# The hidden cost of bananas: The effects of pesticides on newborns' health[§]

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**Abstract:** This paper examines the effects of aerial fumigation of banana plantations on newborns' health during the period 2015-2017 in Ecuador. Using the mothers' addresses, the perimeter of the plantations, and the amount of pesticides applied in each plantation, we determine newborns' exposure to pesticides. We then implement a difference-in-differences strategy that exploits seasonal variations in the use of pesticides to identify the causal effect of fumigations on newborns' health outcomes. Our analysis shows that newborns with a high exposure to pesticides during gestation have a birth weight deficit of between 80 and 150 grams. Moreover, exposure to pesticides increases the likelihood of low birth weight and preterm delivery. We validate our results with a maternal fixed effect model that compares the health outcomes of siblings exposed and not exposed to intensive fumigations. We also carry out placebo and falsification tests considering newborns exposed to other crops not using aerial fumigations.

**Key words:** Air pollution, pesticides, aerial fumigation, birth weight, spatial buffers, banana plantations, Ecuador.

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## 1. Introduction

The increasing demand for agricultural products, combined with land restrictions and changing weather conditions, has impelled farmers across the world to adopt extensive use of agrochemicals so as to increase productivity and reduce crop loss (Cassou, 2018). This use of chemicals has severe negative effects on the populations living close to the farms or working on them. It is estimated that pesticides cause 200,000 acute poisoning deaths each year, most of them in developing countries, and have catastrophic impacts on health in communities living near agricultural land (Svensson et al., 2013; UNHR, 2017). In recent decades, national governments and international institutions have adopted different initiatives to limit the use of pesticides and to protect their populations (UNEP, 2014; Watts, 2013; USEPA, 1996). However, there are few studies using information for large-scale communities that demonstrate a causal effect of pesticides on the population's health and that can be used to guide public policies. This paper helps to broaden the understanding of the health effects of pesticides by examining the impact of aerial fumigation of banana plantations in Ecuador.

There is a growing body of literature addressing the consequences of air pollutants on children's health.[2] The economic research has shown that birth weight, gestational length, and in utero survival are all affected by pollution from industrial activity (Hansman et al., 2019), environmental regulations (Greenstone and Hanna, 2014; Tanaka, 2015), major forest fires (Frankenberg et al., 2005; Tan-Soo and Pattanayak, 2019), agricultural fires (Rangel and Vogl, 2019) and indoor pollution (Hanna, Duflo, and Greenstone, 2016; Barron and Torero, 2017). Several papers have also raised concern about the persistent effects of air pollutants on physical development and cognitive ability (Almond et al., 2005; Almond and Currie, 2011; Bharadwaj et al., 2013; Currie et al., 2014; Molina, 2021). However, there are few studies analyzing the effects of environmental pollution on health outcomes, and more specifically, very few that leverage quasi-experimental variation to estimate the health effects of the use of pesticides in agriculture (some relevant exceptions are Gemmill et al 2013, Larsen et al., 2017; Dias et al., 2020; Maertens, 2019; Jones, 2020; Frank, 2021 and Taylor, 2021). Farms around the world use pesticides to fight against fungus, pests, and crop disease, but to correctly regulate these activities it is important to understand their causal impact on health outcomes for workers and the neighboring population.

Ecuador provides an excellent context for analyzing the effects of pesticide use in agriculture. Ecuador is the world's fifth largest banana producer, and the largest exporter. In the last few decades, national producers have dedicated significant efforts to increasing their efficiency and have adopted the use of agrochemicals on a massive scale at different stages of the production cycle (FAO, 2016). In the early 1970s, banana producers started to use aerial fumigations to treat the disease known as *Sigatoka Negra*, the main fungal disease affecting

[2] The US Federal Clean Air Act identifies six common air pollutants, which are known as the "criteria air pollutants" (ground level ozone, sulfur dioxide, nitrogen dioxide, particulate matter, lead, and carbon monoxide). The U.S. Environmental Protection Agency sets and periodically revises national ambient air quality standards for these pollutants.

banana fruit plants. Despite the effectiveness of fumigations in stopping the spread of this fungus, their environmental and health implications have raised major concern (Defensoría del Pueblo, 2019). Children and adult populations who live, attend school or work near banana fields are exposed to high levels of pesticides via inhalation, ingestion, and by penetration through the skin, and this makes them vulnerable to different types of diseases. Public interest in this problem has prompted the regulation of aerial fumigations. Specifically, in 2012, the government of Ecuador passed a regulation that sets a protection distance between fumigated areas and neighboring households. However, the lack of enforcement capacity of the authorities responsible and the challenging climate conditions are likely to reduce the effectiveness of this measure (UNHR, 2017).[3]

The objective of this study is to examine the effects of pesticides used in banana plantations in Ecuador on newborns' health outcomes (weight at birth, gestational length, low birth weight and preterm). Specifically, we use a difference-in-differences (DID) approach that exploits the seasonal changes in the fumigation of banana plantations as an identification strategy. The analysis of the causal effects of agricultural pesticides on newborns' health presents several difficulties of measurement and identification. First, for reasons of confidentiality, households' addresses are not usually available and, as a result, location is usually approximated using the centroid of the reported neighborhood or municipality (Bustos et al., 2016; Camacho and Mejia, 2017; Dias et al., 2020; Maertens, 2019; Rangel and Vogl, 2019). Moreover, the lack of information on the perimeter of the plantations generates inaccuracies in the measurement of exposure. Our paper overcomes these problems by using the address of the mothers during pregnancy and precise information on the perimeter of the plantations so as to compute the mothers' distance from the plantations and the area of fumigated plantations (in square meters) near their place of residence. Our analysis shows that the newborns potentially most affected by pesticides were those born to mothers living within 150 meters of the nearest plantation and surrounded by a relatively large number of square meters of fumigated plantations.[4] We use this result to construct a *geographical exposure* dummy variable (*Banana Exposure*) that defines the group of treated and control newborns for use in the causal analysis.

An additional challenge facing the analysis of the effects of pesticides is the possibility that households living close to the plantations present different characteristics from those living further away, which makes it difficult to disentangle the causal impact of pesticides from

[3] The Ecuadorian Ombudsman's Office has analyzed the working conditions of employees of banana plantations in the period 2010-2017. Defensoría del Pueblo (2019) shows evidence of the direct and frequent application of pesticides in populated areas as well as in essential facilities such as schools and health centers. It shows that, on many occasions, fumigations did not comply with the safety distance established by the regulations and that there were no tree barriers that might have protected essential facilities. In addition, it provides examples of plantations that were fumigated while workers were present. The study also collects information on the few inspections and judicial proceedings initiated in recent years by various institutions and ministries in the country. It is also important to explain that local communities and workers in the plantations face many difficulties in taking legal action against those responsible for illegal fumigations: https://www.diariocorreo.com.ec/25568/ciudad/fumigaciones-https://www.cdh.org.ec/testimonios/308-fumigaciones-aereas-y-despidos-denuncian-trabajadores-de-bananeras.html; https://www.planv.com.ec/investigacion/investigacion/vivir-y-morir-del-banano

[4] This result is in line with those of other papers showing that the effects of pesticides (and of other types of air pollutants) fall notably at distances greater than 100-250 meters (Currie et al., 2009; Currie et al., 2015; Dereumeaux et al. 2020; Gibbs et al., 2017).

unobservable factors that affect newborns' health (Chay and Greenstone, 2003; Greenstone and Hanna, 2014; Cesur et al., 2017; Rangel and Vogl, 2019). We overcome this potential endogeneity problem by implementing a difference-in-differences (DID) analysis that exploits the seasonal changes in the intensity of fumigations. Banana plantations in Ecuador are fumigated over the whole year, but fumigations are more intense during the rainy season, which is when the *Sigatoka Negra* fungus propagates more easily. We use monthly information on the gallons of pesticides applied in each banana plantation to construct a *seasonal exposure* dummy variable (*Intensive Fumigations*). Specifically, we create a grid of 5 x 5 km cells for the whole country, and we establish that the *seasonal exposure* variable takes the value of 1 for newborns who during their gestation (or during the three months of a gestation trimester) were for at least three months in a grid cell with more than four gallons of pesticides per hectare. Taking this into account, the DID estimation compares the difference between newborns born to mothers living in geographically exposed areas who were gestated during intensive and non-intensive fumigation seasons, relative to the difference between newborns born to mothers living in geographically non-exposed areas who were gestated during the same two seasons.

Our study draws on a public data set obtained from the National Register of Live Births (*Registro estadístico de nacidos vivos*) for the period 2015-2017, which contains information for nearly 270,000 newborns, and from which we obtained the mothers' residential addresses during pregnancy. Almost 51,000 of these mothers resided within 2.5 kilometers of the banana plantations, which is the maximum distance we consider to analysis of effects of fumigations. This data set includes information on several observable characteristics of children and mothers. Information on Ecuador's banana plantations was obtained from the 2013 agricultural census and the 2016 to 2018 register of aerial fumigations. The former contains information on the perimeter of each plantation and the use of aerial fumigations, and the latter contains geocoded data on the application of pesticides (i.e., quantity, toxicity, date of application). We combine the information on the mothers' locations, the perimeters of the plantations and the use of pesticides to compute the *geographical* and the *seasonal exposure* variables for each newborn (*Banana Exposure* and *Intensive Fumigations*). The final dataset consists of nearly 21,400 newborns located across 151 grid cells (distributed over 137 municipalities) that experienced seasonal variation in the use of pesticides.

The results of our analysis confirm the hypothesis that pesticides have a statistically significant impact on newborns' birth weight. We show that newborns living close to the banana plantations and exposed to intensive fumigations during their gestational period have an average birthweight deficit of between 80 and 150 grams relative to non-exposed newborns. Pesticides have a greater impact when intensive fumigations coincide with the first two trimesters of gestation. We also obtain stronger effects for male newborns, and for newborns of less-educated mothers. Moreover, the exposure to pesticides reduces the number of gestation weeks and increases the odds of being born with low birth weight and of preterm delivery.

We complement our analysis with several robustness checks. First, we use a sub-sample of mothers who had more than one child during the period examined to estimate a model with maternal fixed effects. This analysis exploits the difference in birth weight between siblings exposed and not exposed to intensive fumigations during gestation. We find that newborns exposed to pesticides have an average birth weight 327 grams lower than their non-exposed siblings. Likewise, exposed newborns have on average a deficit of 1.5 weeks of gestation relative to the non-exposed siblings.

We also study the possibility that some mothers could strategically avoid pregnancies in periods of intensive fumigations in order to protect their children. The potential endogeneity of the gestational time may bias our estimates and affect the interpretation of the results. We find that mothers with higher levels of education were less likely to live close to the plantations, but there is no evidence that educated mothers planned their pregnancies anticipating the seasonal intensification of the fumigations. Moreover, newborns with older siblings exposed to the pesticides and with mothers living close to the plantations were as likely to be gestated in periods of intensive fumigations as the other newborns.

Finally, we conduct several robustness, placebo, and falsification tests to validate our results. First, we examine the robustness of our results to different periods and intensities in the exposure to pesticides. Second, we perform a placebo test that considers newborns' geographical exposure to other crops (rice, cocoa, and corn), and a falsification test that adds lags and leads time distortions to the periods of intensive fumigations.

Our research contributes to the literature analyzing external factors that affect fetal health during gestation. Previous work has shown that economic shocks during gestation affect newborns' health, especially in the third trimester of pregnancy. This effect has been identified for the Dutch famine (Stein and Lumey, 2000), the food stamp program in the United States (Almond, Hoynes and Schanzenbach, 2011) and the economic crisis in Argentina in the period 2000-2005 (Bozzoli and Quintana-Domeque, 2014). Other papers have evidenced that maternal stress due to exposure to different types of violence affects birth weight, especially when it occurs in the first trimester of pregnancy (Camacho, 2008; Koppensteiner and Manacorda, 2016; Currie et al., 2020). Additional research has documented that fetal health can be negatively affected by in utero exposure to temperature level variations (Andalón et al., 2014; Rocha and Soares, 2015), rainfall shocks (Rabassa et al., 2014), dust storms (Jones, 2020) and natural disasters (Simeonova, 2011; Currie and Rossin-Slater, 2013).

Our paper is more closely aligned with the research documenting the effects of air pollutants on newborns' health outcomes (Currie, Neidell and Schmieder, 2009; Chen, Ebenstein, Greenstone and Li, 2013; Rangel and Vogl, 2019), children (Hyland and Laribi, 2017) and adults (Lai, 2017; Jones and Fleck, 2020).[5] There is also an important body of research studying the effects of the use of pesticides in agriculture on newborns' health (see Table 1

[5] Laboratory and case-control medical research studies have shown the biological mechanisms that intervene in *in-utero* exposure to pesticides. Case-control studies have shown that the number of pesticides in cord blood is inversely related to birth weight (Wickerham et al., 2012; Vizcaino et al., 2014). Laboratory studies have pointed out the negative health implications of fumigation compounds, which can cause skin and brain diseases, fetal malformation and several more diseases in children and adult individuals (WHO, 2005; Byrns and Fuller, 2011; Ling et al., 2018).

for a summary of the results). Camacho and Mejia (2017) used a panel of individual health records in order to study the causal effects of the aerial spraying of herbicides (glyphosate) on illegal crops in Colombia. Maertens (2019) estimated the health impact of the use of pesticides in the US Corn Belt. He applied an instrument variable approach, using as an instrument for the pesticides the expansion in corn production driven by enactment of the Renewable Fuel Standard. Moreover, he exploited the seasonal variation in corn pesticide applications during the year. Jones (2020) investigated the effects on infant health of the use of pesticides in the agricultural sector in the period 2005-2015 in the US, exploiting the fact that pesticides were used after the initial observation of wing drosophila (a fruit fly) at the county level. Dias et al. (2020) assessed the impact of glyphosate use in soybean production on birth outcomes of surrounding populations sharing the same water resource. To deal with the endogeneity of glyphosate adoption, the authors constructed an instrument based on the potential yield gains from the adoption of genetically modified seeds and on their regulation in Brazil (see also Bustos et al. 2016). In addition, to minimize the potential bias of the effect of increased agricultural productivity on local socioeconomic outcomes, they used the direction of water flow inside water basins to isolate the effects of glyphosate water contamination. Frank (2021) considered the staggered expansion of an invasive fungus species in the US that caused high mortality rates in bats and led to the substitution of this biological pest control for the use of insecticides. Using a difference-in-differences strategy, they found that the counties that experienced the bat die-offs saw increases in the use of insecticides and in human infant mortality. Taylor (2021) used the mass emergence of periodical cicadas in 13 and 17-year cycles to identify the impact of insecticides on human health. The effects of the cicadas were greater in counties with large amounts of woody crops (e.g., apple trees) than in herbaceous row crops (e.g., corn and soy). Considering this, the authors assessed the effects of cicada emergences in high apple-producing counties compared to the same counties in non-cicada years, non-apple producing counties in cicada years, and counties lacking endemic cicada broods.

One important difference of our paper with respect to this literature is the fact that the richness of our data allows us to measure newborns who were geographically and seasonally exposed to fumigations with a high degree of accuracy. As a result, we can identify the effect of pesticides on directly exposed newborns. Our research is also related to the medical and environmental studies that use geographical information system tools to examine the effects of pesticides on health at birth. These studies compute the amount of pesticides applied in the area close to the mother's residence during pregnancy, although their identification strategy is based on the mother's residential proximity to the farms (Gemmill et al. 2013; Larsen et al., 2017).

The rest of the paper is organized as follows. Section 2 describes the banana plantations in Ecuador, the use of pesticides and their potential health impact. Section 3 presents the data. Section 4 describes our empirical strategies. Section 5 shows the results. Section 6 considers several robustness checks and falsification tests. Finally, Section 7 concludes.

## 2. Background

### 2.1 Banana plantations in Ecuador

Banana production is one of the main economic activities in Ecuador. In 2017, banana plantations covered more than 186,000 hectares and produced more than 6.5 million tons of bananas, which represents 6% of the world's total production. Banana exportation accounts for 2% of total Ecuadorian GDP and represents approximately 35% of the agricultural sector's share of GDP (BCE, 2017). The banana plantations are mostly concentrated in the coastal region of the country, which has adequate weather conditions and soil nutrients for raising this crop. Most of the country's population is concentrated in this region.

The economic importance of this crop has led the government to control its production. In 2010, the government banned the expansion of banana plantations across the whole country, regardless of their size, structure, and variety of fruit. This was justified by the large number of plantations (registered and unregistered) with very low productivity rates. Moreover, in 2012, the Ministry of Agriculture created the Banana Unit (*Unibanano*), which acts as a registry for plantations, regulates their activities and promotes their efficiency. *Unibanano* assists producers in the exportation of their fruit and the acquisition of inputs, guarantees a minimum reserve price according to the quality of the fruit, and promotes the establishment of specific labor regulations for the sector. The price received by banana producers has been very stable in the period under study (Figure A1 in the Online Appendix A).

### 2.2 Plantations and aerial fumigation

Banana production is an extensive monoculture with a permanent cycle. Bananas are propagated via pups, or baby banana plants, that surface from the banana's underground rhizomes. The phenological stages of banana plantations are vegetative development (six months), flowering (three months) and fruit stage (three months). Individual banana stalks only produce fruit once. After the fruit is picked, the stem dies or is cut and a new one grows from the rhizome to generate a new banana tree. This means that the time between planting a banana plant and the harvest of the banana bunch is from nine to twelve months, depending on the fruit variety and growing conditions. Ecuador produces mostly Cavendish bananas, which have plants that can live for more than ten years.

Farms control the development of banana trees and apply pesticides to preserve the health of the plantations and the quality of the bananas. Pesticides are applied manually with pumps or from airplanes, which can be contracted collectively by several different farmers.[6] Aerial fumigations were first adopted in the early 1970s to treat a fungal disease known as *Sigatoka Negra* (*Mycosphaerella Fijiensis*), a fungus that generates a leaf-spot disease that causes progressive destruction of the foliage and of the photosynthetic process. The infected plant reaches the flowering stage with a reduced number of leaves, accelerating the maturation process and causing the fruits to shrink or die. Fumigations are applied during the vegetative

[6] Pesticides are among the main costs for producers. Around 60% of their annual budget is spent on plantation maintenance, control of pests and fungus diseases (MAGAP, 2013).

development of the trees and the fruits but are also used at other stages of production to reduce the damage caused by this disease.

The number of sprayings of pesticide by crop dusters has risen notably in recent years and may range from 20 applications (cycles) per year per plantation to almost one application per week. The use of pesticides depends on several factors, such as the humidity and rainfall, and the proliferation of pests, fungus diseases and weeds. The decision to apply pesticides is based on regular field scouting and monitoring. The main factors contributing to the spread of *Sigatoka Negra* fungus are high temperature, high rainfall, and sunlight. In the coastal region of Ecuador, there are small variations in temperature and luminosity from one season to the other, but precipitation is concentrated in the winter period (usually from January to May). The rainfall and humidity in the winter season favor the spread of the *Sigatoka Negra* across the banana trees (Jesus Júnior et al., 2008; Khan et al., 2015), and the presence of this fungus leads producers to intensify the fumigations. The seasonal use of fumigations is the basis of the estimation strategy that we use to analyze the causal effect of pesticides on newborns' health.

The Ecuadorian government has passed several measures that ban the use of pesticides in the areas close to households and public spaces. In October 2012, a law established a protection distance of 200 meters from households, schools, health centers and highways and required the construction of natural barriers to protect public spaces. Manual fumigations were banned within 50 meters of these areas. In February 2015, a new regulation established a security distance of 30 meters in the presence of living tree barriers, and 60 meters in their absence, from riversides and water infrastructure not dedicated to human consumption. These regulations force producers to apply pesticides manually in the plantations close to households, which is more expensive. There are also restrictions regarding the weather conditions in which pesticides can be spread. Moreover, the Ministry of Agriculture has promoted the use of greener actions, such as growing soy and maize, to complement the production of traditional crops such as banana, cocoa, and palm oil. These measures are believed to increase the productivity of plantations and to reduce the use of pesticides.

Climate change is another important driver for the use of pesticides in agriculture. Altered temperature, light and rainfall can increase the prevalence of pests, diseases, and weeds (Miraglia et al., 2009), modify the performance of pesticides (Noyes et al., 2009) and affect the growth and development of organisms across regions (Harvell et al., 2002; Delcour et al., 2015). Varma and Bebber (2019) show that the world's leading banana-producing countries have experienced on average an increased crop yield since 1961 due to the changing climate and the more favorable growing conditions. However, these gains could be significantly reduced, or disappear completely, by 2050 if climate change continues at its expected rate. While some countries (including some of the world's largest producers such as India and Brazil) are expected to see a significant decline in crop yields, other countries (including Ecuador and Honduras and a number of African countries) may see an overall benefit.

## 2.3 Pesticides and health

Several medical and environmental studies have shown negative health effects for households close to agricultural land affected by pesticides. According to the World Health Organization (WHO), absorption of pesticides occurs via inhalation, accidental ingestion and by penetration through the skin. Pesticides are absorbed more quickly if the formulation is liquid, oily, or if the skin is hot or bears injuries. The type of exposure that presents most risk for human health is the inhalation of dust, airborne droplets, vapors, or gas, which allows smaller particles to reach the alveoli and to enter the bloodstream directly.

The literature has found high pesticide concentrations in blood and urine tests, and in surface deposition of chlorpyrifos both outdoors and indoors, in residences located within 60-250 meters of agricultural fields (van Wendel de Joode et al., 2012; Gibbs et al., 2017; Dereumeaux et al., 2020). Benner et al. (2014) examined glyphosate aerial drift distances and found high concentrations of glyphosate in areas located within the first 226 meters from the pollution source.[7] Whyatt et al. (2004) and Rauh et al. (2012) showed a direct correlation between chlorpyrifos exposure and higher risk of intrauterine growth restriction, low birth weight and small cranial circumference at birth, when exposure occurs at short distances from the plantations. More recently, Friedman et al. (2020) found that children located within 100 meters of floricultural lands in an Ecuadorian municipality had lower average neurobehavioral performance than those living in locations further away.

Other papers have exploited the seasonal variation in the application of pesticides by comparing seasonally exposed and non-exposed households, finding that seasonally exposed households have higher concentrations of pesticide metabolites in urine samples and a decrease in nervous system functioning (Bradman et al., 2011; Cecchi et al., 2012; Quintana et al., 2017).

The medical literature has also shown the effects of exposure to pesticides in the different stages of the gestation. In the embryonic stage, pesticides are especially damaging, as this is a critical period for prenatal development and birth weight. Later, during the fetal stage, the environment provided by the mother affects the baby's size and health, rather than the formation of organs and limbs (Laborde et al., 2015; Bernstein and Nash, 2008). During the second and third trimester of gestation, growth is important for these structures and organs, and the fetus begins to gain weight steadily. In this period, exposure to pesticides can lead to functional defects such as learning problems (Carlson, 2008; Cochard, 2012; Moore, 2013).

[7] The authors also found pesticide particles at distances beyond 2.5 kilometers. The drift distance mainly depends on meteorological factors, droplet size and the pressurized airflow from the nozzles. For common cases, in which the droplet size is 150 um (dense substance), pesticides will drift less than 226 meters.

## 3. Data and merging strategy

The paper combines different administrative data sets: the Ecuadorian register of newborns for the period 2015-17; the 2013 census of banana plantations; the 2016 to 2018 registers of aerial fumigations; and the 2016 satellite map of other crops such as rice, cocoa, and corn.

### Newborns register

The national register of live births from the National Institute for Statistics and Census (INEC) is a data set containing information for all newborns in Ecuador. We use the information from the years 2015 to 2017, which is the period for which the mother's address during pregnancy is available. The register comprises information for more than 270,000 newborns per year across the whole country, although our analysis focuses on nearly 22,000 newborns who during gestation were living in areas with banana plantations and with seasonal variation in the use of pesticides.

This data set includes the newborns' health outcomes used in our analysis: birth weight measured in grams, the gestation length in weeks and dummy variables showing whether newborns were born with low birth weight and whether they were preterm. In addition, it contains information about birth conditions (number of prenatal controls, type of delivery, number of previous births, multiple births), characteristics of the newborn (sex, birth order) and characteristics of the mother (education level, ethnicity, marital status, C-section, address during gestation) that are relevant factors for the health of newborns (Almond, Chay and Lee, 2005; Almond and Currie, 2011; Bharadwaj et al. 2013). Following Bozzoli and Quintana-Domeque (2014), we focus on mothers aged 15 to 49 and we exclude newborns whose weight was either under 500 grams or above 9,000 grams. Following Larsen et al. (2017), we also exclude very premature births with gestation of less than 26 weeks and those births at later than 50 weeks.[8]

Regarding the mother's address, we use the one they had during pregnancy, which is the only address provided by the register for all mothers. We assume that mothers maintained their address during gestation.

The newborns' date of birth and the number of weeks of gestation are used to calculate the gestational date. With this information, we compute the newborns' trimesters of gestation and the outcome of preterm delivery.

[8] We excluded 4,500 observations of births from mothers aged under 15 and over 49. No observations are excluded from the birth weight criteria. 613 observations are excluded from gestation week criteria. Our results are robust to the reported estimates when including these observations in the analysis.

**Banana plantations census**

Information about the banana plantations comes from the 2013 *Catastro Bananero,* from the *Ministerio de Agricultura, Ganadería Acuacultura y Pesca* (MAGAP). Banana plantations are present in around 140 municipalities in five provinces of the coastal region of Ecuador.

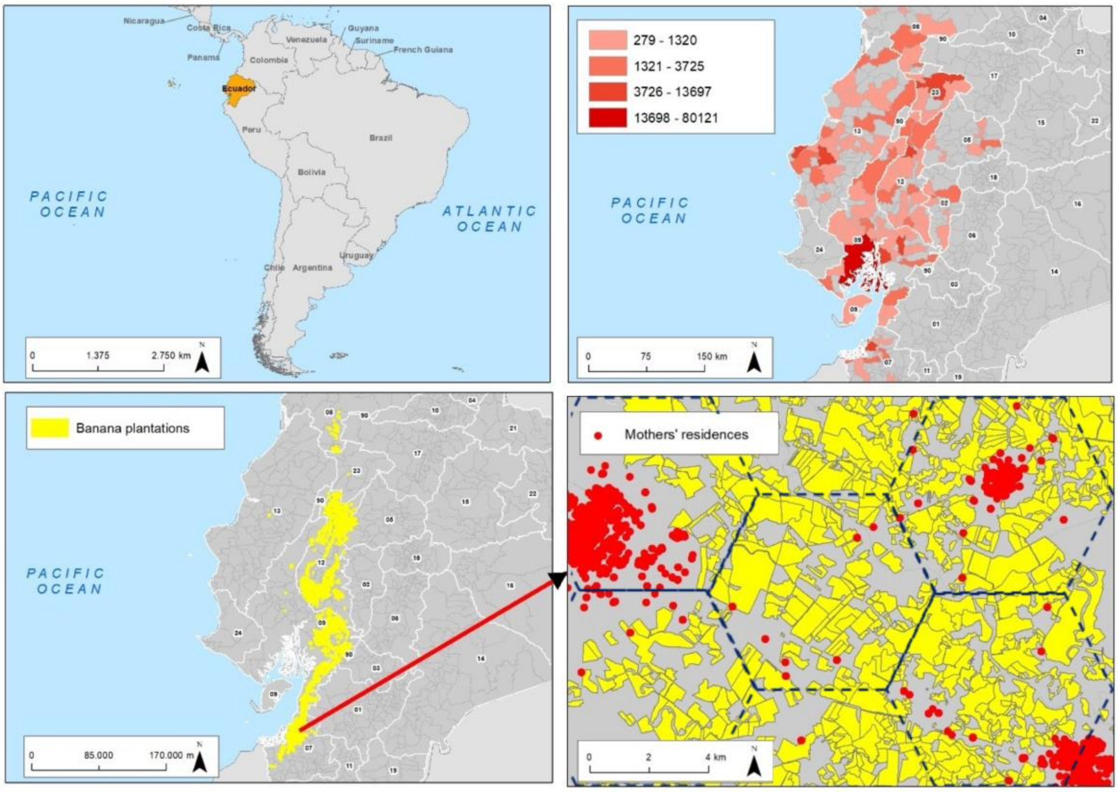
This census contains the information on the plantations' locations and perimeters that we use to construct our exposure variable. It also contains other relevant information about the plantations, such as the fumigation method (aerial or manual) and the surface area. In our analysis, we assume that the plantations' perimeter has remained stable since 2013, which is when the government restricted the amount of land that can be devoted to banana plantations.[9]

Approximately 85% of the plantations in our study use aerial fumigation, which in fact is ubiquitous for large plantations. Indeed, while only 31% of the small plantations (less than 5 hectares) use aerial fumigation, the percentage rises to 97% for large plantations (those of more than 30 hectares). At this point, it is important to note that large plantations usually surround smaller ones, and that small plantations usually contract fumigations collectively.

Figure 1 presents the geographical distribution of the banana plantations in Ecuador and shows how mothers' residences are usually surrounded by several plantations at different distances. In the lower right image, the yellow areas are the banana plantations that apply aerial fumigation, and the red dots are the mothers' residences during pregnancy.

[9] According to the Ministry of Agriculture, the extension of banana plantations has not undergone any substantial changes since 2013. In 2004, the government banned the expansion of plantations (*Ley para Estimular y Controlar la Producción y Comercialización del Banano, Plátano y otras musáceas afines destinadas a la exportación*, *Registro Oficial -S315 del 16 de Abril del 2004*). Between 2012 and 2013, the Ministry of Agriculture created the census of plantations to control production.

**Figure 1. Mother's locations and banana plantations in Ecuador (2015-2017)**




**Note:** The upper left image shows the location of Ecuador in South America. The upper right image presents the geographical distribution of newborns across provinces with banana plantations. The lower left image shows (in yellow) the location of banana plantations in Ecuador. The lower right image is an example to illustrate that mothers' residences (red dots) are usually surrounded by several plantations (yellow areas) at various distances. This panel also shows the grid used in our study to group newborns in a similar neighborhood.
**Data source**: INEC – MAGAP

## Aerial fumigation register

Information on the type and quantity of the pesticides applied in the banana plantations comes from the 2016-2018 register of aerial fumigation activity, gathered by the *Dirección General de Aviación Civil (GDAC)* and provided by the Ministry of Environment, which is responsible for controlling pollution from aerial activity in Ecuador. The register contains information about the dates and coordinates of aerial fumigations, the chemical compounds, toxicity degrees and quantities in gallons of agrochemicals.

Our dataset shows that in the period 2016-2018 nearly 7.4 million gallons of agrochemicals were aerially sprayed in the banana plantations, of which 90% were considered as moderate to high toxicity pesticides. Pesticides are classified from 1 to 5, according to toxicity. The most frequently used pesticides contain chlorpyrifos, dithiocarbamate and triazole chemical compounds, which are described as "less harmful" or "low toxicity". For their application, toxic pesticides are mixed with petroleum-based horticultural oil. As illustrated in Figure 1, mothers' residences are usually surrounded by several plantations, which can be fumigated several times per month using different combinations of pesticides. In order to simplify our analysis, we follow Larsen et al. (2017) and calculate the gallons of all types of pesticides applied in each grid cell, in each month.

We combine these registries using geographical information system tools. The final dataset consists of 21,393 newborns located across 151 hexagonal grid cells of 5 x 5 km for which there is seasonal variation in the use of pesticides in banana plantations. The register does not have data on aerial fumigations of other crops.

## 4. Empirical strategy

Our paper aims to analyze the causal effect of pesticides used in banana plantations on health outcomes at birth. One difficulty of this analysis is that unobserved socio-economic characteristics of households might affect both newborns' health outcomes and the location of their residence. For example, it could be that properties close to the plantations are less expensive or that workers in the plantations live nearby. In these cases, variation in birth weight around the plantations could be related to the households' characteristics and not only to the effect of pesticides. To overcome the identification challenges posed by economic correlates, we adopt a Difference-in-Differences (DID) strategy that is based on the seasonality of the fumigations of the plantations surrounding the mother's residence.

Banana plantations are fumigated several times during the year to guarantee the continuous production of the banana fruit. However, fumigations are more intense in the months of the year in which the level of humidity favors the propagation of the *Sigatoka Negra* fungus disease. Using the information from the national registry of aerial fumigations, we create a *seasonal exposure* dummy variable (*Intensive Fumigations*) that shows whether newborns were gestated in a period with intensive fumigations (treatment months). Moreover, using geographical information system tools, we determine the location of the mothers during pregnancy and the perimeters of the plantations surrounding them to construct a *geographical exposure* dummy variable (*Banana Exposure*) that determines whether newborns were close to the fumigated plantations (treatment group). With these measures, we estimate a DID model comparing the difference between newborns gestated in geographically exposed areas during intensive and non-intensive fumigation seasons, relative to the difference between newborns gestated in non-geographically exposed areas during the same two seasons. Next, we explain how we have constructed the seasonal and geographical exposure variables and how we implement the DID estimation.

### 4.1 Seasonal exposure

Farmers fumigate banana plantations throughout the year to prevent the appearance of diseases that can affect the banana trees.[10] However, the frequency and dosage of the

[10] The effect of weather conditions on fumigations is examined in more detail in the Online Appendix B. Figure B1 shows the rainfall and the number of gallons of pesticides per hectare applied in each of the 5 x 5 km grid cells. Figure B2 displays the monthly accumulated rainfall and the pesticides applied in the region we examine.

sprayings increases during the rainy season. We exploit this variability in the use of pesticides to construct the dummy variable *Intensive Fumigations*, which reflects whether newborns were exposed to episodes of intensive fumigations during gestation.

We create a grid of 5 x 5 km cells for the whole area with banana plantations and establish that a cell was subject to an episode of intensive fumigations when it registers more than 4 gallons of pesticides per hectare in the month. According to Cassou (2018), this is the average dosage of pesticides applied across several Latin American countries. In addition, this threshold is very close to the 4.2 gallons of pesticides per hectare that on average are applied in the grid cells of our analysis. Considering this, the variable *Intensive Fumigations* takes the value of 1 for newborns that during gestation spent at least three months (or during the three months of a gestation trimester) in a grid cell with more than 4 gallons of pesticides per hectare. Sub-section 6.4 shows the robustness of our results to alternative threshold levels that might adopt this variable.

Notice that although we have the precise coordinates of each fumigation application, we are unable to determine whether pesticides were applied to one particular plantation or to a group of plantations with the same or with different owners. Indeed, owners of small and medium plantations frequently contract the fumigation of their plantations together so as to reduce costs. To address this problem, we consider the monthly fumigation profiles at the grid cell level (see a similar approach in Gemmill et al., 2013, and Larsen et al., 2017).[11] Sub-section 6.3 presents a robustness analysis that instead of using these fumigation profiles exploits data of the aerial fumigation registry to identify newborns exposed to pesticides in a 150-meter buffer from their residences.

For illustrative purposes, Figure 2 shows the fumigation profile of a group of consecutive grid cells. In general, we observe an intense use of pesticides in the first months of the year. Moreover, while in some cells the dosage of pesticides fluctuates around the 4 gallon per hectare per month, in other cases the dosage is always some way above or below this threshold. Thereby, to capture the impact of an increase in the dosage of fumigations, our empirical analysis will focus on the grid cells which exhibit a variation in dosage above and below the threshold over the year.

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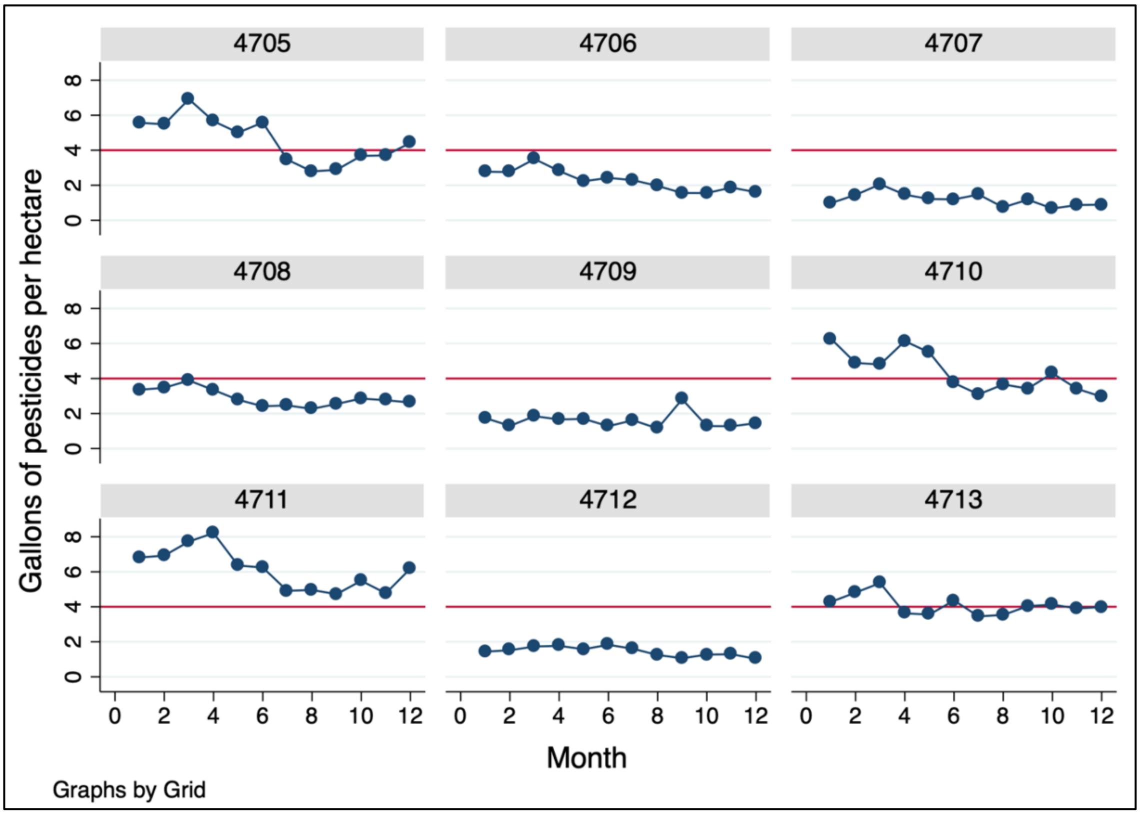
Table B1 shows that rainfall and the rainfall shocks have a positive and significant impact on the number of gallons of pesticides spread per hectare and on the probability of intensive fumigations.

[11] Notice that the monthly fumigation profiles are constructed with information from the aerial fumigation register for the years 2016-2018, while the data from the newborns register corresponds to the period 2015-2017.

**Figure 2. Illustration of seasonal application of pesticides in 2015-18 (gallons per hectare)**



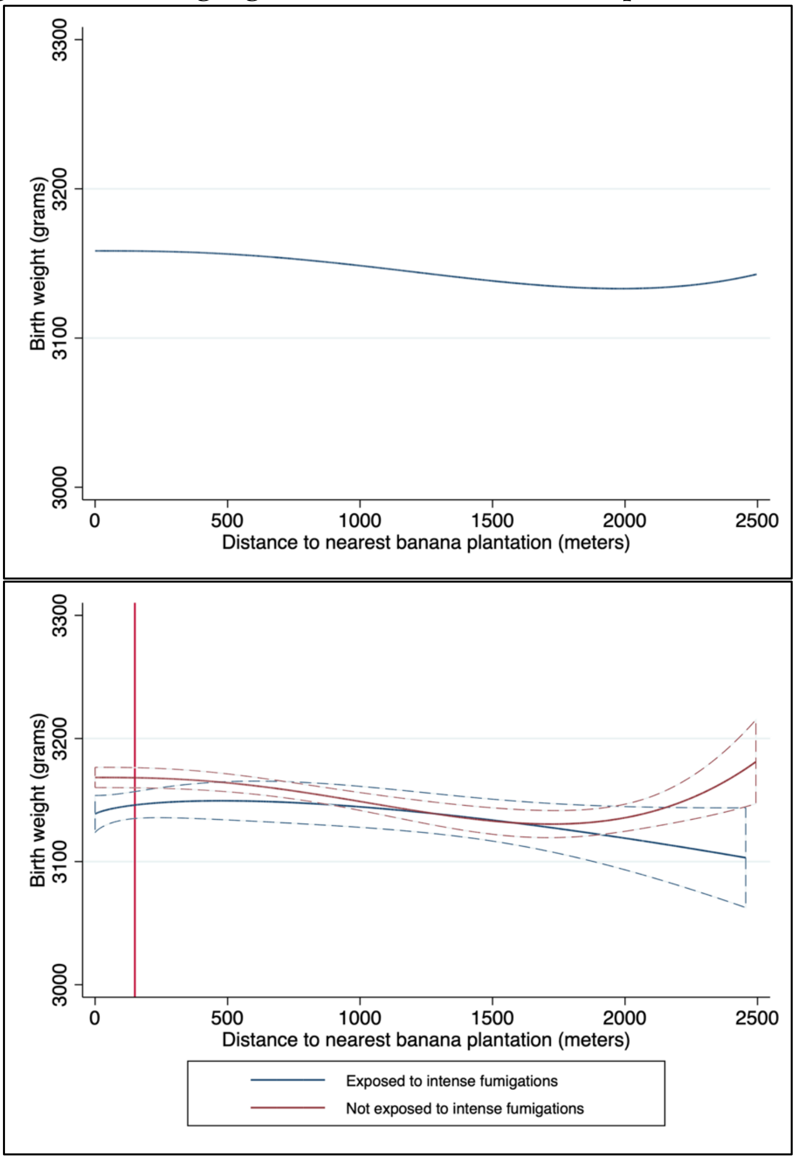

**Data source:** Aerial fumigation registry for 2016-2018

### 4.2 Geographical exposure

If exposure to pesticides has a negative impact on health outcomes, we should observe lower birth weights in newborns of mothers living near the perimeter of plantations. The upper panel in Figure 3 shows the birth weight gradient of the newborns' distances to the perimeter of the nearest banana plantation. This figure does not reveal that proximity to the plantations has a clear effect on birth weight. The lower panel in the figure repeats the analysis using instead the variable *Intensive Fumigations* to identify newborns gestated and not gestated in periods of intensive fumigations. We obtain that the gradients between 150 and 2500 meters from the nearest plantation are quite similar. However, when examining newborns located within 150 meters of the plantations, we observe that those gestated in a period of intensive fumigations have a significant lower birth weight than those non-gestated in this period. Indeed, it is plausible that the two groups of newborns would have had a similar birth weight in the absence of pesticides.

Notice that examining the effects of pesticides while relying only on distance from the plantations would be problematic, as newborns may live near a number of plantations at different distances and with different sizes. To analyze this situation, we compute the area in square meters of air-fumigated banana plantations close to the mothers' residence at different distances. Using the addresses of the mothers during gestation, we construct 25-meter-radius buffers from the mothers' residence up to 2.5 kilometers, and for each buffer we calculate the area in square meters of aerially fumigated plantations. We then weight the resulting 100 buffers considering their distance from the mother's residence and aggregate them to construct the continuous variable *Exposure Buffers*. Online Appendix C presents a detailed explanation of how we calculate the buffers and the functional forms used to weight each of the 25-meter buffers. Specifically, we use the graphical evidence shown in Figure 3 to assume that the impact of pesticides declines for plantations located more than 150 meters away from the mothers' residence.

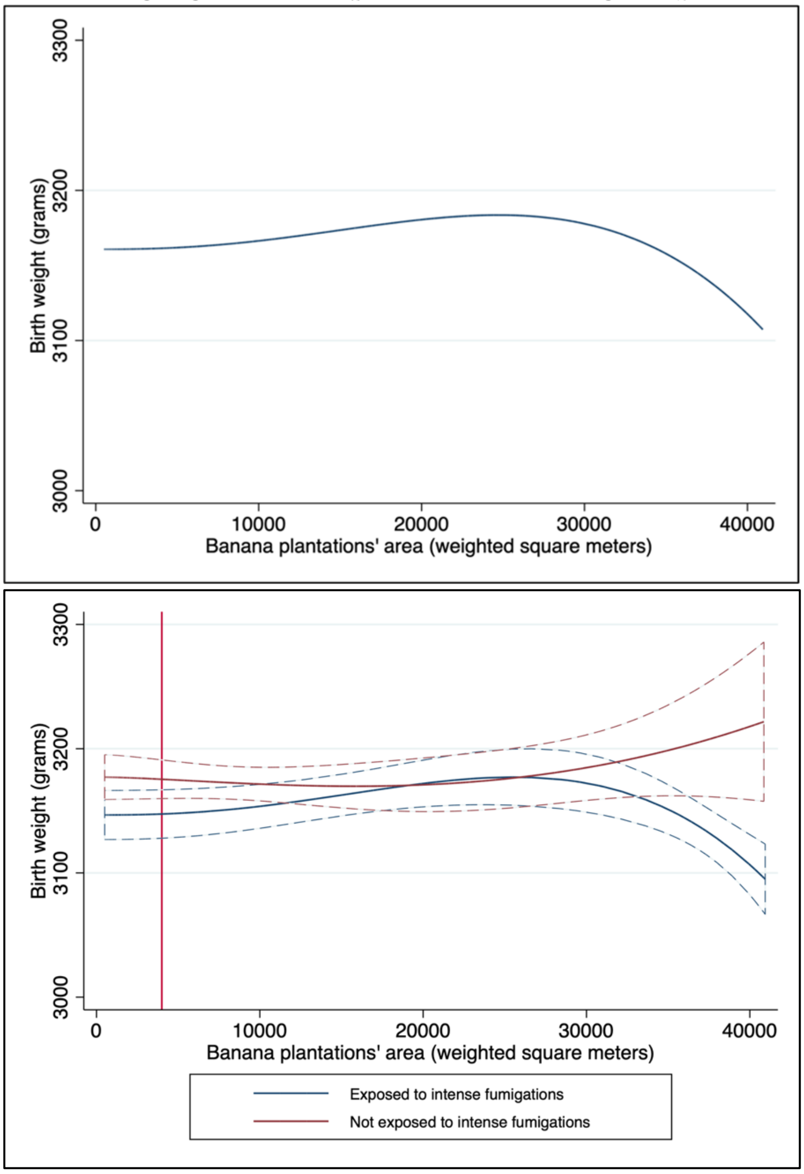
**Figure 3. Birth weight gradient of distances from the plantations**




**Note:** Results from local polynomial regressions of birthweight on distance from the nearest banana plantation. The vertical red line shows the 150-meter distance from the nearest plantations.

The upper panel in Figure 4 shows the birth weight gradient of the newborns' *Exposure Buffers* (weighted square meters of banana plantations surrounding mothers' residences). We observe that a high value of the variable *Exposure Buffers* is associated with a lower birth weight. The lower panel in Figure 4 repeats the analysis showing the gradient for newborns gestated and not gestated in periods of intensive fumigations separately. This figure evidences that newborns with high values of the variable *Exposure Buffers* and gestated in a period of intensive fumigations have lower birth weights than those gestated in a period of non-intensive fumigations.

**Figure 4. Birth weight gradient of square meters of fumigated plantations**




**Note:** Results from local polynomial regressions of birthweight on the number of square meters of fumigated banana plantations surrounding mothers' residences. The vertical red line shows the 150-meter distance from the nearest plantations.

Based on Figure 4, we define the dummy variable *Banana Exposure* that determines the group of newborns geographically exposed to pesticides that we use in our causal analysis.[12] The variable *Banana Exposure* takes the value 1 for newborns from mothers living within 150 meters of the plantation perimeter and with a value for the *Exposure Buffers* above the 6,000 level, which is the value at which one can no longer reject a null hypothesis of a zero treatment effect of pesticides on birth weight (See Table C1 in Online Appendix C). Hence, we assume that newborns potentially affected by fumigations are those living within 150 meters of the plantation perimeter and who live close to a relatively large fumigated area. The variable *Banana Exposure* identifies 8,865 newborns geographically exposed to fumigations, and 41,181 newborns geographically non-exposed, within 2,500 meters of the closest banana plantation. Notice that our empirical analysis will focus on 151 grid cells that exhibit variability in the dosage of pesticides above and below the 4 gallons per hectare per month threshold. As a result, our final sample includes 5,707 exposed and 15,700 non-exposed newborns.

### 4.3 Seasonality analysis

We exploit the seasonal variation in the fumigation of banana plantations to estimate a DID model comparing the difference between newborns of mothers living in geographically exposed areas gestated during intensive and non-intensive fumigation seasons, relative to the difference between newborns living in non-exposed areas in the same two periods. We estimate the following models:

$$\begin{aligned} Y_{ijmy} = {} & \beta_0 + \beta_1 Banana\ Exposure_{ijmy} + \beta_2\ Intensive\ Fumigations_{ijmy} \\ & + \theta\ Banana\ Exposure_{ijmy} * Intense\ Fumigations_{ijmy} + \delta X_i + \mu_j \\ & + \psi_m + \phi_y + \varepsilon_{ijpmy} \end{aligned} \tag{1}$$

$$\begin{aligned} Y_{ijmy} = {} & \beta_0 + \beta_1 Banana\ Exposure_{ijmy} + \sum_{z=1}^{3} \beta_z\, Z^{th}\ Intensive\ Fumigations_{ijmy} \\ & + \textstyle\sum_{z=1}^{3} \theta_z\, Banana\ Exposure_{ijmy} * Z^{th}\ Intensive\ Fumigations_{ijmy} + \delta X_i + \mu_j + \\ & \psi_m + \phi_y + \varepsilon_{ijpmy} \end{aligned} \tag{2}$$

[12] The construction of this variable closely follows the approaches of Linden and Rockoff (2008) and Gibson (2019). It is also related to the literature on air pollution, which considers that most of the effect of pollutants is concentrated in the pollution source area, and it decays at larger distances (Currie et al., 2009; Currie et al., 2015). Similarly, the environmental literature suggests that the effects of pesticides is concentrated in the area close to the plantations and quickly decay with the distance (Gemmill et al., 2013; Larsen et al. 2017; Gibbs et al., 2017; Dereumeaux et al., 2020).

where $Y_{ijmy}$ shows the birth outcomes of newborn $i$, in grid cell $j$, month $m$, and year $y$. $Banana\ Exposure_{ijmy}$ is a dummy variable that takes the value 1 for newborns from mothers geographically exposed to pesticides (newborns within 150 meters of the closest plantation and with the variable *Exposure Buffers* above the 6,000 value). The variable $Intense\ Fumigations_{ijmy}$ is a dummy variable that takes the value 1 for newborns that were affected by intensive fumigations for at least three months during gestation, and the variable $Z^{th}\ Intense\ Fumigations_{ijmy}$ is a dummy variable that takes the value 1 for newborns that were affected by intensive fumigations during the three months of the $Z^{th}$ gestation trimester.

The vector of controls $X_i$ includes child and mother characteristics such as single birth, sex, mother's age, maternal education, number of prenatal controls, marital status (divorced, separated, widowed, married, single, civil union), ethnic group (*mestizo*, *montubio*, white, afroecuadorians, indigenous, other), place of birth (public or private hospital), total number of children, total births, and type of birth (c-section or normal delivery). Table 2 presents the summary statistics regarding selected maternal and newborn characteristics for all newborns in our sample.

The models in equations (1) and (2) include 2.5 x 2.5 km grid-cell ($\mu_j$), month ($\psi_m$), and year ($\phi_y$) fixed effects to control for non-pollution spillovers that can be related to the agriculture activity and the weather. We assume the error term $\varepsilon_{ijmy}$ to be $iid$ and normally distributed, and we cluster the standard errors at the grid cell level.

The parameters of interest in our analysis are $\theta$ and $\theta_z$ (the DID parameters), which capture the change in the birth outcomes generated by intensive fumigations on newborns geographically exposed to this practice. Seasonal variations in the applications of agrochemicals have been exploited in other papers to examine the effect of fertilizers on water sources (Brainerd and Menon, 2014). In the medical literature, this estimation approach has been used to analyze the effects of pesticides on health outcomes for small scale samples (Bradman et al., 2011; Cecchi et al., 2012; Laborde, 2015).

Our analysis makes some important assumptions. First, the variable *Intensive Fumigations* considers that the composition of pesticides used in the fumigations is homogeneous across seasons and plantations. In practice, however, plantations use several types of agrochemicals and apply different dosages according to the severity of the diseases they face. Second, we consider that fumigations are applied under mild weather conditions. According to Ecuadorian regulations, aerial fumigations cannot be applied at high temperatures, in humid conditions, or when wind speed is high. This is an important issue because wind can transport pesticides away from the plantations. Online appendix B shows that the pesticide dosage and the number of fumigations applied on a plantation are negatively related to wind intensity. Also notice that mothers' residences are close to several plantations, which implies that on windy days pesticides can blow simultaneously closer to and further away from the residences.

Finally, a limitation of our analyses is that we cannot observe whether newborns' mothers were working in the plantations. However, it is likely that plantation workers live in a wide area outside the plantation perimeter, exceeding the 150-meter threshold of our *Banana Exposure* variable. Moreover, we expect that few women were working in activities directly exposed to the pesticides. According to Cooper (2015), while in the Caribbean countries 40 to 45% of agricultural workers in the plantations are women, in mainland Latin America the percentage drops to 12.5%. In Ecuador, women constitute 12.5% of the workers in the banana plantations, on many occasions with part-time contracts. This report also shows that in Ecuador women working in the plantations are unlikely to carry out physical or technical tasks, or to have managerial positions in the plantations; they usually work in the banana washing process, weighing the fruit, grouping it and, in some cases, packing it into boxes. In principle, pregnant and breastfeeding women are not assigned tasks with a direct exposure to chemical agents.

## 5. Results

Table 3 presents the estimates of the DID model in equations (1) and (2), analyzing the effects of the seasonal intensification of fumigations on newborns' birth weight. Column (1) shows that the variable *Banana Exposure* is negative and non-significant, which implies that mothers' proximity to the plantations alone does not have an effect on newborns' birth weight. However, column (2) shows that the DID parameter is negative and significant, which means that newborns living close to the plantations who during their gestation were exposed to intensive fumigations had a birth weight deficit of 80 grams relative to non-exposed newborns. Columns (3) to (5) repeat the analysis considering the separate effects of fumigations in each of the gestation trimesters. The results show that the birth weight was 47.4 grams lower for newborns exposed to fumigations in the first trimester of gestation and 63 grams lower for newborns exposed in the second trimester. Finally, Column (6) examines the joint effect of fumigations in the three gestation trimesters. We find a birth weight deficit of 74.2 grams for newborns exposed to intensive fumigations in the first trimester of gestation and one of 75.4 grams for those exposed in the second trimester. The interaction term for the third gestation trimester is negative and non-significant. Table A1 in the Online Appendix A repeats the analysis of Table 3 including weather controls to account for the potential correlation between rainfall and the use of pesticides at the grid cell level. The results are very similar to the ones explained above.

We complete our analysis by estimating the effects of fumigations on other health outcomes. The first four columns in Table 4 examine the effect of pesticides on the duration of the gestation period. Columns (1) and (3) show that when we consider the whole gestation period the exposure to intensive fumigations does not impact the number of gestation weeks and does not increase the likelihood of a pre-term delivery. However, when we separate the analysis by gestation periods, column (2) shows that intensive fumigations reduce gestation weeks by 1 to 2 days when the exposure occurs during the first and second gestation trimester. Moreover, column (4) shows that when the intensive fumigations coincide with the first and the second gestation periods, they increase the likelihood of pre-term delivery by 47% and 46.1%, respectively.

Columns (5) and (6) show the results of a logit model that considers whether newborns had LBW (i.e., a birth weight lower than 2.5 kilograms). Column (5) shows that the interaction of the variables *Banana Exposure* and *Intensive fumigations* is larger than one and is significant. Column (6) shows that the interactions for the first and the second gestation trimesters were also positive and significant, meaning that exposure to intensive fumigations in these periods increases the probability of LBW. In particular, the results show a 56.8% increase in the likelihood of LBW if exposed in the first trimester, and one of 79.9% if exposed in the second. Exposure to pesticides during the third trimester of gestation led to a positive but not significant increase in the odds of being LBW.

To further examine the effects of pesticides, Table A2 in the Online Appendix A repeats our analysis considering the sex of newborns. For girl newborns, we obtain a non-significant effect when the intensive fumigations occurred for at least three months during the whole gestation period and a negative effect of 78.8 grams when they occurred during the second gestation period. We also find that gestation during a period of intensive fumigations increased the odds of being born with LBW, and that this effect was stronger when intensive fumigations coincided with the first and the second gestation trimesters. For boy newborn, we find a birth weight deficit of 95.9 grams when the intensive fumigations occurred for at least three months during the whole gestation period, and a deficit of 87.7 and 75.6 grams when they occurred in the second and the third gestation trimesters respectively. Moreover, the odds of LBW increased when intensive fumigations coincided with the second trimester.

Overall, our results confirm the negative health effects of intensive fumigations in newborns living close to the plantations. Fumigations might reduce the birth weight by more than 80 grams, although the total effect depends on the trimesters during which newborns are exposed. Moreover, exposure to pesticides can reduce the length of gestation and increase the odds of being born pre-term and with LBW. We also found the impact of intensive fumigations on birth weight to be slightly higher on boy newborns, and on the odds of being LBW to be higher on girl newborns.

## 6. Robustness Checks

This section presents several robustness checks carried out to examine the validity of our previous results. First, we estimate the model in equations (1) and (2) considering a sample of mothers who had two or more children in the period examined, and we exploit the fact that during their pregnancies siblings were exposed to different levels of pesticides. Second, we study the possibility that mothers strategically adjusted the time of their pregnancies to avoid exposure to intensive fumigations. Third, we present an alternative analysis that uses data from the aerial fumigation registry showing whether newborns were directly exposed to fumigations. Finally, we consider several placebo and falsification tests to validate our identification strategy. Specifically, we test the robustness of our results to different periods and intensities in the exposure to pesticides. Moreover, we apply a placebo test that considers newborns who were geographically exposed to other crops (rice, cocoa, and corn) and seasonally exposed to banana fumigations, and a falsification test that adds lags and leads time distortions in the periods of intensive fumigations.

### 6.1 Maternal Fixed Effects

This robustness analysis uses mothers' identifiers in our birth record data to link siblings born to the same mother, and estimates a maternal fixed effects model. Following a similar approach by Currie et al. (2020), we estimate equation (1) considering a sample of mothers who had two or more children in the period examined and we exploit the fact that newborns were gestated in different periods and might have been exposed to different levels of pesticides. The vector of control variables $X_{ik}$ considered in the estimation includes birth order and birth interval dummies: first birth, less than 12 months from previous birth, 12-24 months from previous birth, and 24-36 months from previous birth. This vector also includes time variant characteristics of the mother. Moreover, we include the interaction of mother and grid cell fixed effects that account for intrinsic characteristics of newborns of the same mother, who may or may not have changed residence during the pregnancies examined. Finally, we cluster the standard errors at the mother level.

The coefficients of interest in equations (1) and (2) are $\theta$ and $\theta_z$, which captures the effect on the health outcomes of being exposed to intensive fumigation during the gestation period. These effects are estimated using a sample of 1,961 newborns from 970 mothers who had at least one pregnancy highly exposed to aerial fumigations, and one pregnancy not exposed to pesticides.[13]

Table 5 shows the results of the maternal fixed effects estimation. Columns (1) to (4) analyze the effects on birth weight, while Columns (5) to (8) analyze the effects on gestation weeks. Column (1) shows that geographical exposure to banana plantations had a non-significant effect on birth weight. Columns (2) and (3) show that the interaction of the *Banana Exposure* and *Intensive Fumigations* variables is negative and non-significant when we consider the whole gestation period, and negative and significant when the exposure to intensive fumigations occurred in the first trimester of gestation. Specifically, Column (3) suggests a birthweight deficit of 327 grams for those siblings geographically exposed to banana plantations and for whom the first trimester of gestation coincided with a period of intensive fumigations, relative to their non-exposed siblings.

Columns (5) to (8) repeat the analysis considering the number of gestation weeks as the outcome variable. Column (8) shows that the interaction term is negative and significant for the first and third trimester of gestation. Specifically, the gestation period is nearly 1.5 weeks shorter for siblings who were exposed to intense use of pesticides compared to those who were not exposed[14].

[13] Out of the 21,393 newborns considered in the analysis, 1,963 (9%) are from mothers who had at least two pregnancies, and 1,567 (7%) from mothers who had at least two pregnancies and who lived at the same address in the period examined.

[14] We have also re-estimated the model in equation (1) using the sample of mothers with multiple births (i.e., we use the same control variables and fixed effects as in equation 1). We find similar results to those in Table

Finally, columns (4) and (8) repeat the previous analysis but restrict the sample to mothers who maintained the same place of residence in all pregnancies. This implies a reduction in the sample size from 970 to 777 mothers. The results are qualitatively the same as in the case of the unrestricted sample.

### 6.2 Selection of gestation time

A potential endogeneity problem that could affect our analysis is the possibility that mothers strategically avoid pregnancies during periods of intensive fumigations so as to protect their children. Mothers can plan their pregnancies considering the periods in which fumigations are most likely and most intensive. In this section, we use two approaches to identify potential selection on gestation time. First, we examine whether there are characteristics of the mother that make gestation of a child less likely during periods of intensive fumigations. Table 6 considers the same empirical model as in equations (1) and (2), but using mothers' characteristics as outcome variables. Column (5) shows that mothers with a relatively higher education are less likely to live close to the plantations but are more likely to gestate their child in periods of intensive fumigations. It also shows that the interaction of the *Banana Exposure* and the *Intensive Fumigations* variables is not significant. These results suggest that educated mothers might strategically avoid living close to the plantations, but there is no evidence that they plan their pregnancies considering the periods of intensive fumigations.

We complement this analysis with Table A3 in the Online Appendix A, which shows the effect of pesticides separating the analysis for newborns from mothers with lower and higher school education. The analysis reveals that pesticides reduced birth weight and increased the probability of LBW for newborns of mothers with lower education. In the case of newborns of more educated mothers, fumigations had a negative but not significant effect on birth weight, and a positive and significant effect on the probability of LBW. All in all, the stratification of the sample considering the mother's level of education suggests that mothers with higher school education could have adopted protective practices in periods of intensive fumigation. This result indicates that policies informing the population about the adverse effects of pesticides could offer positive results.

Table 6 also shows that the interaction of the variables *Banana Exposure* and *Intensive Fumigations* is not significant for other outcome variables such as number of births, the number of previous children, the number of newborns born in the same labor, and the likelihood of giving birth in a private hospital. However, we do obtain that mothers that were pregnant in periods of intensive fumigations made less prenatal visits and were less likely to have a c-section during labor (significant at the 10% level).

Our second approach to assess whether mothers planned the gestation time is to examine whether they used their experience from previous pregnancies to avoid intensive fumigations. Using the sample of mothers that had multiple births, we examine whether the

3. Specifically, exposure to pesticides during the first trimester leads to a birthweight deficit of nearly 157.1 grams. Moreover, the gestation period fell by 3 to 6 days when exposure to intensive fumigations occurred during the first and third trimesters of gestation.

probability of having a pregnancy in a period of intensive fumigations was lower in mothers who had previously had a pregnancy under these conditions. Table A4 in the Online Appendix A shows that younger newborns of mothers geographically exposed to the banana plantation were no less likely to be exposed to intensive fumigations than newborns of mothers living further away from the plantations. We also show that younger newborns that had an older sibling exposed to the intensive fumigations were *more* likely to be gestated in periods of intensive fumigations. Moreover, focusing on newborns of mothers living close to the plantations we obtain that younger newborns that had an older sibling exposed to the intensive fumigations were no less likely to be gestated in periods of intensive fumigations that the rest of newborns. To sum up, our results suggest that mothers with newborns exposed to intensive fumigations during pregnancy did not plan their subsequent pregnancies to avoid intensive fumigations.

### 6.3 Buffers with data on pesticide applications

Our baseline model used fumigation profiles at the grid cell and month level to identify the newborns exposed to high pesticide applications. In this section, we use the information from the aerial fumigation registry for the years 2016 and 2017 to calculate buffers at the newborns' level that reflect whether newborns were directly exposed to fumigations during the gestation period.

The variable *Exposure* is a dummy variable that takes the value of 1 for newborns affected by fumigations. To construct this variable, we consider buffers of up to 150 meters' radius from the mother's place of residence and establish that exposed newborns were those with a buffer that received any dosage of pesticides during at least three gestation months (or during the three months of a gestation trimester). In principle, this variable should allow us to identify with precision the newborns affected by fumigations. Notice, however, that this measure might erroneously assign newborns exposed to pesticides to the non-exposed group. This can occur when airplanes fumigate several plantations and the aerial registry only geolocates the fumigation of one of them (i.e., small plantations can contract fumigation services collectively, but the register will geolocate only one). As a consequence, the registry may generate imprecise information about the gallons of pesticides sprayed in each plantation. This is our main justification for the use of fumigation profiles at the grid cell and monthly level in our baseline model. To test the robustness of our results, we next use the variable *Exposure*, which reflects whether during gestation newborns were affected by fumigations in the area surrounding their mother's place of residence. We estimate the following equation:

$$Y_{ijmy} = \beta_0 + \sum_{z=1}^{3} \beta_z \, Z^{th} \, Exposure_{im} + \delta X_i + \mu_j + \psi_m + \phi_y + \varepsilon_{ijpmy} \qquad (3)$$

where $Y_{ijmy}$ shows the birth outcomes of newborn $i$, in grid cell $j$, month $m$, and year $y$. The variable $Z^{th}\ Exposure_{ijm}$ is a dummy variable that takes the value 1 for newborns affected by fumigations in the $Z^{th}$ gestation trimester. Our parameter of interest is $\beta_Z$, which captures the effect in the birth outcome generated by the exposure to the pesticides during the $Z^{th}$ gestation trimester. The vector of controls $X_i$ includes the same newborns' and mothers' characteristics considered in equation (1). Moreover, the models include 2.5 x 2.5 km grid-cell $(\mu_j)$, month $(\psi_m)$, and year fixed effects $(\phi_y)$ to control for non-pollution spillovers that may be related to agricultural activity and the weather.

Table A5 in the Online Appendix A presents the results of our analysis. We find that newborns who during the second and the third gestation trimesters were directly exposed to pesticides had birth weight deficits of 30.3 and 17.7 grams respectively. We then repeat this analysis including in the control group those newborns within a 150-meter buffer that contains banana plantations, but who according to the aerial fumigation registry were not exposed to any fumigation in the period examined. This analysis shows that direct exposure to pesticides for at least three months during gestation has a negative effect on birth weight, and that exposure to pesticides during the second gestation trimester generated a birth weight deficit of 28.2 grams. As discussed above, these results should be interpreted with caution. First, according to the banana plantations census a large number of the newborns that we are allocating to the control group were very close to aerially fumigated plantations and were possibly exposed to pesticides. And second, in order to compare these results with those in Table 3 it is important to remember that now we are analyzing the effects of any amount of pesticides on birth weight, and not the effects of intensive fumigations.

### 6.4 Variations in the exposure thresholds

Our DID analysis relies on the definition of the variables *Intensive Fumigation* and *Banana Exposure* which determines the extent to which newborns were exposed to high dosages of pesticides during gestation. We next examine the robustness of our results by considering changes in the thresholds that characterize these variables. Table A6 in the Online Appendix A repeats the estimation of equation (1) considering instead that the group of treated newborns are the ones who during gestation were exposed to intensive fumigations for at least two months, rather than for three months as in Table 3. Our results show that a lower exposure to the pesticides is still associated with a birth weight deficit. Specifically, we find a birth weight deficit of nearly 30 grams for newborns exposed to intensive fumigations for at least two months during the whole pregnancy (the coefficient is not significant) and a birth weight deficit of 44 grams for newborns exposed in the second trimester of gestation. Fumigations also increase the likelihood of being born with LBW, but the coefficients are not significant.

We also repeated the analysis in equation (1) considering instead that the grid cells exposed to intensive fumigations are the ones with more than 3 or 5 gallons of pesticides per hectare per month, rather than the 4 gallons per hectare per month considered in Table 3. Our analysis in Table A7 reveals that with a threshold of 3 gallons per hectare exposure to intensive fumigations does not generate a significant effect on newborns' birth weight. With the 5 gallons threshold, we find a negative and significant effect of 104.3 grams when newborns are exposed to fumigations for at least three months during the gestation period, and an effect of 46.1 grams when the exposure occurred in the second gestation trimester. These results highlight the importance of the definition of the variable *Intensive Fumigations* for our conclusions.

Our results are also determined by the definition of the *Banana Exposure* variable, which considers that newborns potentially exposed to the pesticides are the ones gestated within 150 meters of the closest plantation and for which the variable *Exposure Buffer* takes a relatively high value. Notice, however, that exposure to pesticides might still exist outside the 150-meter perimeter, a circumstance that might attenuate our estimates. Table A8 in the Online Appendix repeats our analysis excluding all the newborns living between 150 and 250 meters from the nearest plantations, due to potential persistence of the effect of the pesticides. The results are qualitatively similar to the ones in Tables 3 and 4.

### 6.5 Placebo test with other crops

The next verification test examines whether the health effects that we observe in periods of intensive fumigations of banana plantations is restricted to newborns living near these plantations, or whether they also appear in newborns living near other crop plantations (cocoa, rice, corn) that make a much more limited use of pesticides.[15] Table A10 in the Online Appendix A shows the results of a placebo test in which we estimate equation (1) substituting the variable *Banana Exposure* with the variable *Exposure to Other Crops*, which is a dummy variable that takes the value of 1 for newborns geographically exposed to other crop plantations. We interact this variable with the variable *Intensive Fumigations* to examine whether being gestated in periods of intensive fumigations of banana plantations affects newborns geographically exposed to other crops. The sample considered in this specification excludes those newborns located within 150 meters of a banana plantation and includes those grids that exhibit a variation above and below the 4 gallons of pesticides per hectare threshold. As expected, we did not find a negative and significant effect of exposure to other crop plantations on birthweight or LBW in any of the estimations.

### 6.6 Falsification tests

Two additional falsification tests were performed to validate our analysis. The first consists of adding time lag distortions to the monthly pesticide profiles at the grid cell level. Specifically, we consider that the applications of pesticides took place two months before the real fumigations. The second falsification test consists of adding lead time distortions to the current pesticides use profiles. Specifically, we add two-month lead distortions to the monthly profiles of pesticides in Table 3, meaning that we assume that the fumigations took place two months later than the real ones. The results of these analyses are shown in Table

[15] Figure A2 in the Online Appendix A shows that use of pesticides in the production of the other crops (rice, cocoa and corn). Table A9 shows the mean maternal and newborn characteristics for newborns exposed to banana plantations and to other crops.

A11 in the Online Appendix A. We do not find any evidence implying that pesticides caused a decrease in birthweight or an increase in the odds of LBW.

## 7. Conclusion

Aerial pesticide fumigation plays a key role in the agriculture industry, but its massive and uncontrolled use is causing major health problems in nearby populations. Our paper contributes to the existing economic, medical, and environmental literature by examining the causal relationship between newborns' in-utero exposure to pesticides and adverse health outcomes. To this end, we study the effects of the aerial fumigation of banana plantations in Ecuador.

Using precise mothers' addresses and the perimeter of the banana plantations, we show that newborns potentially affected by fumigations are those living within 150 meters of the plantations' perimeter and close to relatively large areas of fumigated land. We apply this result to define the group of geographically exposed and non-exposed newborns that are used in our causal analysis.

An important concern in the identification of the effects of fumigations on newborns' health is the fact that households living close to the plantations might have different characteristics to those living at a larger distance from them. We have overcome this potential endogeneity problem by implementing a difference-in-differences (DID) analysis that exploits the seasonal changes in the intensity of fumigations. We have used monthly information on the gallons of pesticides applied in each banana plantation to construct a *seasonal exposure* dummy variable at the cell grid level. Our DID estimation compares the difference in health outcomes for newborns geographically exposed to banana plantations who were and were not gestated in periods of intensive fumigations, relative to the difference for newborns living in geographically non-exposed areas gestated in the same two periods. Our analysis has shown that newborns exposed to intensive fumigations have a birth weight deficit of between 80 and 150 grams, with an impact that depends on the number of months of exposure to pesticides during gestation. Moreover, we found that exposure to intensive fumigations increases the odds of LBW and of being preterm by over 46%.

We complemented our analysis with several robustness checks. First, we estimated a maternal fixed effects model for a sub-sample of newborns of mothers who had two or more children in the period examined. This analysis allows a comparison of different pregnancies of the same mother, when one newborn was exposed in utero to intensive fumigations and the other was not. The results show that newborns exposed to pesticides in the first gestation trimester have a birth weight deficit of nearly 327 grams compared to their non-exposed sibling. One explanation for this large effect is that high exposure to pesticides in pregnancy shortens the gestation period by an average of 1.5 weeks. We also examined the possibility that mothers strategically adjust the time of their pregnancies to avoid heavy exposure to pesticides. Our analysis has shown that mothers did not plan their pregnancies to avoid fumigations. However, the stratification of the sample suggests that educated mothers could have adopted some measures to protect themselves and their children from pesticides.

Finally, we conducted several placebo and falsification tests to validate our identification strategy; specifically, we tested the robustness of our results to different periods and intensities in the exposure to pesticides. Moreover, we used a placebo test that considers newborns' geographical exposure to other crops (rice, cocoa, and corn) and seasonally exposed to banana fumigations, and a falsification test that added time lags and leads distortions in the periods of intensive fumigations.

Our results are in accordance with the findings reported in medical and environmental papers that examine the effects of pesticides in agriculture on health at birth (Gemmill et al., 2013; Larsen et al. 2017). Our effects are much larger than the 30 grams found by Bozzoli and Quintana-Domeque (2014), in their analysis of the effects of the economic crisis in Argentina, or the 23 grams found by Range and Vogl (2019), who examined the effects of the fire pollution caused by sugar cane harvesting in Brazil. However, our findings are close to the 200-gram effect found for mothers that smoke (Kramer, 1987; Lindbohm et al., 2002) and to the 107-175-gram impact obtained by Burlando (2014) examining the consequences of an unexpected blackout in Tanzania. We also confirm previous reports in studies on air pollution of a larger effect of pollution when it coincides with the first and the second trimesters of gestation (Almond et al., 2011; Bozzoli and Quintana-Domeque, 2014; Burlando, 2014).

We believe that this research can help to improve the design of public policies regulating fumigation practices in different kinds of plantations across the world and that it can be used to enhance pregnancy protocols in affected regions. Our conclusions reinforce the calls for a modification of the use of agrochemicals in agriculture and for increased protection for neighboring populations and the plantation workers. We have shown that aerial fumigations in Ecuador have a major impact on the health of newborns of mothers residing close to the banana plantations. These results highlight the urgency of enforcing and reviewing the protection distances established in Ecuador in 2012 and 2015 in order to safeguard the health of the population.

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**Table 1: Effects of pesticides on newborns' health – A comparative review**

| Authors | Country, Sample, Years | Environmental pollutant | Identification strategy | Results |
|---|---|---|---|---|
| Calzada, Gisbert, Moscoso, 2023 | Ecuador, Individual level data, N=21,393 2015-2017 | Pesticides in banana production | Difference-in-differences based on seasonal aerial fumigations of banana plantations | 80 to 150 grams birth weight deficit; Odds of LBW increases by 57%; Odds of preterm increases by 46%; Gestation length decreases by 2 to 3 days |
| Camacho and Mejia, 2017 | Colombia, Individual level data N= 39,925,671 2003-2007 | Aerial spraying of herbicides on coca crops to reduce supply of cocaine | Quasi-experiment; individual fixed-effects regressions | Increased number of medical consultations (dermatological and respiratory illnesses), and of miscarriages. |
| Dias et al. 2020 | Brazil, Local level data, N=12,309 2000-2010 | Use of glyphosate in soybean production. Exposure through water sources | Instrument-based 2SLS estimation. Pesticides instrumented with the potential yield gains from use of genetically modified soybean seeds | Increase in the infant mortality rate of 0.93 per 1,000 births, in the likelihood of pre-term births, and in low birth weights. |
| Frank, 2021 | US, Country level data, N=35,000+ 1997-2017 | Pesticides in agriculture | Quasi-experimental shock to biological pest control. Mortality shocks to bats caused by an invasive fungus that led to the use insecticides | The increase in the use of insecticides increased human infant mortality by 5% |
| Gemmill et al. 2013 | California, US, Individual level data, N=442 1999-2000 | Use of methyl bromide in agriculture | Adjusted linear regressions. Estimated use of methyl bromide near each woman's residence | High methyl bromide used within 5 km of the home during the second trimester associated with a 113.1 grams of birth weight deficit |
| Jones. 2020 | US, County level data, N= 20,000+ 2005-2015 | Pesticides in fruit production | Instrument-based 2SLS estimation. Detection of spotted wing drosophila used as an instrument for pesticide use | A 10% increase in insecticide and fungicide associated with 0.18% and 0.15% increase in cases of infant prematurity and 0.08% and 0.08% increase in cases of LBW, respectively |
| Larsen et al. 2017 | California, US, Individual level data, N=500,000+ 1997–2011 | Pesticides in agriculture | Fixed-effects estimation. Regional and temporal fixed-effects. Pesticide use in small geographical areas | 13 to 30 grams birthweight deficit. Top 1% exposed had a 11% increased probability of preterm birth, 20% increased probability of LBW, and 30 grams decrease in birth weight |
| Maertens. 2019 | Corn Belt, US Individual level data, N=500,00+ 2001-05 and 2006-11 | Use of atrazine pesticides in corn production | OLS and instrument-based 2SLS estimation. Sources of variation: regulations; heterogeneous corn production; timing of sprayings. | Increased risk of: (1) abdominal wall defect by 216 %; (2) being born small-for-gestational age by 5 %, if exposed in 3rd gestational period, and (3) perinatal death by 71 % if exposed last 2 trimesters. |
| Taylor. 2021 | Cicada states, US County level data N=140,000+ 1950-2016 | Use of insecticide in cicada emergences | Triple-difference: temporal, spatial, land use. Cicadas emerge in 13 -17-year cycles. They only damage tree crops and not agricultural row crops. | 5% increase in infant mortality. Small but positive impact on the probability of adverse birth outcomes |

**Table 2 – Descriptive Statistics: Means (standard deviations) of selected variables**

| Variable | All newborns | Not geographically exposed to banana plantations | Geographically exposed to banana plantations | Not seasonally exposed to intensive use of pesticides | Seasonally exposed to intensive use of pesticides |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Birth weight | 3,127.8 | 3,119.1 | 3,151.8 | 3,113.8 | 3,143.2 |
| | (3.53) | (4.11) | (6.88) | (4.94) | (5.04) |
| Gestation weeks | 38.44 | 38.42 | 38.52 | 38.41 | 38.48 |
| | (0.01) | (0.01) | (0.02) | (0.02) | (0.02) |
| Low birth weight | 0.08 | 0.08 | 0.08 | 0.09 | 0.08 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| Preterm | 0.06 | 0.06 | 0.06 | 0.07 | 0.06 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| Mother's age | 24.53 | 24.59 | 24.36 | 24.57 | 24.48 |
| | (0.04) | (0.05) | (0.09) | (0.06) | (0.07) |
| Male newborn | 0.51 | 0.51 | 0.52 | 0.52 | 0.51 |
| | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) |
| Mother's education | 0.43 | 0.41 | 0.49 | 0.42 | 0.44 |
| Less than HS | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) |
| Mestizo ethnicity | 0.96 | 0.96 | 0.97 | 0.96 | 0.96 |
| | 0.01 | (0.00) | (0.00) | (0.00) | (0.00) |
| Normal birth | 0.53 | 0.52 | 0.57 | 0.53 | 0.53 |
| | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) |
| Non marital union | 0.40 | 0.4 | 0.39 | 0.4 | 0.39 |
| | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) |
| Single | 0.42 | 0.42 | 0.44 | 0.42 | 0.43 |
| | (0.00) | (0.00) | (0.01) | (0.00) | (0.00) |
| Married | 0.14 | 0.14 | 0.13 | 0.13 | 0.14 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| Public hospital | 0.83 | 0.81 | 0.89 | 0.85 | 0.82 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| Number of births | 2.28 | 2.27 | 2.34 | 2.29 | 2.28 |
| | (0.01) | (0.01) | (0.02) | (0.01) | (0.01) |
| Number of children | 2.32 | 2.3 | 2.38 | 2.33 | 2.32 |
| | (0.01) | (0.01) | (0.02) | (0.01) | (0.01) |
| Prenatal control | 6.03 | 6.05 | 5.98 | 6.03 | 6.02 |
| | (0.02) | (0.02) | (0.03) | (0.02) | (0.02) |
| Single birth | 0.99 | 0.99 | 0.98 | 0.98 | 0.99 |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| Observations | 21,393 | 15,686 | 5,707 | 11,182 | 10,211 |

**Table 3 - Effects of the seasonal intensification of fumigations on birthweight**

| | Birth weight | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Banana Exposure | -48.58 | 0.998 | -37.59 | -33.93 | -49.38 | -5.965 |
| | (39.57) | (50.21) | (47.72) | (43.96) | (51.55) | (47.67) |
| Intensive Fumigation | | 29.64*** | | | | |
| | | (10.09) | | | | |
| Banana Exposure x Intensive Fumigation | | -80.02*** | | | | |
| | | (30.81) | | | | |
| Intensive Fumigation during 1st Trimester | | | 17.58 | | | 24.19* |
| | | | (14.23) | | | (14.03) |
| Intensive Fumigation during 2nd Trimester | | | | 14.34 | | 20.09 |
| | | | | (15.04) | | (15.65) |
| Intensive Fumigation during 3rd Trimester | | | | | 8.135 | 18.26 |
| | | | | | (17.88) | (16.27) |
| Banana Exposure x Intensive Fumigation during 1st Trimester | | | -47.44** | | | -74.29** |
| | | | (20.58) | | | (32.61) |
| Banana Exposure x Intensive Fumigation during 2nd Trimester | | | | -63.09*** | | -75.40*** |
| | | | | (20.40) | | (24.44) |
| Banana Exposure x Intensive Fumigation during 3rd Trimester | | | | | 4.933 | -43.17 |
| | | | | | (23.54) | (37.84) |
| Mother's controls | X | X | X | X | X | X |
| Month x Year F.E. | X | X | X | X | X | X |
| Grid F.E. | X | X | X | X | X | X |
| Observations | 21,393 | 21,393 | 21,393 | 21,393 | 21,393 | 21,393 |
| R2 | 0.1096 | 0.1102 | 0.1098 | 0.1100 | 0.1096 | 0.1104 |
| Number of Clusters | 151 | 151 | 151 | 151 | 151 | 151 |

Notes: Estimation of equation (1) when the outcome variable is birth weight. All regressions are estimated using bootstrapped standard errors with 1000 repetitions. Results of interest is the DID coefficient, which reflects the effect that the intensification of fumigations had on the health of newborns geographically exposed to banana plantations (interaction of *Banana Exposure* and *Intensive Fumigations* during pregnancy). The sample is limited to births by mothers living up to 2.5 kilometers from the banana plantations, and to grid cells that exhibit a seasonal variability in the application of pesticides. The vector of control characteristics is explained in section 4. Standard errors are clustered at the grid cell level and are shown in parentheses. The number of clusters is detailed at the bottom of each column, excluding single observations. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

**Table 4 - Effects of the seasonal intensification of fumigations on gestation weeks, preterm and low birth weight**

| | OLS fixed effects | | Logit fixed effects | | | |
|---|---|---|---|---|---|---|
| | Gestation weeks | | Preterm birth | | Low birth weight | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Banana Exposure | 0.0482 | 0.106 | 1.250 | 1.252 | 1.304 | 1.249 |
| | (0.153) | (0.154) | (0.360) | (0.281) | (0.287) | (0.248) |
| Intensive Fumigation | 0.0125 | | 0.829** | | 0.791*** | |
| | (0.0385) | | (0.0710) | | (0.0648) | |
| Banana Exposure x Intensive Fumigation | -0.0183 | | 1.426 | | 1.429** | |
| | (0.105) | | (0.400) | | (0.259) | |
| Intensive Fumigation during 1st Trimester | | 0.0631* | | 0.747** | | 0.714*** |
| | | (0.0366) | | (0.106) | | (0.0902) |
| Intensive Fumigation during 2nd Trimester | | -0.0417 | | 1.029 | | 0.849* |
| | | (0.0580) | | (0.155) | | (0.0822) |
| Intensive fumigation during 3rd Trimester | | -0.00557 | | 0.989 | | 0.869* |
| | | (0.0375) | | (0.103) | | (0.0668) |
| Banana Exposure x Intensive Fumigation during 1st Trimester | | -0.142** | | 1.470** | | 1.568*** |
| | | (0.0677) | | (0.269) | | (0.221) |
| Banana Exposure x Intensive Fumigation during 2nd Trimester | | -0.121* | | 1.461* | | 1.799*** |
| | | (0.0728) | | (0.293) | | (0.246) |
| Banana Exposure x Intensive Fumigation during 3rd Trimester | | -0.0594 | | 1.319 | | 1.204 |
| | | (0.0686) | | (0.229) | | (0.176) |
| Mother's controls | X | X | X | X | X | X |
| Month x Year F.E. | X | X | X | X | X | X |
| Grid F.E. | X | X | X | X | X | X |
| Observations | 21,393 | 21,393 | 20,871 | 20,871 | 21,086 | 21,086 |
| R2 | 0.0842 | 0.0850 | - | - | - | - |
| Pseudo-R2 | - | - | 0.1161 | 0.1170 | 0.1170 | 0.1180 |
| Number of Clusters | 151 | 151 | 91 | 91 | 99 | 99 |

Notes: Estimation of equation (1) when the outcome variable is gestation weeks, preterm birth and low-birthweight (LBW). Columns (1) and (2) are estimated using bootstrapped standard errors with 1000 repetitions. The results of these columns are very similar when we use as a sample the newborns considered in regressions (3) to (6). Standard errors are clustered at the grid cell level and are shown in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

**Table 5 - Effects of the seasonal intensification of fumigations on birth weight and gestation weeks – Maternal fixed effects**

| | Birth weight | | | | Gestation weeks | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Banana Exposure | 38.04 | 77.94 | 109.5 | | -0.711 | -0.643 | -0.346 | |
| | (154.9) | (176.5) | (186.2) | | (0.679) | (0.727) | (0.815) | |
| Intensive Fumigation | | 13.04 | | | | 0.535** | | |
| | | (66.84) | | | | (0.252) | | |
| Banana Exposure x Intensive Fumigation | | -122.4 | | | | -0.268 | | |
| | | (129.1) | | | | (0.438) | | |
| Intensive Fumigation during 1st Trimester | | | 121.2 | 90.25 | | | 0.574 | 0.396 |
| | | | (97.20) | (101.2) | | | (0.365) | (0.323) |
| Intensive Fumigation during 2nd Trimester | | | -94.10 | -130.5 | | | 0.146 | 0.322 |
| | | | (111.2) | (100.6) | | | (0.429) | (0.545) |
| Intensive Fumigation during 3rd Trimester | | | 64.10 | 74.84 | | | 0.702* | 0.674* |
| | | | (103.7) | (121.5) | | | (0.399) | (0.398) |
| Banana Exposure x Intensive Fumigation during 1st Trimester | | | -327.0* | -319.0*** | | | -1.539* | -1.614*** |
| | | | (175.2) | (108.2) | | | (0.795) | (0.406) |
| Banana Exposure x Intensive Fumigation during 2nd Trimester | | | 92.60 | 163.8 | | | -0.156 | -0.439 |
| | | | (135.0) | (141.4) | | | (0.540) | (0.492) |
| Banana Exposure x Intensive Fumigation during 3rd Trimester | | | -246.2 | -239.3 | | | -1.407** | -1.508*** |
| | | | (179.4) | (147.6) | | | (0.647) | (0.511) |
| Mother's controls | X | X | X | X | X | X | X | X |
| Month x Year F.E. | X | X | X | X | X | X | X | X |
| Maternal to Grid F.E. | X | X | X | X | X | X | X | X |
| Observations | 1,961 | 1,961 | 1,961 | 1,567 | 1,961 | 1,961 | 1,961 | 1,567 |
| R2 | 0.861 | 0.861 | 0.862 | 0.873 | 0.848 | 0.849 | 0.850 | 0.879 |
| Number of mothers | 970 | 970 | 970 | 777 | 970 | 970 | 970 | 777 |

Notes: Estimation of equation (1) when the outcome variable is birth weight and gestation weeks. All columns are estimated using bootstrapped standard errors with 1000 repetitions, while columns (5) and (10) are estimated using two-way clustered standard errors at the mother and grid cell level (shown in parentheses). The vector of control characteristics is explained in section 4, except that it only includes time variant characteristics of the mother. Each regression controls for birth order condition and birth intervals. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

**Table 6. Effects of the seasonal intensification of fumigations on maternal characteristics: main estimation approach**

| | OLS fixed effects | | | | Logit fixed effects | | |
|---|---|---|---|---|---|---|---|
| | Number of labors | Number of children | Pregnancy output | Prenatal controls | Education | Private hospital | Type of birth |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Banana Exposure | -0.0321 | 0.0351 | -0.0189** | 0.256 | 0.806** | 0.810 | 0.827 |
| | (0.0237) | (0.0243) | (0.00916) | (0.234) | (0.0704) | (0.203) | (0.132) |
| Intensive Fumigation | -0.00665 | 0.00570 | -0.00537 | 0.0126 | 1.094** | 0.857*** | 1.034 |
| | (0.00764) | (0.00876) | (0.00362) | (0.0666) | (0.0481) | (0.0493) | (0.0369) |
| Banana Exposure x Intensive Fumigation | -0.00302 | 0.00259 | 0.000543 | -0.222* | 0.916 | 1.195 | 0.871* |
| | (0.0122) | (0.0129) | (0.0109) | (0.117) | (0.0847) | (0.327) | (0.0659) |
| Mother's controls | X | X | X | X | X | X | X |
| Month x Year F.E. | X | X | X | X | X | X | X |
| Grid F.E. | X | X | X | X | X | X | X |
| Observations | 21,393 | 21,393 | 21,393 | 21,393 | 21,347 | 15,986 | 21,340 |
| R2 | 0.975 | 0.975 | 0.201 | 0.155 | - | - | - |
| Pseudo R2 | - | - | - | - | 0.109 | 0.375 | 0.152 |
| Number of Clusters | 151 | 151 | 151 | 151 | 134 | 110 | 130 |

Notes: Estimation of equation (1) using as outcome variable several maternal characteristics. The vector of control characteristics is explained in section 4. All columns are estimated using bootstrapped standard errors with 1000 repetitions. Standard errors clustered at the grid cell level and are shown in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.