adopted considers the aggregate number of employed people in municipalities, estimating the effect of the policy on the number of employed people while distinguishing between formal and informal workers. In contrast, Campos-Vázquez et al. (2015) use data at the individual level and specifically estimate the probability of being employed.

Campos-Vázquez et al. (2015) are able to observe individuals only for two periods (one prior to the introduction of the policy and one after). To verify the robustness of their outcomes, the authors check different panels made up from different individuals; however, their results are not consistent across these panels in terms of significance or even, on occasions, of sign. In this paper, the study takes municipalities as its measure of observation, which have the advantage of being easy to follow over time. The municipalities assigned to treatment and control groups are followed over eight periods (quarters) prior to the introduction of the policy and eight after.

Two key labor market characteristics that Campos-Vázquez et al (2015) do not account for are economic conditions and specific labor market dynamics. Here, by using a dynamic panel, and by means of the robustness tests presented in section 6, the approach adopted is able to account for these characteristics, resulting in a robust estimation of the policy's impact on employment.

Thus, in short, this study contributes to the literature by analyzing employment numbers after a minimum wage increase, while considering labor market dynamics and aggregate economic conditions. The analysis is further enhanced by the distinction that it draws between formal and informal labor markets, allowing us to determine which group of workers are affected most. It also allows us to identify whether the workers that lost their jobs because of the policy moved out of the formal labor market and entered the informal market.

3. Institutional Framework

A minimum wage was officially introduced in Mexico in 1934. After lengthy institutional developments, a national commission – the Mexican Minimum Wage Commission (*Comisión Nacional de Salarios Mínimos*, CONASAMI) – was made responsible for determining changes to the minimum wage in 1987. This decentralized, public institution determines all modifications to the minimum wage, taking into consideration economic well-being and the country's broader social environment. In theory, its decisions aim to foster equality and justice between the factors of production (that is, capital and labor).[12]

[12] Own translation from the CONASAMI website <http://www.conasami.gob.mx/ >

CONASAMI updates minimum wage levels once a year (in December), thus allowing economic actors to anticipate the increases. However, the commission can, at its discretion, modify the minimum wages during the year, should economic conditions call for such an intervention. Although CONSAMI does not expressly disclose the mechanism applied in updating minimum wages, the increases are discussed with business and labor representatives. Despite this, minimum wage updates appear to have adhered to criteria related to inflation expectations, similar to the mechanisms employed in countries such as Belgium, France, and the Netherlands. Having said that, during the period 1990-2010, minimum wage increases were consistently below the inflation rate. Only recently has the institution announced minimum wage increases above inflation.

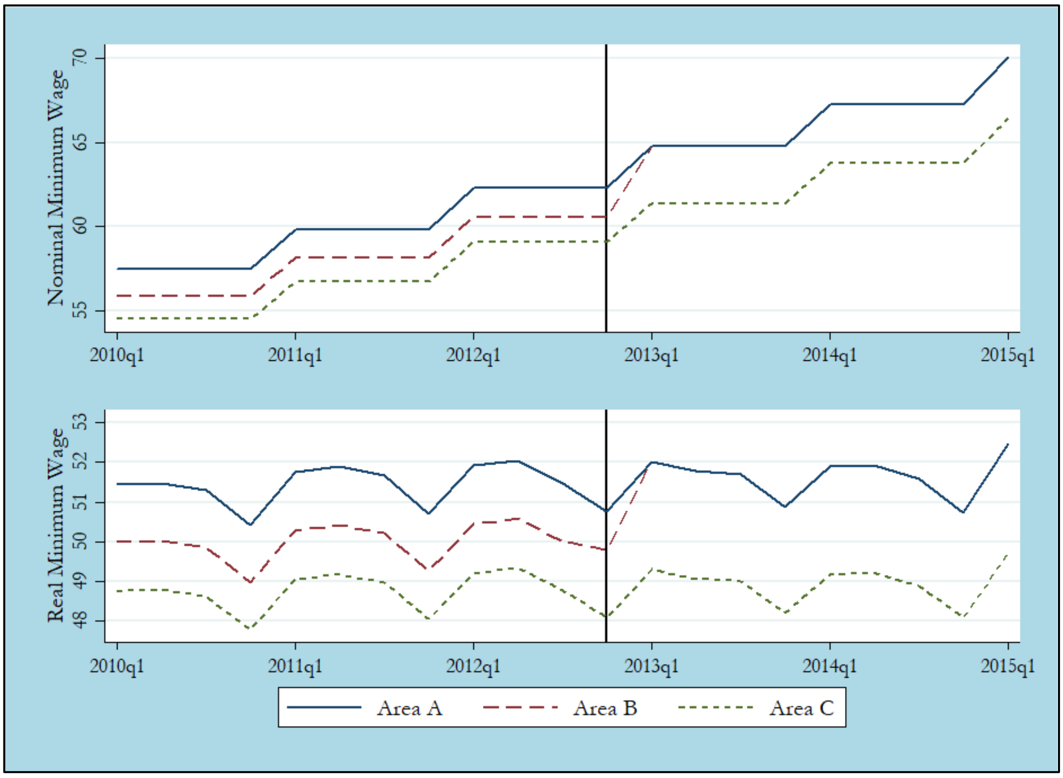
4. Policy

Until November 2012, Mexico operated three distinct minimum wage areas, which depended on where people worked (areas A, B or C). Workers in areas considered to have higher living costs (food, transport, housing, etc.), e.g. Mexico-City, were categorized into area A, earning a higher minimum wage than workers employed in minimum wage areas B and C.

On November 23rd, 2012, CONASAMI announced that minimum wage area B was to disappear, its wage being placed on a par with that in area A. This change meant an increase, from one quarter to another, of 4.5% in real terms (or 6.9% in nominal terms) for area B, while the other two minimum wage areas (A and C) experienced a real increase of 2.5% (a nominal increase of 3.9%). Minimum wage area B includes a number of municipalities in the following states only: Jalisco, Nuevo León, Sonora, Tamaulipas and Veracruz. The evolution of nominal and real minimum wages is shown in Figure 4.3.

At the same time, the federal government acknowledged the informal labor problem and decided to implement various programs to reduce informal labor, including the Employment Formalization Program (*Programa para la formalización del empleo*), the launch of Unemployment Insurance, and a Universal Pensions Program in 2016 (see ILO, 2014, 2015). However, these programs were all launched after the modification to the minimum wage area, which means they should not affect the analysis presented in this study.

Figure 4.3: Evolution of minimum wages by area in Mexico for the period 2010-2014, wages in Mexican pesos



Source: Based on data from CONASAMI and INEGI.

5. Empirical Strategy and Methodology

The panel data used for this analysis is unbalanced. Due to the absence of a randomized trial, a natural experiment is analyzed using a differences-in-differences methodology, which has been widely used to estimate the impact of policy interventions. The econometric specification is the following:

$$N_{it} = \alpha + \gamma Policy_{it} + \sum_{l=1}^{L} \rho_l N_{it-l} + \mu X_{it} + \theta_i + \delta_t + \varepsilon_{it} \qquad (1)$$

where N_{it} is the logarithm of employment measures. In applying this model, the number of employed people in each municipality are used (differentiating between males and females). Furthermore, a distinction is drawn between those working in the formal labor market and those identified as working in the informal sector of the economy. The variable $Policy_{it}$ is the binary vector indicating the policy intervention.

The inclusion of lags of the dependent variable allows for the inclusion of labor dynamics. This is relevant because one labor market can have particular characteristics that other labor markets do not share. It also controls for specific labor trends that might characterize certain municipalities (for example, there may be regions that have especially high or low employment figures). In addition, the model includes municipality specific effects to control for unobservable municipality characteristics that are constant over time. These municipality fixed effects control for a possible correlation with the policy change linked to the minimum wage (Card and Krueger, 1995; Brown, 1999).

The matrix X_{it} contains several explanatory variables, including the economically active population. It also includes the Kaitz index, i.e. the ratio between minimum wages and average wages, as is common in the literature (Broecke and Vandeweyer, 2015; Dolton et al., 2015; Arpaia et al., 2017). The model also controls for the average number of years of schooling of the general population aged above fifteen in order to proxy the level of education in each municipality, which is denoted by the variable Edu_{it}. Furthermore, population density is included in the matrix X_{it} to control for possible agglomeration effects. The model includes a constant term (α), municipality fixed effects (θ_i) and time fixed effects (δ_t). Finally, ε_{it} is the stochastic error term.

The variable of interest in this differences-in-differences analysis is $Policy_{it}$. This binary dummy is associated with the coefficient γ. This policy coefficient measures the difference between the average change experienced by the minimum wage in area B (treatment group) and the average change experienced in areas A and B (control group). When using differences-in-differences, the coefficient γ is defined as follows:

$$\begin{aligned}\gamma = {} & [E(N_B|Policy = 1) - E(N_A|Policy = 1)] \\ & - [E(N_B|Policy = 0) - E(N_A|Policy = 0)]\end{aligned} \tag{2}$$

where N_B and N_A denote the employment variable before and after the merger of the two minimum wage areas. $Policy = 1$ and $Policy = 0$ denote treatment and control group conditions respectively.

Since minimum wage area B was only present in a certain fraction of Mexican states, the study is centered on just four states: Jalisco, Nuevo León, Sonora, and Tamaulipas. The state of Veracruz is not included because too few of its municipalities are assigned to area B. Therefore, the treatment group is defined as those municipalities within these four states that were part of minimum wage area B, while the control group is defined as those municipalities within these four states that do not belong to minimum wage area B. Selecting treatment and control groups from the same state has the advantage that municipalities share the same institutional framework. A map of the municipalities making up each group can be found in Figure A4.1 in the Appendix.

Satisfying the parallel-trend assumption, which is central for the differences-in-differences analysis, ensures that the temporal trends of the treated and control groups are indeed parallel prior to the policy intervention. The satisfaction of this condition is essential to guarantee that the measured impact is unbiased. Figures A4.3-A4.5 in the Appendix present graphical evidence of the satisfaction of the parallel trend assumption.[13] A helpful characteristic of the differences-in-differences methodology highlighted in Bertrand et al. (2004) is that the method considers potential endogeneity problems that might bias the impact. Related to this, an additional assumption is that unobservable characteristics of the municipalities remain constant over time.

Using the dynamic model specification described in (1), the model accounts for time-specific effects while considering the trend of employment numbers in the different municipalities. The importance of controlling for labor dynamics is derived from the fact that "large negative elasticities in the traditional specification are generated primarily by regional and local differences in employment trends that are unrelated to minimum wage policies" (Dube et al., 2010, p. 962). Other studies that specifically addressing this question are Page et al. (2005), Lemos (2009), Addison et al. (2013), and Arpaia et al. (2017).

6. Data Sources and Construction of Samples

For the analysis of minimum wages in Mexico, the data used in this study are taken from Mexico's labor force survey, *Encuesta Nacional de Empleo y Ocupación* (ENOE), for the period 2010-2014. The ENOE is a household survey that follows a rotating panel design. It is conducted all year long and is answered by over 120,260 households each quarter. The microdata extracted from this survey include employment characteristics, including wages, as well as information on whether the person is employed in the formal or in the informal

[13] The numerical test can also be provided upon request.

sectors of the economy. A technical limitation of this survey is the inability to follow subjects over time. This study circumvents this limitation by aggregating respondent numbers for each municipality, and then using these municipalities as units of observation that can be followed over time.

Employed people are defined by the Mexican Statistics Institute (INEGI) as people with a minimum age of 15 that carry out at least one hour of labor per week. This category includes workers who have a job but were unable to perform it during the reference week, as well as people that were absent from the workplace but who continue to have a working relationship with their employer. Unpaid work is also included in this category. Informal workers are those people working for an economic unit that is not formally registered as a society or an enterprise.

Although the ENOE survey is representative at both state and national levels, not all municipalities have a representative number of respondents in the survey. In many cases, the population of a municipality is small and the survey is answered by few respondents. This means many municipalities have survey respondent numbers that cannot be considered representative. For this reason, only those municipalities that consistently present a representative number of survey respondents over time are included. The others are excluded (see Figure A4.2 in the Appendix).

Further data are taken from the ENOE survey, including the economically active population and the average number of years of education of the population aged 15 and above. Average wages by municipality are also computed from the data in the survey in order to construct the Kaitz index.

To complement these employment data, information not contained in the survey is added, including population density (also provided by INEGI). For the robustness specifications presented in section 6.1, the quarterly state economic activity index (ITAEE) is included to serve as a proxy for state-level GDP. The real exchange rate, calculated as weighted averages of bilateral exchange rates adjusted by relative consumer prices, is also included as a control. These data are retrieved from the Federal Reserve Bank of St. Louis. As a final control, the model uses the 28-day equilibrium interest rate between banks to reflect market conditions affecting financial institutions and the external sector.

Table 4.1 describes the variables used in the econometric specification of the model, whereas Table 4.2 presents the respective descriptive statistics for the variables employed.

Table 4.1: Description of Variables included in the Model

Variable	Description	Source
Employed	Logarithm of the number of all employed workers aged 15-65 (by sex)	ENOE
Formal Employed	Logarithm of the number of employed workers aged 15-65 laboring in the formal labor market	ENOE
Informal Employed	Logarithm of the number of employed workers aged 15-65 laboring in the informal labor market	ENOE
Policy	Binary variable: 1 if the period is after December 2012 and the municipality belongs to the treatment group; 0 otherwise	CONSAMI
Econ. Active Pop. (EAP)	Logarithm of the economically active population (by sex)	ENOE
Kaitz Index	Logarithm of the Kaitz index: ratio between minimal wages and average wages for workers aged 15-65 (by sex)	ENOE
Education	Logarithm of average years of schooling of the general population aged above fifteen in each municipality (by sex)	ENOE
Density	Logarithm of the population density: population divided by the municipality area	CONAPO/ INEGI
State Econ. Activity	Logarithm of the quarterly state economic activity index (ITAEE)	INEGI
Exchange Rate	Logarithm of the real exchange rate (2010=100) of Mexican Pesos and US Dollars	FED

Table 4.2: Descriptive Statistics of the Variables (Variables before Logs)

Variable	Mean	Std. Deviation	Min.	Max.	Obs.
Employed	180,441	154,025	6,580	793,230	473
Employed (Females)	70,832	64,018	1,645	351,380	473
Employed (Males)	109,610	90,473	4,935	455,205	473
Emp. Formal	102,628	90,059	1,143	432,590	473
Emp. Formal (Females)	37,599	35,655	235	185,535	473
Emp. Formal (Males)	65,029	55,020	381	253,874	473
Emp. Informal	77,813	66,291	3,614	363,073	473
Emp. Informal (Females)	33,233	29,254	834	166,354	473
Emp. Informal (Males)	44,580	37,300	2,585	202,144	473
Policy	0.2791	0.4490	0	1	473
Econ. Active Pop.	192,034	162,942	7,050	836,866	473
Econ. Active Pop. (Females)	75,689	67,688	1,946	367,135	473
Econ. Active Pop. (Males)	116,344	95,715	4,935	479,772	473
Kaitz Index	0.3570	0.0588	0.1527	0.5367	473
Kaitz Index (Females)	0.4216	0.0826	0.1284	0.7180	473
Kaitz Index (Males)	0.3295	0.0570	0.1453	0.5702	473
Education	4.2106	0.1320	3.8310	4.6875	473
Education (Females)	4.2427	0.1449	3.7517	4.7201	473
Education (Males)	4.1780	0.1710	3.6629	4.9048	473
Density	1464.50	2208.59	11.88	7992.92	473
State Economic Activity	109.930	7.326	98.236	130.820	473
Real Exchange Rate	99.674	3.506	91.703	104.157	473

7. Results

The benchmark model measuring the impact of the policy includes, as explanatory variables, the lags of the dependent variable, the economically active population, the Kaitz index, the level of education, and the population density. The estimations are run for all workers, and then separately for males and females.

Table 4.3 presents the results for all workers in employment regardless of whether they work in the economy's formal or informal sectors. Column 1 shows the results for all workers regardless of sex, while columns 2 and 3 present the results for female and male workers, respectively. The impact of the larger minimum wage increase in Area B had different effects depending on the group of workers considered. Compared to the control group, treated municipalities experienced a 2% increase in real minimum wages, which significantly reduced the number of male workers by 2.07%, while the number of female workers was unaffected (the policy coefficient is negative but non-significant). If we consider the effect of the policy on all workers, the policy reduced the number of workers by 1.1%.

Some of the lags of the dependent variable are highly significant. This supports the inclusion of lags and confirms the existence of labor market dynamics. Furthermore, both the economically active population and the Kaitz index have positive and highly significant effects. Level of education does not have any effect on employment in this table and population density is significant for female and male workers but not for the two combined.

The Chi^2-statistic of the Wald-Test allows us to state that the models in their different specifications are well fitted since the test statistic in each case strongly rejects the null-hypothesis of the joint statistical insignificance of the covariates. First order autocorrelation is significant, which is expected, given the dynamic construction of the model. By not being able to reject the null-hypothesis of the second-order autocorrelation test, it can be affirmed that the models are correctly specified and that the moment conditions are valid. Lastly, the null-hypothesis of the Hansen over-identification test cannot be rejected either, which indicates that the models do not suffer any problems of overidentification. The combined statistics reported at the bottom of the table indicate that the use of the GMM model is correct.

Table 4.3: Difference GMM estimation results for the Mexican labor market (Dep. Variable: Logarithm of the number of employed workers)

Dep. Variable: Log of Employed	(1) All	(2) Females	(3) Males
Policy	-0.0110***	-0.00954	-0.0207***
	(0.00340)	(0.00861)	(0.00727)
Log of Employed (t-1)	0.0156**	-0.00421	0.0408**
	(0.00703)	(0.0122)	(0.0193)
Log of Employed (t-2)	0.0225***	-0.0228*	0.0738***
	(0.00752)	(0.0119)	(0.0183)
Log of Employed (t-3)	0.0299**	0.0806***	-0.0609**
	(0.0118)	(0.0141)	(0.0262)
Log of Employed (t-4)	0.000358	0.0269	-0.0330**
	(0.0120)	(0.0229)	(0.0162)
Log of Econ. Active Pop.	0.985***	1.004***	0.983***
	(0.00603)	(0.00926)	(0.00737)
Log of Kaitz Index	0.0806***	0.0434***	0.0911**
	(0.0156)	(0.0107)	(0.0375)
Log of Education (t-1)	-0.00251	-0.0399	0.00324
	(0.0412)	(0.0556)	(0.113)
Log of Density (t-1)	-0.0307	-0.406**	0.398*
	(0.171)	(0.204)	(0.222)
Observations	430	430	430
Number of Municipalities	30	30	30
Municipality FE	YES	YES	YES
Time FE	YES	YES	YES
Chi^2 of the Wald-Test	260,554***	645,649***	5.934e+06***
AR(1)	-3.606***	-2.649***	-2.966***
AR(2)	-1.275	-0.988	-0.191
Hansen Test p-value	0.960	0.996	0.971

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

The estimation in Table 4.4 presents the results for the impact of the policy considering only the workers employed in the formal sector. The coefficient of the policy variable is greater than in the previous specification, with a more negative effect on the number of all workers (not differentiated by sex). The implementation of the minimum wage policy reduced the number of all workers in the formal sector by 4.18% (significant at 10%) and more significantly the number of male workers by 4.8%. The number of female workers does not present a significant reduction as a result of the policy.

The economically active population and the Kaitz index are again positive and significant, while years of education and population density are not.

Once again, the test statistics at the bottom indicate the correct use of the difference GMM method.

Table 4.4: Difference GMM estimation results for the formal labor market (Dep. Variable: Logarithm of the number of employed workers in the formal labor market)

Dep. Variable: Log of Formal Employed	(1) All	(2) Females	(3) Males
Policy	-0.0418*	-0.0187	-0.0482**
	(0.0230)	(0.0399)	(0.0202)
Log of Formal Employed (t-1)	-0.0254	0.128***	-0.0137
	(0.0293)	(0.0487)	(0.0302)
Log of Formal Employed (t-2)	0.000343	-0.0439	0.119***
	(0.0297)	(0.0801)	(0.0266)
Log of Formal Employed (t-3)	-0.0392	0.0920**	-0.192**
	(0.0443)	(0.0419)	(0.0867)
Log of Formal Employed (t-4)	0.111***	0.274***	-0.0579
	(0.0213)	(0.0632)	(0.0557)
Log of Econ. Active Pop.	1.099***	1.024***	1.094***
	(0.0423)	(0.0351)	(0.0513)
Log of Kaitz Index	0.619***	0.127*	0.361**
	(0.102)	(0.0721)	(0.147)
Log of Education (t-1)	0.375	-0.236	0.0479
	(0.446)	(0.260)	(0.264)
Log of Density (t-1)	-0.274	-1.017	0.838
	(0.650)	(0.698)	(0.951)
Observations	430	430	430
Number of Municipalities	30	30	30
Municipality FE	YES	YES	YES
Time FE	YES	YES	YES
Chi^2 of the Wald-Test	21,413***	12,403***	11,907***
AR(1)	-1.859*	-2.432**	-1.636
AR(2)	0.760	1.088	1.058
Hansen Test p-value	0.953	0.808	0.999

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0

In accordance with the International Labor Organization, the Mexican Statistics Institute defines informal workers as those people working in places, firms or companies that are not properly registered. This number also includes workers not receiving any social security benefits, people that work for themselves in agriculture at subsistence levels and workers who are not paid at all.

The analysis of the informal labor market, presented in Table 4.5, shows no significant effect of the merger of the minimum wage areas. However, the signs of the coefficients are positive. Considering the results for the formal market, a positive though non-significant effect for the policy coefficient in the informal market would be reasonable. However, the number of workers crossing over from the formal to the informal sector was not high enough to increase the number of informal workers significantly.

Despite this, interestingly, most covariates that were significant for overall employment and for formal employment are not significant for the informal labor market. The Kaitz index might not be significant because informal workers are not bound by minimum wage regulations. Education levels of informal workers are often below those of formal workers. Moreover, it is possible that the lower education levels of workers in this sector do not undergo much variation in time and space, so that the coefficients remain non-significant.

Table 4.5: Difference GMM estimation results for the informal labor market (Dep. Variable: Logarithm of the number of employed workers in the informal labor market)

Dep. Variable: Log of Informal Employed	(1) All	(2) Females	(3) Males
Policy	-0.00537	0.00565	-0.00113
	(0.0299)	(0.0750)	(0.0450)
Log of Informal Employed (t-1)	-0.0774**	-0.166	-0.121
	(0.0353)	(0.107)	(0.0757)
Log of Informal Employed (t-2)	0.0720	0.0201	-0.0753
	(0.0460)	(0.0567)	(0.0922)
Log of Informal Employed (t-3)	0.00446	0.0209	-0.114
	(0.0443)	(0.187)	(0.0725)
Log of Informal Employed (t-4)	-0.247***	-0.158	0.00475
	(0.0612)	(0.152)	(0.0973)
Log of Econ. Active Pop.	0.960***	1.045***	0.956***
	(0.0326)	(0.113)	(0.0647)
Log of Kaitz Index	0.0258	0.121	-0.222**
	(0.119)	(0.273)	(0.0873)
Log of Education (t-1)	0.539	0.293	0.523
	(1.113)	(1.392)	(0.747)
Log of Density (t-1)	-1.179*	-1.964*	-0.953
	(0.619)	(1.181)	(1.499)
Observations	430	430	430
Number of Municipalities	30	30	30
Municipality FE	YES	YES	YES
Time FE	YES	YES	YES
Chi^2 of the Wald-Test	25,827***	555.7***	901.9***
AR(1)	-2.290**	-1.047	-2.097**
AR(2)	-1.174	-0.902	-0.0403
Hansen Test p-value	0.492	0.344	0.994

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

7.1 Robustness: Effects beyond Municipalities

Municipalities are seldom immune to events taking place at the state level. Thus, a municipality that experiences an economic shock – be it positive or negative – is likely to have an impact on it neighboring municipalities, especially if they belong to the same local labor area. Moreover, while institutions may vary significantly across states, they rarely differ across the municipalities within the same state.

To account for these factors and to demonstrate the robustness of the reported effects of the minimum wage policy on employment, the state economic activity index is added to the control variables. This index captures the effects of economic expansion and contraction on the municipalities within the same state.

Table 4.6 presents the results of the three employment panels when including the state economic activity index. The policy, which is our variable of interest, remains unchanged in terms of its sign, significance and magnitude for overall employment, formal employment and informal employment. The overall effect of the policy on employment is a reduction of 1.01% and a 3.71% cut in formal employment. The impact on the informal labor sector remains non-significant.

Broadening the spectrum of possible external effects affecting labor markets in the treated municipalities, macroeconomic effects are considered. These effects do not only impact the municipalities and states considered here but also the entire country. In an additional attempt to demonstrate the robustness of the previous estimates, the real exchange rate between the Mexican Peso and the US Dollar is included in Table 4.7. This variable should model the interaction with Mexico's main trading partner, the US, as well shocks that affect the entire Mexican economy.

The results of the policy intervention follow the same pattern as with the previous case, although the effects are slightly larger. The negative coefficient for the policy variable rose from 0.0101 to 0.0122 for the panel including all workers. For formal workers, the policy's negative effect increased from 0.0371 to 0.0459. Informal labor continues to be positive and statistically non-significant. As such, the real exchange rate seems to have no impact on employment for any of the groups considered during the period of analysis.

Table 4.6: Difference GMM estimation results including the indicator for state economic activity (Dep. Variable: Logarithm of the number of employed workers)

Dep. Variable: Log of Employment Variable	Employment (1) All	Employment (2) Females	Employment (3) Males	Formal Employment (4) All	Formal Employment (5) Females	Formal Employment (6) Males	Informal Employment (7) All	Informal Employment (8) Females	Informal Employment (9) Males
Policy	-0.0101***	0.00102	-0.0207***	-0.0371*	0.00810	-0.0479*	-0.00317	0.00369	-0.00143
	(0.00262)	(0.00546)	(0.00733)	(0.0204)	(0.0300)	(0.0271)	(0.0221)	(0.0785)	(0.0729)
Log of Empl. (t-1)	0.00955	0.0256	0.0623**	0.0470	0.0582	-0.000572	0.106*	-0.0167	0.0268
	(0.00623)	(0.0194)	(0.0285)	(0.0354)	(0.0516)	(0.0372)	(0.0543)	(0.122)	(0.162)
Log of Empl. (t-2)	0.0232***	-0.00528	0.0688***	0.0852	-0.0846*	0.104*	0.0600	-0.0879	-0.0283
	(0.00662)	(0.0168)	(0.0185)	(0.0675)	(0.0457)	(0.0559)	(0.0521)	(0.0772)	(0.106)
Log of Empl. (t-3)	0.0302**	0.0259*	-0.0542**	-0.331***	-0.0721	-0.343***	-0.0747	-0.0160	-0.154
	(0.0118)	(0.0139)	(0.0246)	(0.0669)	(0.0649)	(0.0460)	(0.0649)	(0.0825)	(0.0986)
Log of Empl. (t-4)	-0.00990	0.00446	-0.0481**	-0.158***	0.105**	0.230***	0.0862	-0.0730	0.0889
	(0.0114)	(0.0390)	(0.0203)	(0.0543)	(0.0450)	(0.0695)	(0.0699)	(0.111)	(0.164)
Log of EAP	0.983***	1.010***	0.987***	1.075***	1.062***	1.111***	1.005***	1.085***	0.978***
	(0.00587)	(0.00964)	(0.0117)	(0.0187)	(0.0513)	(0.0384)	(0.0304)	(0.109)	(0.157)
Log of Kaitz Index	0.0757***	0.0760**	0.0819*	0.328***	0.177*	0.293*	-0.167	0.0409	-0.239
	(0.0150)	(0.0322)	(0.0442)	(0.122)	(0.0913)	(0.157)	(0.130)	(0.198)	(0.185)
Log of Education (t-1)	0.00750	-0.00897	-0.123	-0.114	-1.114*	-0.352	0.923**	-0.201	0.352
	(0.0478)	(0.0571)	(0.174)	(0.912)	(0.572)	(0.753)	(0.396)	(0.499)	(0.578)
Log of Density (t-1)	-0.0502	-0.401*	0.298	2.693***	0.394	2.147**	-0.623	-0.692	0.117
	(0.144)	(0.206)	(0.220)	(1.017)	(0.973)	(0.988)	(0.619)	(0.874)	(1.780)
Log of Econ. Activity	0.0511**	0.00771	0.0695*	-0.271***	-0.166	-0.326*	0.117	0.127	0.0109
	(0.0241)	(0.0616)	(0.0411)	(0.0864)	(0.120)	(0.178)	(0.101)	(0.340)	(0.258)
Observations	430	430	430	430	430	430	430	430	430
Number of Mun.	30	30	30	30	30	30	30	30	30
Municipality FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Chi^2 of the Wald-Test	570,428***	2.769e+06***	2.015e+06***	212,323***	17,187***	116,933***	21,471***	992.7***	297.5***
AR(1)	-3.557***	-3.148***	-3.221***	-1.592	-2.474**	-1.781*	-3.607***	-1.976**	-2.316**
AR(2)	-1.557	-1.461	-0.607	-1.542	0.580	0.164	-0.701	0.328	-0.912
Hansen Test p-value	0.965	0.429	0.980	0.926	0.879	0.909	0.833	0.236	0.431

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 4.7: Difference GMM estimation results including macroeconomic effects (Dep. Variable: Logarithm of the number of employed workers)

	Employment			Formal Employment			Informal Employment		
Dep. Variable: Log of Employment Variable	(1) All	(2) Females	(3) Males	(4) All	(5) Females	(6) Males	(7) All	(8) Females	(9) Males
Policy	-0.0122**	0.00730	-0.00360	-0.0459**	0.00734	-0.0432*	0.00703	0.00605	0.00607
	(0.00484)	(0.00970)	(0.00494)	(0.0230)	(0.0593)	(0.0259)	(0.0239)	(0.0653)	(0.0387)
Log of Empl. (t-1)	0.0125*	-0.0113	-0.00405	-0.0645	0.0544	-0.0535	-0.0236	-0.0344	-0.0892
	(0.00639)	(0.0178)	(0.0115)	(0.0423)	(0.0944)	(0.0491)	(0.0304)	(0.123)	(0.171)
Log of Empl. (t-2)	0.0179**	-0.0571***	0.0351**	-0.0712*	0.0890*	0.167***	-0.0107	-0.0650	-0.0725
	(0.00732)	(0.0188)	(0.0145)	(0.0400)	(0.0468)	(0.0495)	(0.0604)	(0.0853)	(0.119)
Log of Empl. (t-3)	0.0192**	0.0513**	-0.00906**	-0.142***	-0.0160	-0.389***	0.00932	-0.0703	-0.0744
	(0.00847)	(0.0239)	(0.00442)	(0.0545)	(0.0677)	(0.0575)	(0.0522)	(0.0894)	(0.130)
Log of Empl. (t-4)	-0.0130	0.0436**	-0.0535***	0.353***	0.223***	-0.169	0.0348	-0.117	-0.0406
	(0.0164)	(0.0193)	(0.0185)	(0.0371)	(0.0672)	(0.159)	(0.0966)	(0.137)	(0.115)
Log of EAP	0.986***	1.012***	0.974***	1.079***	1.016***	1.088***	1.008***	1.018***	0.969***
	(0.00538)	(0.0111)	(0.00740)	(0.0259)	(0.0630)	(0.0580)	(0.0408)	(0.134)	(0.0611)
Log of Kaitz Index	0.0664***	0.0940*	0.0327***	0.543***	0.305***	0.641***	-0.207**	-0.221	-0.0873
	(0.0132)	(0.0526)	(0.0121)	(0.0974)	(0.112)	(0.141)	(0.103)	(0.263)	(0.286)
Log of Education (t-1)	-0.0306	0.0664	0.0685*	0.994**	-0.198	0.345	0.860	-0.0327	0.763
	(0.140)	(0.0620)	(0.0406)	(0.473)	(0.382)	(0.213)	(0.672)	(1.088)	(1.541)
Log of Density (t-1)	0.0467	-0.692***	0.205**	0.720	-1.325**	1.730**	-0.441	0.141	-2.790*
	(0.160)	(0.164)	(0.102)	(0.975)	(0.539)	(0.781)	(0.993)	(2.462)	(1.583)
Log of Econ. Activity	0.0488**	0.0905	0.0925***	-0.493***	-0.367**	-0.276	0.279**	-0.197	0.232
	(0.0238)	(0.0597)	(0.0350)	(0.120)	(0.147)	(0.175)	(0.142)	(0.686)	(0.205)
Log of Exchange Rate	0.0166	0.0188	0.0193	0.0835	-0.211	-0.0141	-0.181	-0.254	0.137
	(0.0231)	(0.0724)	(0.0206)	(0.0942)	(0.241)	(0.147)	(0.176)	(0.446)	(0.303)
Observations	430	430	430	430	430	430	430	430	430
Number of Mun.	30	30	30	30	30	30	30	30	30
Municipality FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Chi^2 of the Wald-Test	1.098e+06***	1.375e+06***	118,272***	17,134***	3,009***	31,676***	188,776***	316.2***	1,058***
AR(1)	-3.536***	-2.548**	-3.419***	-1.848*	-2.212**	-1.835*	-3.411***	-2.169**	-1.466
AR(2)	-1.704	-1.094	-0.159	1.001	0.423	-0.819	-0.146	0.0153	0.0347
Hansen Test p-value	0.965	0.841	0.891	0.982	0.467	0.547	0.990	0.754	0.996

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

8. Conclusions

This study presents an impact evaluation of the minimum wage policy introduced in Mexico at the end of 2012. By using a differences-in-differences approach, the natural experiment is exploited by analyzing the change in employment figures in the formal as well as in the informal labor markets in the four Mexican states affected by the policy.

The causal evidence obtained from the analysis indicates that minimum wages have small, negative effects on employment, especially, in the case of male employment. By distinguishing between formal and informal labor markets, those working in the formal market are identified as the group of workers most strongly affected by the policy. The results also suggest that those workers that lost their jobs as a result of the policy may have moved from the formal sector to the informal sector of employment. These results are line with the findings in the studies of Khamis (2013), Grau and Landerretche (2011) and Ham (2018), all of which employ differences-in-differences to study the effects of minimum wage increases on employment in Latin American countries.

As this study has shown, small minimum wage updates can have a significant effect on employment numbers. Results show that the policy, which represented a real increase in minimum wages of 2.0% for the treated municipalities, resulted in an overall reduction in employment of 1% for all workers and a more marked reduction of 2.0% for male workers. Female workers were not affected by the policy.

When distinguishing between formal and informal workers, results show that the policy resulted in a 4.1% reduction in the employment of formal workers, with male workers being affected more strongly, suffering a reduction of 4.8%. The policy did not have a significant effect on the number of female workers employed in the formal sector. Likewise, workers in the informal labor market did not experience a significant impact of the policy.

Overall, therefore, we can state that a moderate increase (2%) in real minimum wages in Mexico, which employers are unable to anticipate, will negatively impact the number of male workers but not the number of female workers, and the number of formal workers will be reduced. A minimum wage increase of this dimension will not affect the number of informal workers.

Readers should be careful when extrapolating the impact of such increases due to the potential nonlinearities of minimum wage increases.

However, we can safely assume that a 1% increase in the real minimum wage will result in a 0.5% reduction in employment numbers.

Based on the results obtained from this policy evaluation, the Mexican labor market resembles a market in perfect competition. This classification particularly applies to low-wage male workers in the states of Jalisco, Nuevo León, Sonora, and Tamaulipas.

The quasi-experimental evidence presented in this study should not discourage policy makers in Latin American countries from updating minimum wages, but it should serve to make them aware of the consequences of such increases. Minimum wage increases should, it appears, be followed up with policies that counter their effects on employment. It is to be hoped that future research will be able to find more natural experiments in the region, so that regional differences across the countries of Latin America can be highlighted.

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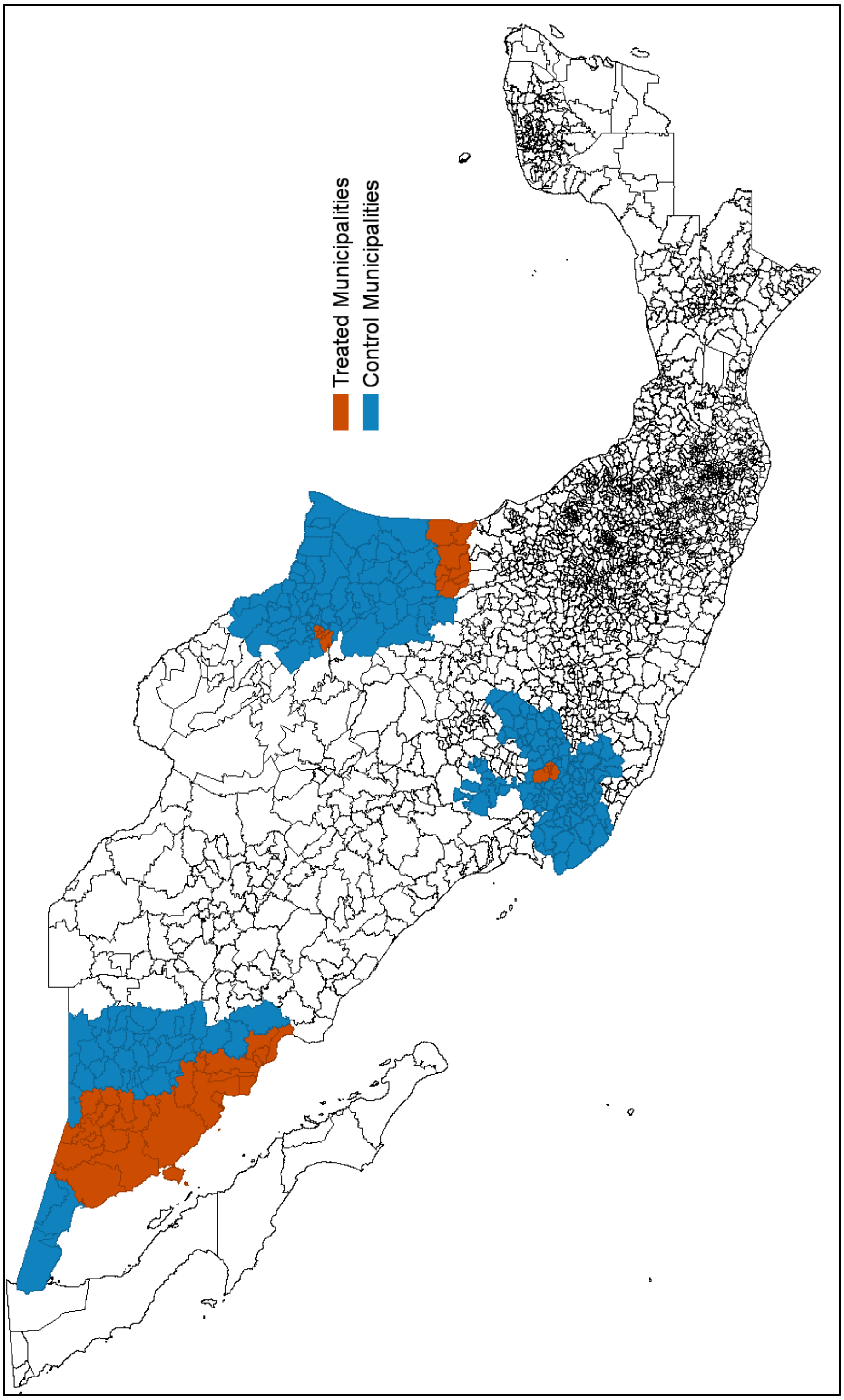
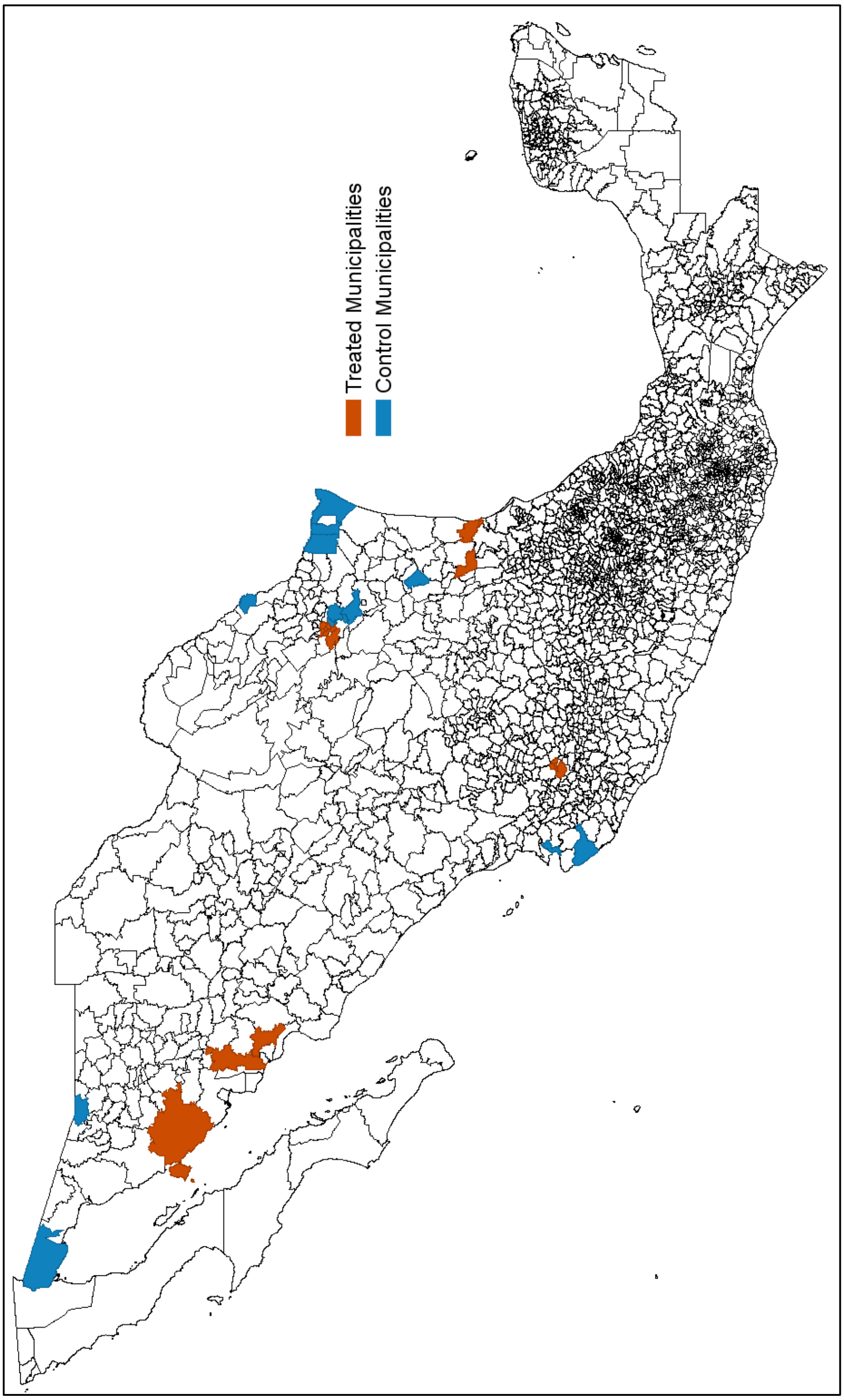
APPENDIX

Figure A4.1: Map of the Mexican municipalities eligible to be selected into treatment and control groups



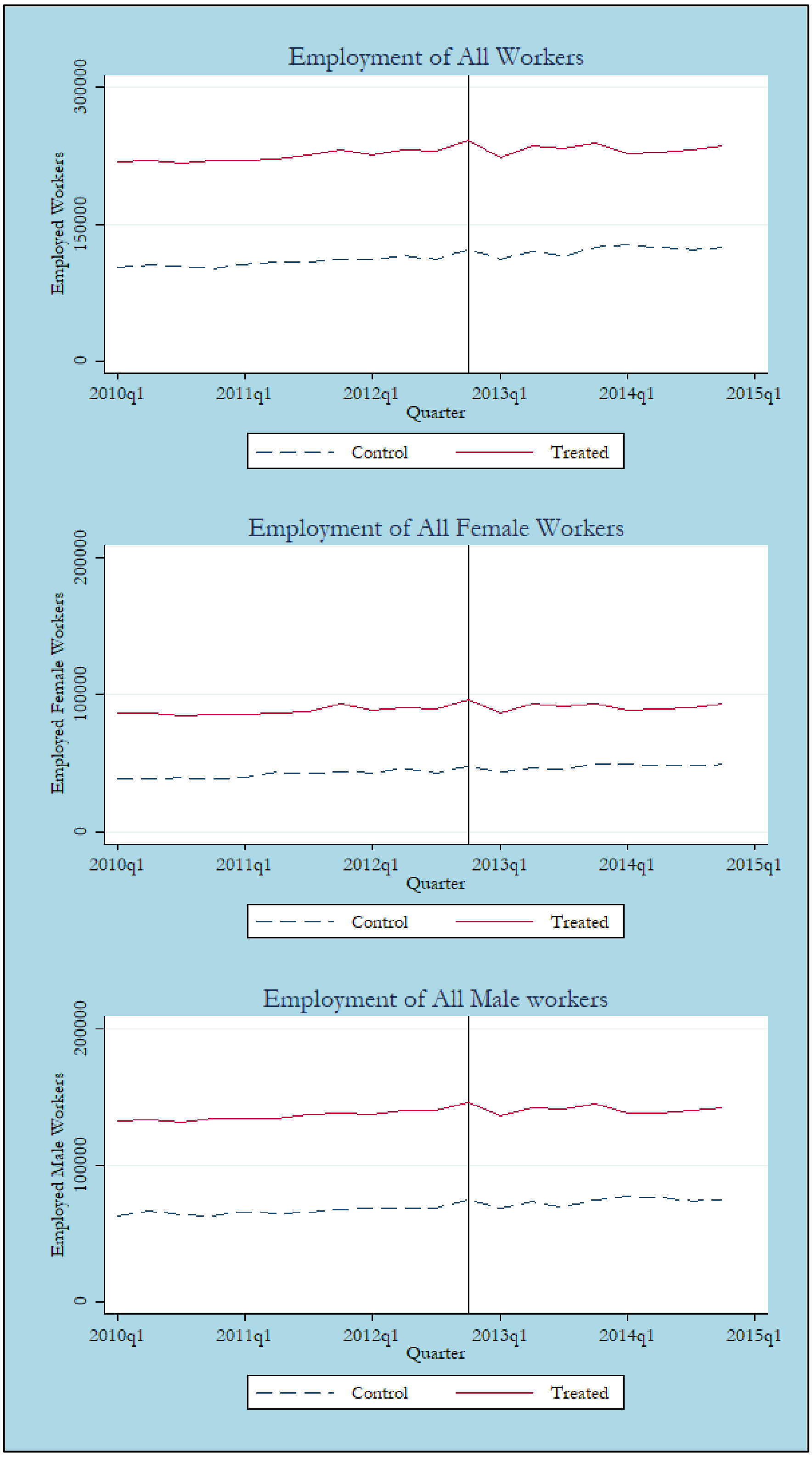
Source: underlying map from CONABIO. Own coloring and group selection.

Figure A4.2: Map of the municipalities from treatment and control groups with a representative number of survey respondents



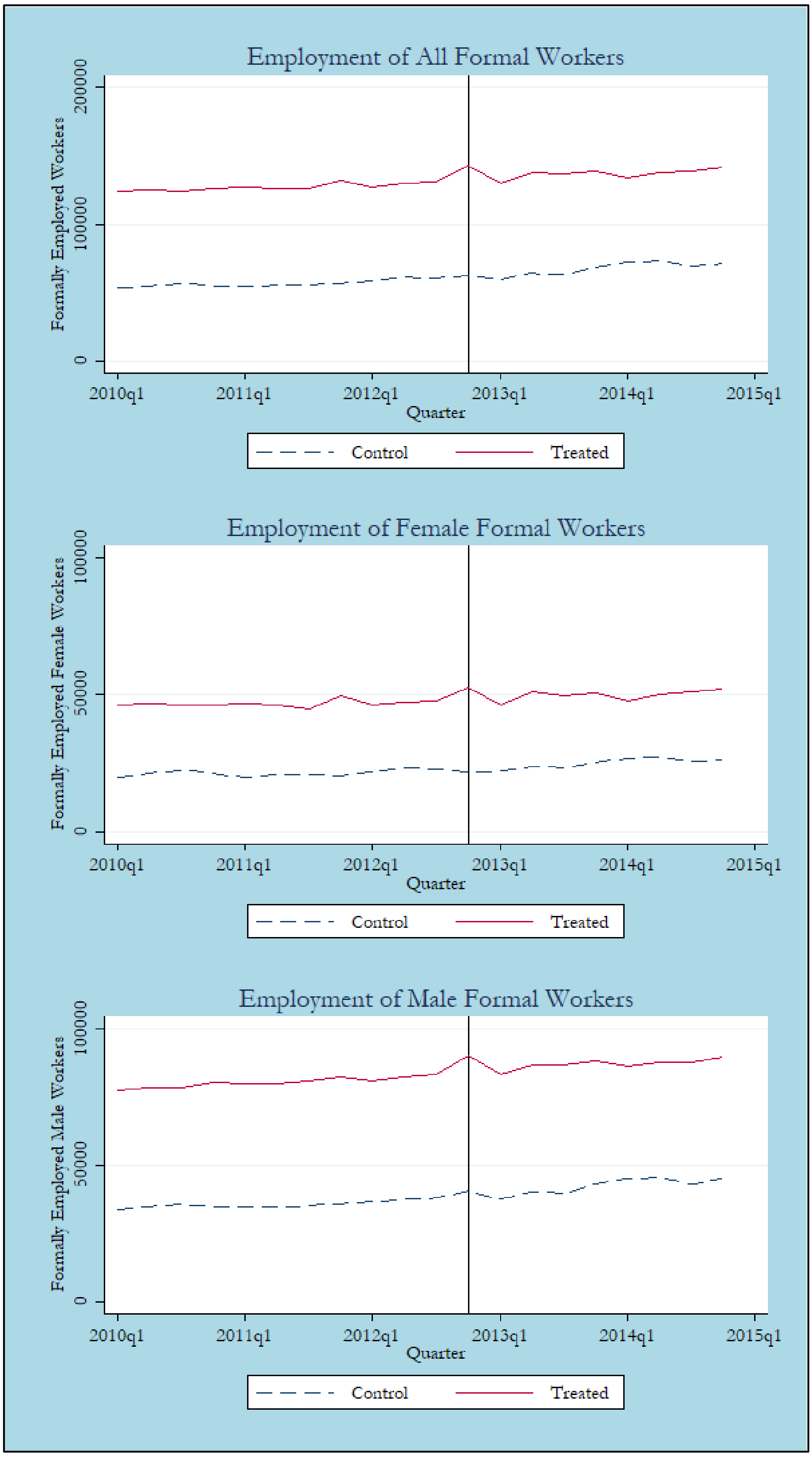
Source: underlying map from CONABIO. Own coloring and group selection.

Figure A4.3: Parallel trends of treatment and control groups for all groups of workers



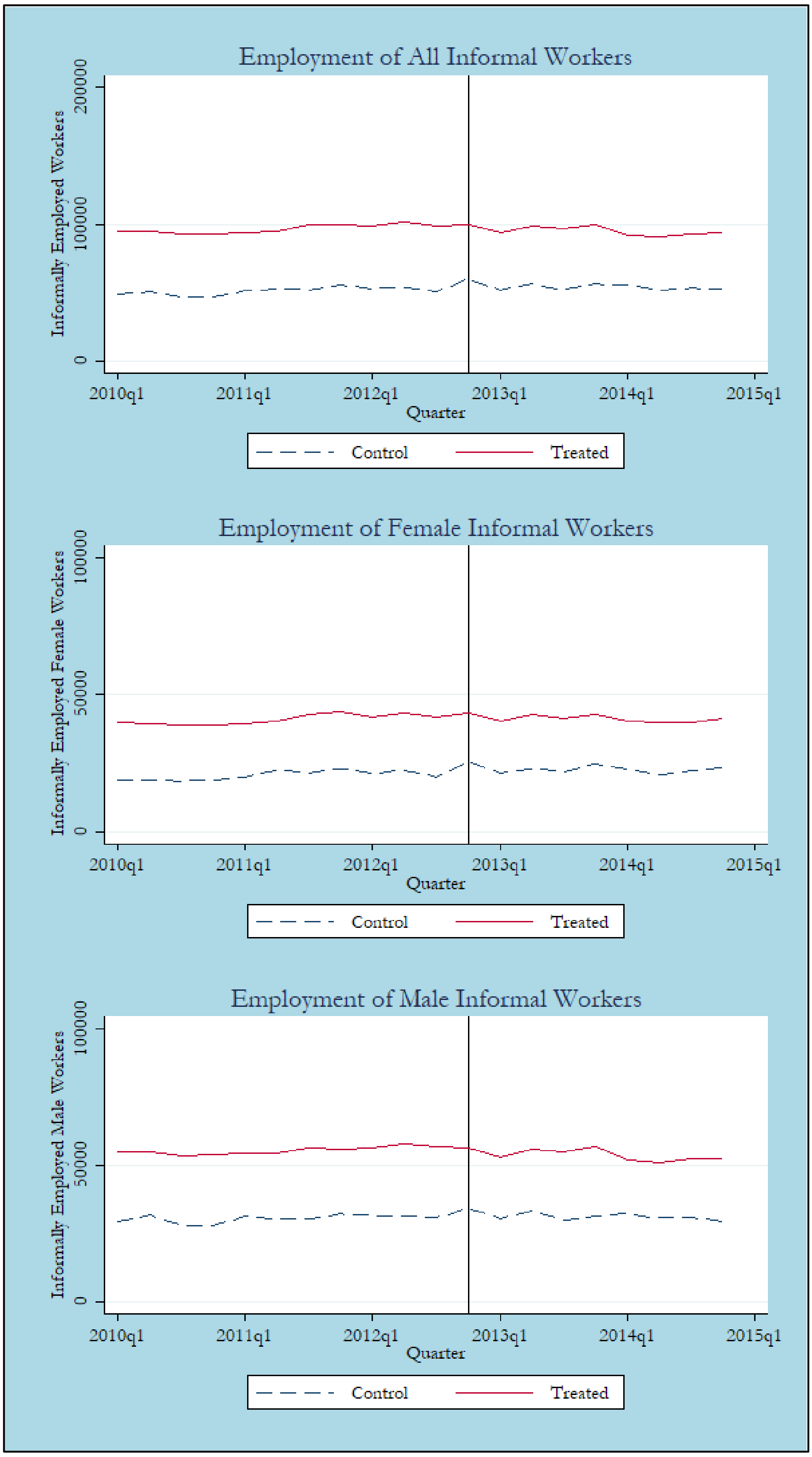
Source: Based on data from ENOE.

Figure A4.4: Parallel trends of treatment and control groups for formal workers



Source: Based on data from ENOE.

Figure A4.5: Parallel trends of treatment and control groups for informal workers



Source: Based on data from ENOE.

Chapter 5

Conclusions

1. Conclusions and Policy Implications

Public policy evaluation can serve different purposes: a) to identify whether a government program is achieving its desired goal; b) to quantify the impact on other variables or indicators; c) to inform the policy maker about unintended effects caused by the policy; or d) to determine its efficiency for achieving a particular target compared to alternative policies. Armed with this information, policy makers can expand successful policies, improve those that fell short of their desired targets, and replace a policy with another if the intervention proves ineffective or even worse if it has unintended negative effects.

The purposes of the evaluations reported in this thesis differ for each of the policies. In chapter two, the impact of BRT implementation in Mexico City is analyzed with respect to the specific target established before the intervention. This target was to reduce congestion and with it to reduce air pollutants. In chapter three, the Drug War policy initiated in December 2006 is assessed. Here the target was clearly not to impact the states' economic growth, but rather to dismantle drug trafficking organizations and to apprehend criminals, something that local police forces had been unable to do. The unfortunate repercussion of this intervention was an increase in homicides and other crimes, including kidnappings, extortions, robberies, etc. In chapter four, the change in the minimum wage territorial policy presented a natural experiment which provides useful information regarding the effects of minimum wages on employment in Mexico.

The introduction of the BRT meant more than simply substituting old buses with newer vehicles. The policy also reduced the number of traffic lanes, enforced the use of bus stops, and changed people's behavior by encouraging some commuters to switch from their private vehicles to public transport. The aggregate effect of these changes reduced CO, NO_x and PM_{10} levels in areas close to the BRT corridor in Mexico City. Knowledge of the fact that the introduction of BRT cut emissions and reduced the concentrations of pollutants should encourage the local government to expand the network of BRT routes. The outcomes should also be of interest for cities with similar geographical and traffic features to those of Mexico City.

The assessment of Mexico's Drug War policy and how it affected economic growth went beyond a simple consideration of homicide and crime rates, and introduced a key component into the analysis: namely, the effect of the public expenditure shock represented by the increase in military spending. While the violence variables had a sufficiently large effect to have a significant and negative impact on state economic growth, military expenditure showed a positive effect. These outcomes – recording significant signs – give some idea of the scale of the problem created by DTOs in Mexico. However, the policy analysis undertaken is not able to offer policy recommendations in terms of what the policy maker might have done differently. If there is one thing that the fight between government forces and DTOs has shown, it is that the structure of the drug cartels does not depend on the role played by single individuals. The detention of these drug lords gave rein to more violence as battles broke out among those seeking to replace them. Moreover, there are indications that the DTOs have diversified their operations beyond drug trafficking. The confrontational strategy adopted by the government to date has done little to check the operations of the DTOs.

The decision by Mexico's minimum wage commission to unify minimum wage areas in the country provides an opportunity to analyze how real minimum wage increases affect employment in a country with high levels of informality. The 2% increase in minimum wages reduced employment by 1%. This result gives policy makers insights into the effect such an increase is likely to have on employment, allowing them to anticipate this reduction and implement a jobs program to counterbalance the effect. Furthermore, it also shows policy makers that increasing minimum wages moderately will not augment the number of workers employed in the informal sector of the economy.

To summarize, the cases analyzed in this thesis have covered three public policies of great current relevance to Mexico. Although the research reported here focuses on the country of Mexico, the insights drawn from the different analyses should be helpful not only to Mexican policy makers but also to governments from other developing countries with similar characteristics to Mexico. Moreover, the methodologies employed here should allow for replication in other countries.

2. Limitations and Future Research

Empirical studies often seek to find real-world evidence of the predictions and behaviors described in theoretical work. However, a common obstacle to doing that is the availability of data. Regardless of data limitations in terms of data quality and availability, the reader should not lose sight of the fact that empirical models are never more than an abstraction of reality aimed at capturing a simplified version of events. As such the chapters that make up this thesis present certain limitations.

In chapter two the availability of data is certainly a shortcoming. The model would be considerably enhanced if traffic data were available. However, the government of Mexico City has no infrastructure in place to count the number of cars crossing the city. Moreover, the analysis undertaken in this chapter centers on mean concentrations of pollutants. Future research needs to explore how the policy impacted pollutant concentrations along the different parts of the distribution using quantile regression techniques. For this chapter, daily data were used; however, it would be interesting to obtain higher frequency data so as to be able to incorporate the daily pollution cycles (i.e. peak pollution hours) into the analysis.

Chapter three, which includes data on the budget allocation of the Mexican military, also suffers a number of shortcomings related to these data. Obtaining data about the military, navy and federal police from the Mexican government is far from easy. When seeking specific information, most requests were rejected on the grounds of "national security concerns", which is perhaps understandable. An additional difficulty is the inability to attribute a specific illicit activity to a particular drug trafficking organization. Having this information would improve the analysis significantly.

Chapter four is limited by the representativity of the Mexican labor force survey conducted at the municipal level. New data have become increasingly available and perhaps in the future administrative data will also be made available. A similar merger of minimum wage areas took place recently; however, full data are not yet available. It would be interesting to replicate the analysis with the more recent policy. In addition, this natural experiment could also be exploited to explore the inflation effects of minimum wage increases.

3. The future of policy evaluations in Mexico

Institutions that evaluate public policies are necessary to hold government officials accountable for their expenditure. By further institutionalizing the evaluation of government interventions, blinds spots in the policy making process will be easier to detect, and government policies will become more effective and more efficient.

While policy evaluations can be undertaken in Mexico today thanks to the data that are available, the country is making important steps towards strengthening its institutions with responsibility for conducting such evaluations. The creation of CONEVAL has made more information available and increased transparency in the social policy field. But greater efforts and more funding are needed to expand the scope of analyses, not only into other fields of public policy, but also at the subnational level so as to foster a stronger evaluation culture.

It is to be hope that the upward trend recorded in the number of policy evaluations will continue and become more pronounced in the future and that public policy evaluations will become an integral part of the policy making process in Mexico ensuring the enhancement of people's welfare.

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