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Country Department Andean Group

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Local Socieconomic Impacts of Large-scale Mining Projects in Ecuador: The Case of Fruta del Norte*

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Abstract

This study seeks to determine whether the Fruta del Norte project affected the main economic and social indicators of the Yantzaza canton, where the large-scale mining project is located. To do so, the analysis centers on key economic variables (such as business productivity and employment) and development variables (such as health and school enrollment). The specific methodology used is a synthetic control model, which enables the generation of a counterfactual for the treated canton. The findings suggest that Fruta del Norte had a positive impact on local economic activity in Yantzaza. The local economic dynamism spurred by Fruta del Norte had positive effects on local formal employment; however, increases in the rates of school dropout and adolescent pregnancy were observed.

Keywords: large-scale mining, causality, synthetic control model, Ecuador

JEL Codes: E62, C32, F20, H63.

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1 Introduction

Several developing countries have achieved economic growth by relying on mining and other extractive activities, capitalizing on the higher prices that natural resources have commanded in recent decades (Alarcón, 2022). At the same time, the increase in mining activities in developing countries has often been accompanied by negative environmental externalities with adverse impacts on society (CIE, 2021). While predatory mining practices can be detrimental to the environment, sustainable mining practices can yield various benefits to societies with minimum environmental harm. Besides providing fiscal income that can be redistributed throughout society, modern mining practices can foster dynamism in the local economies where they take place: the firms involved are major employers and purchasers of goods and of construction, financial, and technical and scientific services (Haddaway et al., 2019).

Because Ecuador is endowed with plenty of unexploited resources and clear comparative advantages in attracting private investment in the mining sector, sustainable mining could play a leading role in that country's development model. Expansion of the mining industry could provide the financial resources needed for Ecuador's achievement of the 2030 Sustainable Development Goals, making Ecuador a leader in the global response to the threat of climate change as addressed by the Paris Agreement.

The initiation of large-scale formal mining in Ecuador began with the signing of the contract for developing the "Mirador" project in 2012. Four years later, the exploitation contract for the "Fruta del Norte" project was signed. According to the country's mining authority, the first project has deposits of 31.43 million ounces of silver, 3.99 million ounces of gold, and 8.595 million pounds of copper, and the second has deposits of 7.94 and 4.09 million ounces of silver and gold, respectively (Ministry of Energy and Non-Renewable Natural Resources, 2020).

That formal mining generates positive local socioeconomic impacts have been previously documented. The empirical evidence suggests that it favors job creation, regional growth, health, and well-being of the local communities where it takes place (Hresc et al., 2018). However, knowledge about the local impacts of specific large-scale mining projects (such as Fruta del Norte) is far from extensive, and there is a need for better documentation. The nature of the investments in large mining projects is distinctive to the country, the type of resources being exploited, the geographies where mining occurs, and the socioeconomic and cultural contexts of the adjacent communities. The impacts might also be contingent on the extractive practices adopted by the companies. Because many factors mediate how large-scale mining affects local economic development, we can expect considerable heterogeneity regarding how mining investments impact the local economies and communities in which firms operate. Consequently, conducting a rigorous evaluation of the local impacts of specific large-scale mining projects on socioeconomic outcomes can support, or call into question, the idea that the benefits outweigh the drawbacks.

In this paper, we're going to do the abovementioned task of generating empirical evidence about the local economic and social impacts produced by the Fruta del Norte mining project in Ecuador. Our study seeks to determine whether the project affected some key economic indicators (firm productivity and employment) and other socioeconomic outcomes (health and school enrollment). Our research can serve as a point of reference for a deeper understanding of how large-scale mining does or does not contribute to local socioeconomic development and what role the state can play in shaping those impacts. Additionally, as one of the first studies on the impact of large-scale mining projects in Ecuador, we hope this product will serve as a methodological guide to conducting this type of study, which is intended to inform policy-making regarding mining investments in Ecuador.

The remainder of the paper proceeds as follows: Section 1 presents an overview of the literature on the economic impact of mining activity. Section 2 contextualizes the importance of the mining sector and the potential contribution of Fruta del Norte. Section 3 introduces the empirical specifications and the data used in this paper, the results are presented and discussed in Section 4, and Section 5 offers concluding remarks.

2 Literature Review

The impact of the mining sector is a widely researched topic because the sector provides most of the inputs used for the construction of infrastructure and economic products used daily (Carvalho, 2017). In addition, it has been considered a fundamental axis for growth and development within some territories (Mohsin et al., 2021). For this reason, several researchers have been motivated to understand the repercussions of the growth of this sector, mainly in territories where mining activity is of high economic importance. These authors have taken a multidimensional approach: their analyses focus on economic growth factors such as production or employment, social and population development factors such as education and quality of life, and environmental factors such as the degradation of ecosystems, erosion, and the instability of river banks (Aroca, 2001; Farahani and Bayazidi, 2018; Hackney et al., 2020; Joyce and MacFarlane, 2001).

Several studies have found that the mining industry contributes positively to the economy of the regions in which it operates because it both generates higher incomes and improves employability for local populations. These effects are maximized due to the industry's chain with other productive sectors. For example, Aroca (2001) analyzes the impacts of the mining sector in the II region of Chile, a country for which mining is one of the most important economic sectors. Furthermore, in the time period under consideration, the sector had seen substantial growth as a result of foreign direct investment. This author seeks to calculate the impact of this growth on production, income, and employment. To do so, the author builds an input-output matrix that contains a final demand sector, twelve productive sectors, and the payments to the factors of production, that is, the salary as the payment of the labor factor and the profit as the payment of capital. In constructing the matrix, the author uses a hybrid methodology that uses both primary and secondary data and estimates different multipliers and linkages.

One of the highlights of Aroca (2001) is that, in an attempt to overcome the main criticism of input-output matrices, which is that they overestimate economic impacts, the author estimates two types of multipliers to measure the impacts of a change in the final demand. The first multiplier assumes an open economy system, where the wage surplus caused by the growth of the mining sector is spent outside the region, while the second multiplier assumes a closed economic system, which means that the surplus is spent entirely within the region. The results show that for every US dollar generated in the mining sector, 9 percent goes to workers in that sector, while between 7 and 15 percent goes to workers in other productive sectors in the region. The author also finds that for one additional worker hired in the private mining sector, approximately three to six additional workers will be hired elsewhere in the region. Finally, the impact on production is seen through the linkages: specifically, the author observes that the mining sector has strong links, forward and backward, with the three most influential sectors in the region, which are fishing, public energy services, and business services.

The findings of Aroca (2001) align with those of other studies, such as Mohsin et al. (2021), which report positive economic effects in Pakistan associated with the coal mining industry that is mainly explained by the generation of new employment opportunities in the sector. However, other research shows that the economic benefits are often only reflected in the macroeconomic aggregates of the countries, not necessarily in the daily lives of people close to mining activities. Such is the case with Farahani and Bayazidi (2018), who evaluate the effects of sand extraction near the Tatao River in Iran on local communities, with the aim of understanding to what extent these communities were affected either positively or negatively or both. The authors use a factor analysis approach (confirmatory and exploratory) and a cost-benefit analysis to identify the impacts. They find that of those residing in these communities, only 14.7 percent had jobs related to mining extraction and that, in general, the economic impacts needed to be improved. Most of the income from this economic activity went to the owners of the lands that were rich in sand and gravel and to those who had the direct capacity to collect and transport the sand to the place of demand. Consequently, the economic inequalities of the sector were accentuated.

Broadening the scope of analysis, some studies investigate the social effects and economic consequences of mining, finding positive results in terms of quality of life, but also negative effects on the safety and health of individuals. In the study above by Farahani and Bayazidi (2018), the authors observe an improvement in social and material well-being in local communities primarily related to housing, due to the improvement in the quality and durability of building materials production (an externality of sand extraction in the area). However, there was also a deterioration in the quality of transport routes, as well as an increase in the rate of vehicular accidents, due to the transfer of sand and gravel.

In the same vein, Mohsin et al. (2021) analyzes coal mining in the Thar desert in Pakistan, to determine the effects of mining activity on the needs and interests of people beyond the economic sphere. The authors find that the mining activity had negative repercussions on people's health and safety, as they observe an increase in mining-related diseases such as cardiovascular and cerebrovascular problems in a fatal spiral. On the other hand, Ahlerup et al. (2020) relates gold mining to the educational levels of people living near mines across Africa. The authors provide evidence at the microeconomic level that when a gold mine was located in the district where an adolescent lived, the adolescent's educational level was significantly lower in the long term, compared to an adol did not live near a gold mine. In addition, the authors find that in districts where a mine was present, there was a higher probability of the occurrence of violent conflicts.

Also concerned with the noneconomic effects of mining, Balza et al. (2021) explores the impact of oil extraction in Colombia on education levels across the country through the use of temporal and spatial data. Specifically, the authors identify the number of wells drilled as the treatment to demonstrate the accumulation of human capital at the local level. To do so, they use an instrumental variables approach in which they exploit the exogeneity of international oil prices, in addition to incorporating a proxy variable of the supply of oil in the country. Similar to the previous study, negative effects are found on education: the authors observe that the exploitation of oil has a negative impact on the rate of enrollment in higher education, and young people who do decide to continue studying after high school have a higher tendency to choose technical and non-academic careers.

The varying nature of the local and national economic and noneconomic effects of mining activity means those effects must be weighed against contemporary society's dependence on the products of that activity. In light of such considerations, Carvalho (2017) compiles the impacts that various mining sectors have and identifies the future challenges each faces. Among the sectors analyzed by the author, the mining of metals (copper, nickel, iron, and arsenic, notably) involves high environmental costs and large investments in infrastructure.

An example is metal mining in Peru, which has caused serious environmental losses in addition to being characterized by a poor safety record. This activity has been found to negatively affect the quality of life in adjacent communities and compromise the agricultural soils and the water resources of the territory (Ponce and McClintock, 2014; Triscritti, 2013). Another example that Carvalho (2017) mentions is the extraction of gas and oil, on the one hand, one of the most remunerated sectors, and on the other, the cause of oil spills and soil contamination. These environmental consequences have been felt around the world, both on land (e.g., in the Ecuadorian Amazon and the Niger River delta) and on the open sea (e.g., the spill in the Gulf of Mexico (Chang et al., 2014)). It should be noted that spills in the ocean can also significantly impact land, specifically on coastal areas, not to mention the consequences for marine biodiversity.

Mohsin et al. (2021) like Carvalho (2017) assess the impacts of the mining sector in terms of environmental sustainability. These authors, using the mathematical models of environmental sustainability of Phillips (2012) with the quantitative bases of Folchi (2003), find that coal extraction could be unsustainable for the environment because, during its operation, toxic gases such as nitrogen oxide, methane, sulfur, and carbon dioxide are released into the air. The direct consequence is that the diffusion of these gases and coal dust increases air pollution and acid rain. More broadly, coal extraction negatively affects all four layers of the Earth: the atmosphere, the hydrosphere, the lithosphere, and the biosphere: the impacts are not limited to a reduction in air quality, as they also include an increase in water pollution, soil erosion, and biodiversity loss.

Within the strand in the literature of the environmental analysis of mining activity, one of the most studied effects is the ecological impact of sand extraction (Duan et al., 2019; Farahani and Bayazidi, 2018; Hackney et al., 2020; Koehnken et al., 2020). These studies are fundamental because sand is one of the most valuable commodities due to its economic importance (many industries require sand to manufacture their products), and the mining of sand contributes significantly to the creation of jobs and increased investment across a range of sectors. Consequently, this activity promotes the economic growth of sand-producing and importing countries (Leal-Filho et al., 2021). Unfortunately, sand mining has negative environmental impacts, widely felt as mining activity has ramped up. The repercussions can be seen in the locales where the extraction takes place and at a global level (Huang et al., 2018). The problem is further aggravated in developing countries, where the rules and regulations established for these activities need to contemplate the scientific understanding of the consequences, causing projects to be carried out without environmental impact assessments Peduzzi (2014).

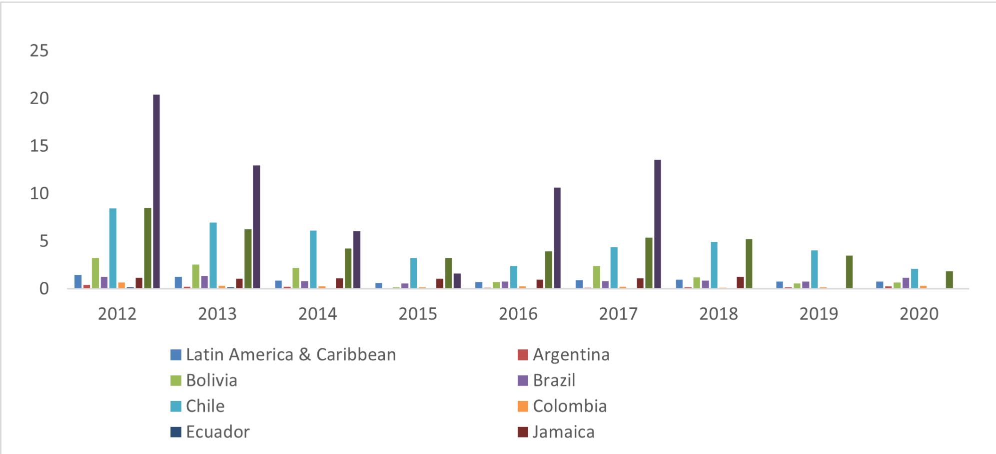
Farahani and Bayazidi (2018) presents substantial evidence of the adverse effects of sand mining on the environment. The authors highlight that the reduction of water resources associated with this activity leads to wider environmental degradation and the destruction of ecosystems with a high frequency, in addition to generating the loss of the rural landscape and consequently reducing the amount of arable land. Other studies such as (Hackney et al., 2020) seek to provide better information on sand extraction rates, given that there is uncertainty about how much is being extracted from the beds of large rivers around the world, and in this specific case, from the part down the Mekong River. In this regard, the study provides a first description of the extent to which current sand extraction rates are unsustainable: the authors show that excessive mining has caused the riverbed to drop, which is problematic as this will lead to riverbank instability. To quantify bed-load transport rates in the lower river, the authors recompiled a series of repeated high-resolution bathymetric surveys (done in six areas), enabling the tracking of dunes between the surveys. They are thus able to show that the total flow of sand entering the Mekong River Delta is much lower than current extraction rates, even when suspended sand is considered. This is detrimental not only at an environmental level due to the potential instability of the riverbank; it will also affect the surrounding infrastructure and homes, endangering the lives of the residents.

3 The Fruta del Norte Project

3.1 Mining in Latin America and Ecuador

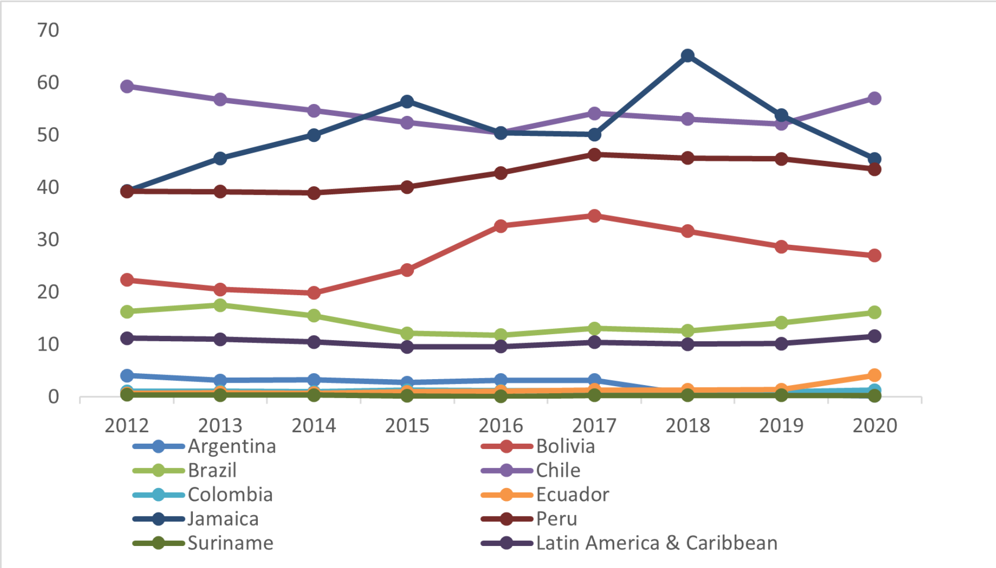
Mining is a major industry in six countries of the Latin American and Caribbean (LAC) region: Bolivia, Chile, Guyana, Jamaica, Peru, and Suriname. These countries derive revenues of between 2 and 7 percent of their GDPs from the industry as seen in Figure 1 (World Bank, 2022). Mining is also significant in Brazil, Colombia, and Mexico, but in these countries it is responsible for only a small percentage of GDP. In the case of Ecuador, although mining rents increased from 2012 to 2020, they account for less than 1 percent of GDP. By contrast, the oil sector generated 42 percent of the total revenue for the country in 2020. It should be noted that there has been a prominent decline in mining rents in the LAC region due to a decline in iron ore prices over the last decade and lower investment in the sector (Moritz et al., 2017).

Figure 1: Mining rents between 2012 and 2020 in Latin America and the Caribbean (% of GDP



The importance of mining is also reflected in Latin American exports. Products of the mining industry, including steel, gold, iron, and other metals, account for around 10 percent of total exports (Figure 2). In Chile (54.46 percent), Peru (50.70 percent), and Jamaica (42.36 percent), the participation in the mining sector was the highest between 2012 and 2020. For Ecuador, mining exports achieved a key milestone in 2020, representing 4.12 percent of all exports, an increase of 66 percent compared to 2019.

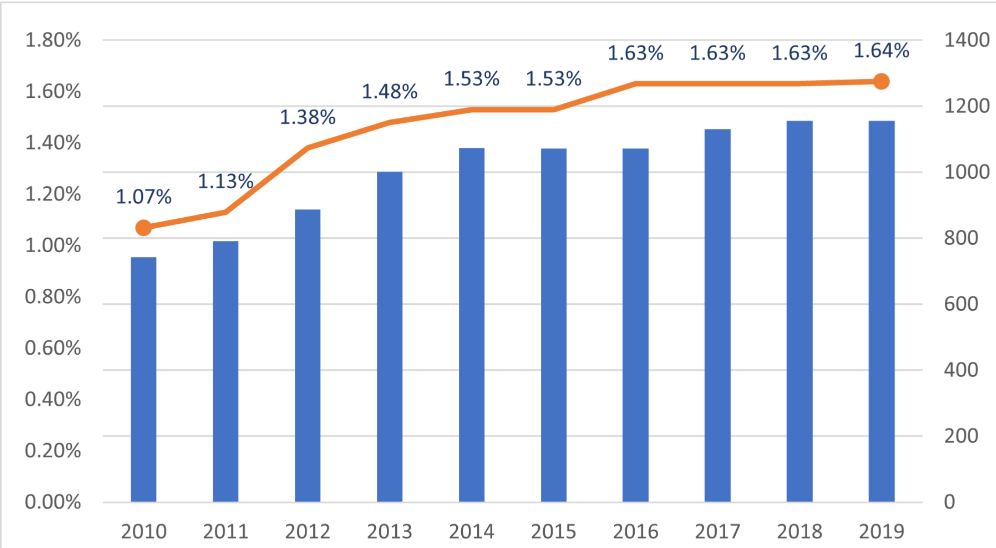
Figure 2: Ore and other metals exports from Latin American and Caribbean countries, 2012–2020 (% of total exports)



In Ecuador, the extractive industries sector has been led mainly by oil extraction, with mining having a minority share. Currently, to diversify the country's productive matrix, it is hoped to take advantage of Ecuador's mining potential by attracting large investments from both the public and private sectors.

The contribution of mining to Ecuador's GDP is reported in two categories. The categories are "Mining and quarrying" and "Manufacture of other non-metallic mineral products." From 2010–2019, mining contributed an average of 1.46 percent of the Ecuadorian GDP (see Figure 3). In addition, in 2018, metallic mining revenues reached USD 526 million and in 2019, exports from the mining sector reached USD 326 million. This increase in mining's proportion of GDP could be because in 2018, 53 percent of foreign direct investment went to mining and the following year, while the proportion declined, to 43 percent, it was still significant (CBE, 2021). These figures underscore the importance of the sector for national economic development.

Figure 3: Contribution of the mining sector to GDP in Ecuador, 2010–2019 (USD, millions, and as %



As discussed above, Ecuador has important mining potential. Presently there are five strategic projects in the country: Fruta del Norte, Loma Larga, Mirador, Río Blanco, and San Carlos Panantza. These represented a cumulative investment of USD 2,685 million through contracts executed between 2007 and 2019. The initiation of large-scale formal mining in the country began with the signing of the contract for the development of the Mirador project in 2012 and Fruta del Norte continued the trend (CBE, 2021).

3.2 Fruta del Norte and large-scale mining in Ecuador

In 2016, the government of Ecuador signed the exploitation contract for the Fruta del Norte project with Lundin Gold Inc. for which advance royalties of USD 65 million have been paid to date. After acquiring the asset, the Canadian mining company completed the feasibility study and project update and signed another round of major agreements with the Ecuadorian government to initiate its development. This project, with an investment of USD 1,334 million (CBE, 2021), represents 50 percent of the total investment in Ecuador's mining sector executed from 2007 to 2019. Table 1 shows the amounts Lundin Gold paid in advance royalties from 2016 to 2018 (Lundin Gold, 2021).

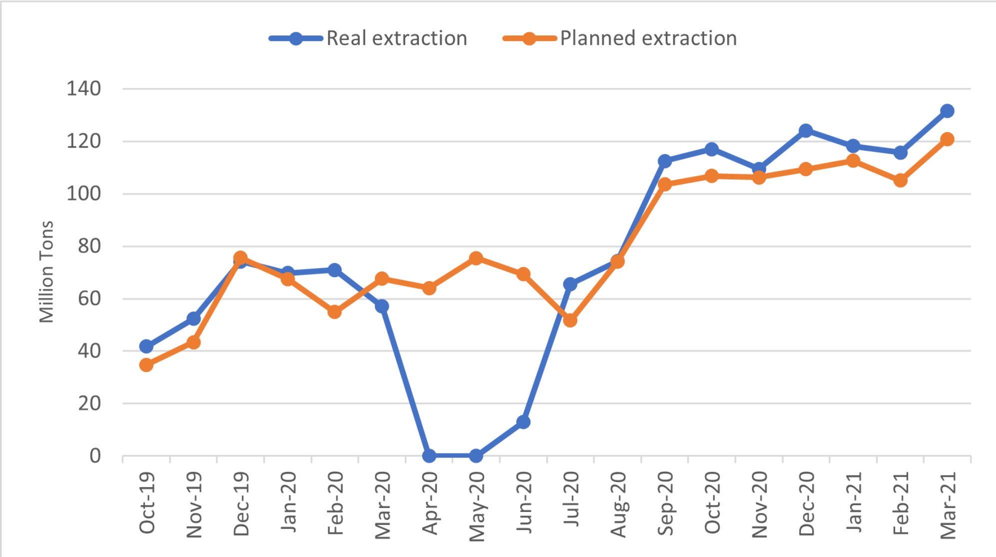
Table 1: Royalties paid by Lundin Gold

Year	Royalties (USD, millions)
2016	25
2017	20
2018	20

The project contemplates the exploitation of gold and silver for 25 years through an underground mine that involves the drilling of galleries of more than 500 meters deep and the extraction and treatment of 3,500 tons of ore per day by flotation and cyanidation (Soliz et al., 2018). According to the feasibility study, the project's potential is 15.5 million tons of ore with an average concentration of 9.67 g/t gold and 12.7 g/t silver (Lipiec et al., 2016).

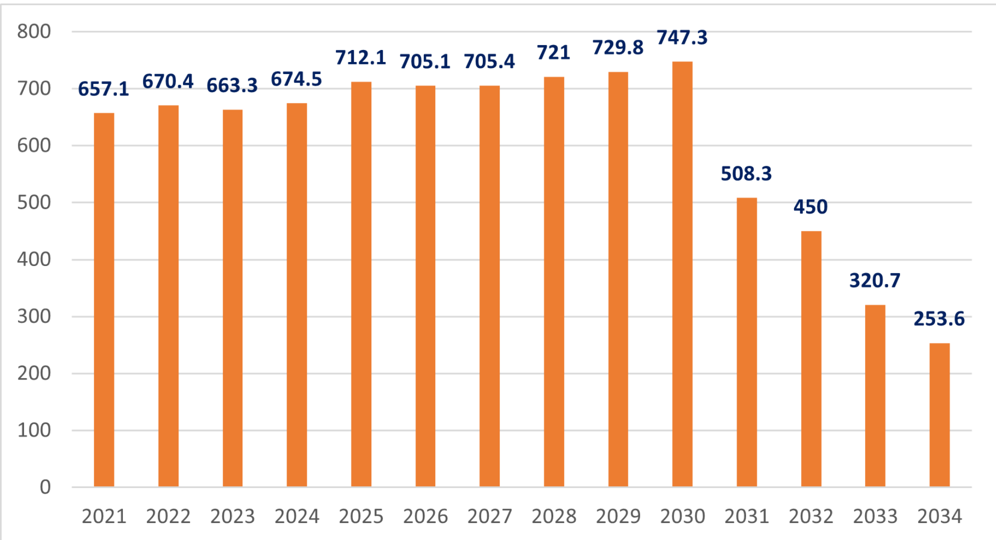
As reported by the Central Bank of Ecuador, from October 2019 to March 2021 the quantity of ore extracted was 1,541.94 thousand tons (Figure 4); of that, the plant on-site processed 1,392.99 thousand tons.

Figure 4: Total amount of ore extracted, Fruta del Norte, October 2019–March 2021 (million tons)



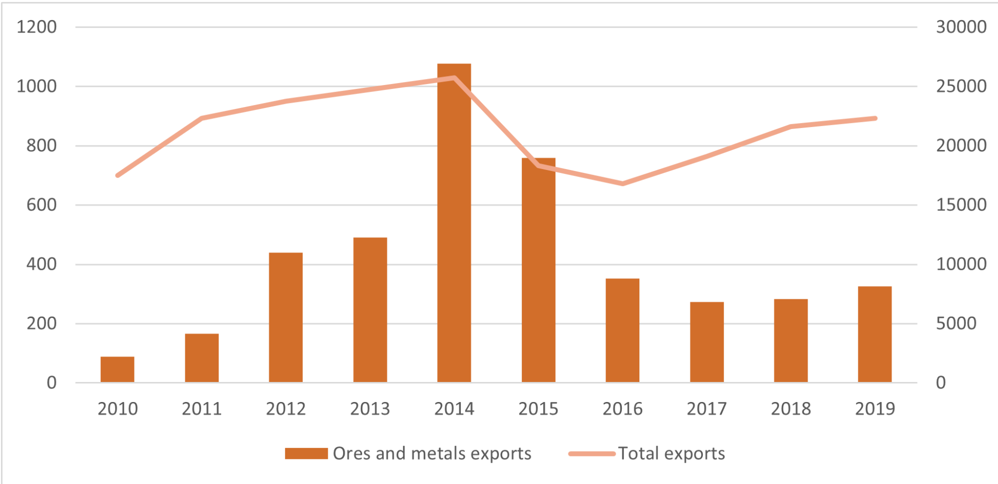
According to the Ministry of Energy and Non-Renewable Natural Resources (2020), the total exports projection for the Fruta del Norte mine for the period 2021–2034 is USD 8,518.54 million (Figure 5).

Figure 5: Total exports projected for Fruta del Norte 2021–2034 (USD, millions)



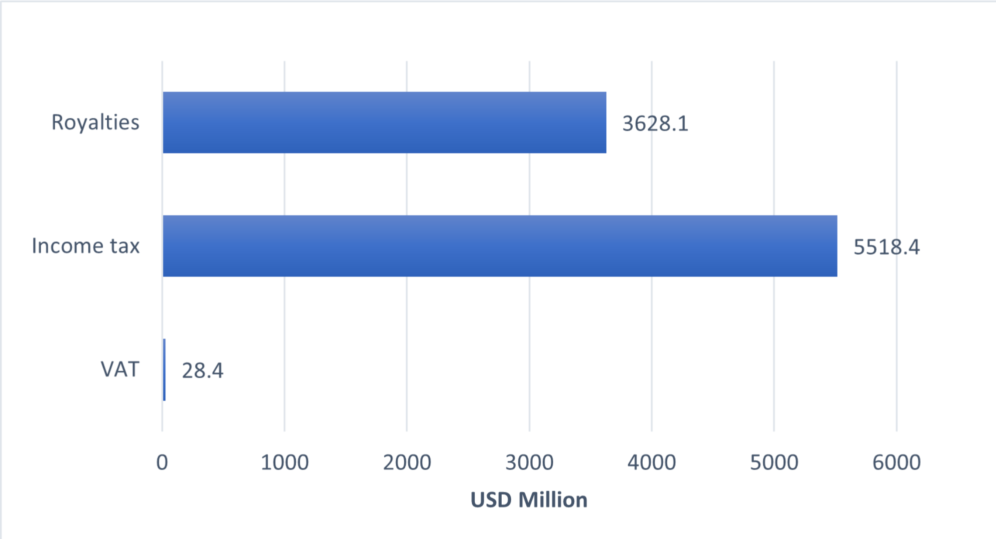
These exports would help to significantly increase the contribution of the mining sector to Ecuador's trade balance. For 2010–2019, exports of gold and other metals were, on average, 1.20 percent of Ecuador's total exports (Figure 6).

Figure 6: Mining exports totals, Fruta del Norte, 2010–2019 (USD, millions)



The Ministry of Energy and Non-Renewable Natural Resources (2020) has projected that the country will benefit from the mine's future development. Lundin Gold is expected to contribute USD 13,171.16 million in corporate taxes, Value-Added Tax (VAT), and royalties, as shown in Figure 7.

Figure 7: Total projected benefits of Fruta del Norte, 2012–2049 (USD, millions)



In addition, the mining operations in Fruta del Norte have resulted in a significant increase in employment opportunities in the area, with more than USD 31 million distributed in the form of wages and benefits between 2017 and 2020 (Lundin Gold, 2021).

4 Econometric Strategy

4.1 Data

In this paper, we study the impact of the Fruta del Norte mining project on three categories of local-level outcomes: business performance, health, and education. The geographic unit of analysis for each outcome variable in our study is the "Canton." Cantons are the second-level administrative divisions of Ecuador (the first-level divisions are provinces), with 221 cantons split across the country's 24 provinces. We construct a panel database aggregating data for all outcomes with cantons as the unit of analysis and with a time dimension spanning between 2009 and 2019.

As we explain in detail in the next section, our identification strategy builds a counterfactual using data at the canton level to answer the question of the outcomes for the

Yantzaza canton (where the Fruta del Norte mining project is located) would have been in the absence of the project. To do that, we examine three groups of cantons (or "donor panels"), the aggregated data of which could be deemed plausible as input to build a "credible counterfactual" to help answer that evaluation question. For this study, we use three donor panels. Donor panel 1 (DP1) is our main one and donor panels 2 (DP2) and 3 (DP3) are used as robustness checks (Table 2):

- Donor panel 1: We exclude the cantons of the province of Zamora Chinchipe (where the project is located), the cantons of the provinces of Pichincha and Guayas (due to the bigger economic dynamics present in these provinces), the cantons of the provinces of Manabí and Esmeraldas (due to the noise that the 2016 earthquake could generate), and the cantons of the provinces that have large-scale transnational metal mining.

- Donor panel 2: All the cantons in the country except for those of the provinces of Zamora Chinchipe, Pichincha, Guayas, Manabí, and Esmeraldas.

- Donor panel 3: The cantons of DP 2 except the cantons that have a very different level of rurality than the Yantzaza canton (more than 20 percentage points' difference in the upper and lower ranges).

Table 2: Number of units J in each donor panel

Donor Pxcluded cantons	Number of cantons in J	
DP 1	Cantons of the Zamora Chinchipe province, of the provinces with different economic dynamics, of the provinces affected by the 2016 earthquake, and of the provinces that have large-scale transnational metal mining	88 cantons
DP 2	Cantons of the Zamora Chinchipe province, of the provinces with different economic dynamics, and of the provinces affected by the 2016 earthquake	149 cantons
DP 3	The cantons excluded in DP 2 plus those that don't meet the condition of rurality	22 cantons

The data used in this analysis come from three official information sources, namely Servicio de Rentas Internas (SRI, the official tax authority) Instituto Ecuatoriano de Seguridad Social (IESS, the social security administration office), and Instituto Nacional de Estadísticas y Censos (INEC, the official statistics agency). With data from those agencies, we form a panel database of administrative records at the canton level that spans 11 years (2009–2019). The panel database has eight preintervention years (the preprogram period between the years 2009 and 2016) that we use to build the synthetic controls. We have three postintervention periods (the postprogram period between the years 2017 and 2019).

To monitor business performance, we isolate the following variables: *Income of the companies* and *Costs and expenses of the companies.* These data were available from the "Directory of Companies and Establishments" produced by SRI. We also extract the variable *Employment* (a count of the number of formal employees) from IESS's "Registered Employment database." Note that these variables only capture information about the business performance in the formal sector of the economy. For this reason and to the extent that the informal sector of the economy follows different productivity and employment dynamics, the external validity of our analysis might be limited.

The variables we use to measure education outcomes come from administrative records at the school level that the Ecuadorian Ministry of Education shares with INEC periodically. The data consist of student enrollment by school and education level for the whole country and include the canton where each school is located. Using that database, we aggregate counts of students at the canton level to form three variables: *Preschool enrollment rate*, *Elementary school enrollment rate*, and *"High school enrollment rate.* Finally, we construct canton-level variables using health-related events data from the "Statistical Registers of General Deaths" and the "Statistical Registers of Live Births" produced by INEC. The variables that we use in this study are *Mortality rate*, *Neonatal mortality rate*, *Number of live births*, *Number of live births with medical assistance at childbirth*, and *Number of adolescent mothers from 10 to 19 years of age.*

In Table 3, we compare the means of each outcome variable for our principal donor panel, DP1, and the Yantzaza canton in the pre-and postprogram periods. Columns 1 and 2 show the means of the outcome variable in the preprogram period for DP1 and the Yantzaza canton, respectively, and columns 3 and 4 do the same for the postprogram period. Column 5 presents an estimate of the unconditional difference in differences between the outcomes in the Yantzaza canton and DP1. As Table 3 shows, the mean differences in most of the outcomes are small in the preprogram period but not in the post-program one. The unconditional difference-in-differences (DID) estimates suggest that Fruta del Norte might have impacted several of the presented outcomes. For instance, there seems to have been an increase in employment and a decrease in high school enrollment in canton Yantzaza, with respect to the counterfactual formed by the cantons in DP1.

Table 3: "2x2" difference-in-differences

	Preperiod		Postperiod		**Difference in differences**
Variables	**Yantzaza**	**DP1**	**Yantzaza**	**DP1**	**"2x2"**
Income	15.7	15.78	17.1	16.35	0.83
Expenditure	16.04	15.76	18.08	16.34	1.46
Employment	9.92	9.64	10.8	9.92	0.60
Preschool	5.97	5.64	6.1	6.04	-0.27
Elementary school	8.69	8.59	8.61	8.49	0.02
High school	7.37	6.98	7.34	7.14	-0.19
Mortality rate	4.27	4.61	4.31	4.72	-0.07
Neonatal mortality	0.92	1.04	0.46	1.22	-0.64
Teenage pregnancy rate	4.86	4.56	4.8	4.44	0.06
Med. assisted births	6.03	5.78	6.16	5.91	0.00
Birth rate	6.18	6.03	6.2	6.01	0.04

In Figures 8 and 9, we present the trends of each variable for canton Yantzaza and compare them with those of the variables for the rest of the country between 2009 and 2019 (DP1). The figure enables us to explore (1) whether the rest of the country served as a good counterfactual to answer our evaluation question and (2) whether the implementation of Fruta del Norte changed the dynamics of the outcomes. Figures 8 and 9 shows the evolution from 2009 to 2019; recall that the contract for the mining project was signed in 2016. The purple lines represent the evolution of the indicator in the Yantzaza canton, while the gray line shows the average of the rest of the cantons in the country. As seen in the graph, the preprogram trends in business performance outcomes (businesses income, costs and expenses, and formal employment) in canton Yantzaza are similar to those in the rest of the cantons in the country. This suggests that, for those outcomes, the DID estimates shown in Table 3 could be a good first approximation of an estimate of the effects of the Fruta del Norte project. However, the preprogram trends are quite dissimilar (not even parallel) when considering the health and education variables, invalidating their use as valid data to estimate the counterfactual.

While the DID and graphical evidence suggest the possible impacts of Fruta del Norte on some of the outcomes of interest, it needs to be more conclusive as to how the project impacted business performance, health, and education. In the next section, we describe our implementation of the synthetic control approach to get closer to identifying the causal effects of the Fruta del Norte project on those outcomes.

Figure 8: Trends in economic and educational variables: Yantzaza compared to the rest of the country's cantons

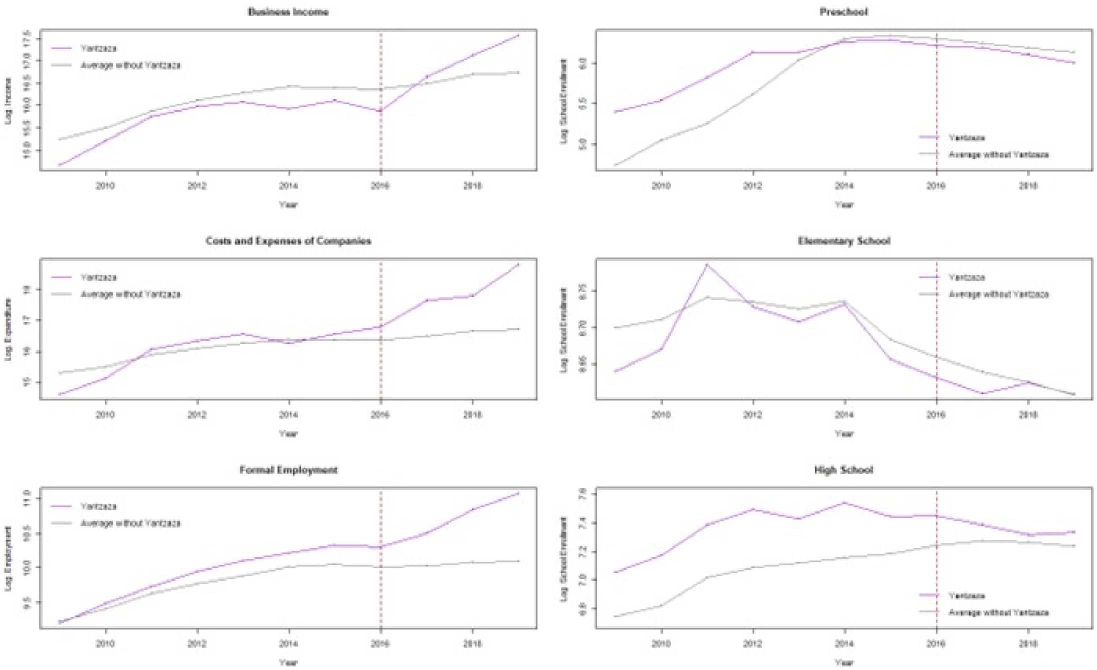
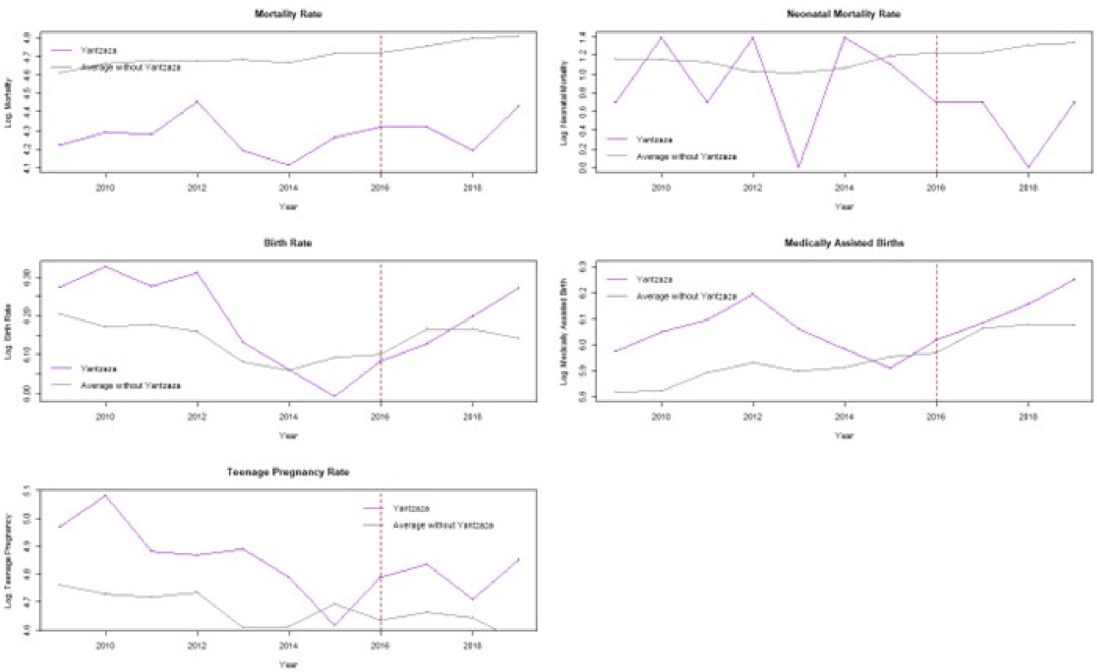


Figure 9: Trends in health variables: Yantzaza compared to the rest of the country's cantons



4.2 Synthetic control estimator

This section discusses the identification strategy that we use to estimate the impact of Fruta del Norte on business performance, health, and education outcomes. We use the synthetic control (SC) estimator proposed by Abadie et al. (2010); Abadie and Gardeazabal (2003). The SC design proposes to estimate a counterfactual of the treated unit as a weighted average of the outcomes across several comparison units that are not affected by the intervention (donor panel). A causal impact is obtained as the difference between the outcomes of the treated and the synthetic unit Abadie (2021). Our study estimates the impact of Fruta del Norte in the Yantzaza canton, building a "synthetic" Yantzaza canton using data from DP1 described in the previous section.

The SC estimator falls within two classes of estimators, the propensity score matching

(PSM) and the DID estimators. It shares with the former method that, relying on the similarity across the treated and untreated units, it constructs a propensity index that serves as the key input for building the weights that will be assigned to the untreated units to compute the counterfactual outcome. It is similar to the DID estimator in that it seeks to fulfill what in the DID parallel is the preprogram trends assumption. Yet, the SC estimator does so in a "extreme" fashion, for it matches preprogram trends to be as similar as possible (not only parallel).

In the SC estimator, the main task is to create counterfactuals by weighting the units in a comparison group proportionally to a measure of "proximity" (similarity) with the individuals in the treatment group. The key difference between the SC and PSM approaches is that in the former case there is only one treated unit. Consequently, the SC approach cannot compare differences in averages across the treated and weighted comparison groups (which is what the PSM estimator does). With the SC method the untreated group is "synthetically" constructed as a weighted average of the outcomes in a donor panel. That average outcome (the counterfactual) is compared to the outcome for the sole treatment unit. In our case, we can obtain the effect of the Fruta del Norte project by subtracting the values of outcomes of interest of the Yantzaza canton, from the corresponding average of the "synthetically constructed" Yantzaza counterfactual, as mentioned above (see Abadie et al., 2010).

Using the standard notation for the SC method, let Y be an outcome variable and assume that there are $J + 1$ units observed in periods $1, 2, \ldots, T$. Unit "one" is the Yantzaza canton (i.e., the unit exposed to the intervention of interest or the "treated" unit) during periods $T_0+1, T_0+2, \ldots, T$ and a preprogram period denoted by $T_0-1, T_0-2, \ldots, P$. The J are the elements (cantons) in the donor pool. Let Y_{1t}^0 be the outcome that would be observed for unit i at the moment t in the absence of the intervention and Y_{1t}^1 the outcome observed for unit i at the moment t if unit i is exposed to the intervention in periods $T_0 + 1$ and T. The treatment parameter is

$$\delta_{1t} = Y_{1t}^1 - Y_{1t}^0$$
$$= Y_{1t} - Y_{1t}^0,$$

where for each posttreatment period, $t > T_0$ and Y_{1t} is the outcome of the treated unit (the Yantzaza canton) at time t. The counterfactual Y_{1t}^0 is calculated using data from the J units in the donor panel. To construct the counterfactual, a vector of optimal weights $W^* = \left(w_2^*, \ldots, w_{J+1}^*\right)'$ of dimensions $Jx1$ is used, where each weight is strictly positive, and the sum of all the weights of the vector is equal to 1, so that $\widehat{Y}_{it}^N = \sum_{j=2}^{J+1} w_j^* Y_{jt}$. The estimation of the optimal W^* is carried out through a nested optimization process, in which there is an internal and external optimization. In the internal optimization, the Euclidean distance between Y_1 and Y_0 W is minimized as follows:

$$W^* = \arg\min_{W} \|X_1 - X_0 W\| \, v = \sqrt{(X_1 - X_0 W)' \, V \, (X_1 - X_0 W)}, \tag{1}$$

where X_1 is of dimension $(r + k) \times 1$ and $X_0 W$ of dimensions $(r + k) \times J$, with the understanding that k equals the number of covariates and r equals the number of linear combinations of premining outcomes used as predictors. In this sense, V is a positive, symmetric diagonal matrix with dimensions $(r+k) \times (r+k)$ that contains the predictor weights assigned to the adjusted pretreatment variables. In the external optimization, V^* is estimated with the minimization of the mean squared error (MSE) of the synthetic control for the pretreatment period:

$$V^* = \arg\min_{V} \left(\sum_{t=1}^{T_0} (Y_{1t} - \sum_{j=2}^{J} W_j^*(V^*) Y_{jt})^2 \right). \tag{2}$$

This is the standard way of choosing the weights determining the synthetic control groups in applied research. In this case, the construction of the vector of optimal weights is carried out using a linear optimization method called "Simplex," which has already been used to obtain an optimal vector W^* in the synthetic control methodology (Abadie et al., 2010; Ferman and Pinto, 2021). The use of this optimization algorithm allows us to improve the selection of weights, avoiding any subjective bias of the researcher.

One of the things that must be kept in mind when using a synthetic control is that the methodology assumes that the treated unit (Yantzaza in our case) is the only one affected by the implementation of the mining project and that the rest of the cantons J are not affected by this implementation. These assumptions imply that not only did no canton anticipate the effect of the entrance of Fruta del Norte to the canton before time period T, but also that there was no spillover effect to the rest of the units J in the donor panels after the initiation of the project. This postulation is known as the stable unit treatment value assumption (SUTVA) (see Abadie, 2021).

Finally, to quantify the uncertainty of the SC estimates we use the conditional prediction method proposed by Cattaneo et al. (2021). This approach develops conditional prediction intervals that are not conventional confidence intervals in statistics; instead they define a region "on the support of a random variable where a new realization is likely to be observed." The method exploits two sources of randomness that exist in the prediction for synthetic control: one that comes from the construction of the weights of the SC in the pretreatment period and another from the nonobservable stochastic error in the posttreatment period. We apply the SC estimator of Abadie et al. (2010) and the conditional prediction interval of Cattaneo et al. (2021) using the SCPI package in the R-Studio tool (a software package developed by Cattaneo et al. (2022)). The benefit of using this package is the direct execution of the prediction intervals, which are added to the point estimate of the SC (giving us the estimate of the treatment effect).

5 Results

In this section, we present SC estimates of the impact of Fruta del Norte on business performance, health, and education outcomes using data from DP1 (Table 4). In subsection 5.5, we present results where we estimate those impacts using data from DP2 and DP3 as robustness checks. While the results using the DP2 donor panel (where all other cantons enter the pool) are similar, we worry that some cantons in that pool are simply too "different" (for instance, the pool includes urban cantons in which big cities are located) to serve as proper donors for answering the counterfactual question. In the case of DP3, while we are certain that those cantons are similar to the Yantzaza canton, but they do not form a sufficiently large pool on the basis of which we can make reliable statistical inferences.

We select DP1 because it both contains a set of cantons sufficiently large to quantify uncertainty in the inferences and includes cantons that we deem "comparable ex-ante" in terms of predefined exclusion criteria. Note that by choosing a donor panel based on a predefined set of eligibility criteria, we are, in fact, producing an estimator that matches the Yantzaza canton to observationally equivalent cantons in two stages (as defined in (Smith and Todd, 2005)), the first of which is based on the selection of eligible cantons and the second of which relies on the matching algorithm embedded in the SC estimator. In the appendix, we show that for DP1, the weight structure for the most relevant cantons in SCs includes several cantons (and they are not influenced by the dynamics of a single canton).

Table 4: Synthetic control results

	2017			2018			2019		
Variables	**ATT**	**Left bound**	**Right bound**	**ATT**	**Left bound**	**Right bound**	**ATT**	**Left bound**	**Right bound**
Income	0.765	1.612	0.313	1.118	2.134	0.715	1.315	2.404	0.532
Expenditure	1.267	1.922	0.892	1.311	2.177	1.120	2.406	3.370	2.177
Employment	0.182	0.256	0.100	0.460	0.529	0.345	0.687	0.767	0.552
Preschool	0.065	0.169	-0.010	-0.022	0.054	-0.206	-0.067	0.011	-0.282
Elementary school	-0.110	-0.063	-0.323	-0.087	-0.040	-0.340	-0.081	-0.034	-0.341
High school	-0.085	-0.025	-0.121	-0.130	-0.018	-0.190	-0.030	0.153	-0.121
Mortality rate	-0.053	0.105	-0.205	-0.230	-0.110	-0.289	-0.001	0.165	-0.149
Neonatal mortality	-0.348	-0.014	-0.607	-1.181	-0.847	-1.439	-0.662	-0.328	-0.920

5.1 Impact of Fruta del Norte on business performance

One working hypothesis of this paper is that Fruta del Norte would have had impacts on the number, size, and sales of formal businesses in the Yantzaza canton. In line with that (very basic) change theory, employment in those firms would have also increased. In this section, we falsify those hypotheses.

Figures 10, 11, and 12 display the three business performance outcomes in the pre- and postprogram periods for canton Yantzaza and the synthetic counterfactuals based on data from DP1. The graphs first lend themselves to a general assessment of the quality of the match between canton Yantzaza and the weighted cantons in the donor pool (with reference to the preprogram period). In addition, for those figures displaying the outcomes for both the treated and synthetic counterfactuals, we can use the postprogram data in them to qualify the magnitude of and uncertainty around the effects (with the aid of the prediction intervals) of the Fruta del Norte project on those outcomes. Table 4 summarizes the values of the Fruta del Norte treatment effects through time (which we label ATT in the table) and the associated prediction intervals that we show in Figures 10, 11, and 12.

The first observation we can make is that the dynamics of the outcomes in the synthetic controls in the preprogram period for each of the three outcomes fit that of Yantzaza very well. This speaks to the reliability of our results, for the best counterfactual outcome will be that which, as in our case, is constructed as a weighted average of cantons that can reproduce the preprogram dynamics in the unit of interest (canton Yantzaza in our case).

Figure 10: Business income

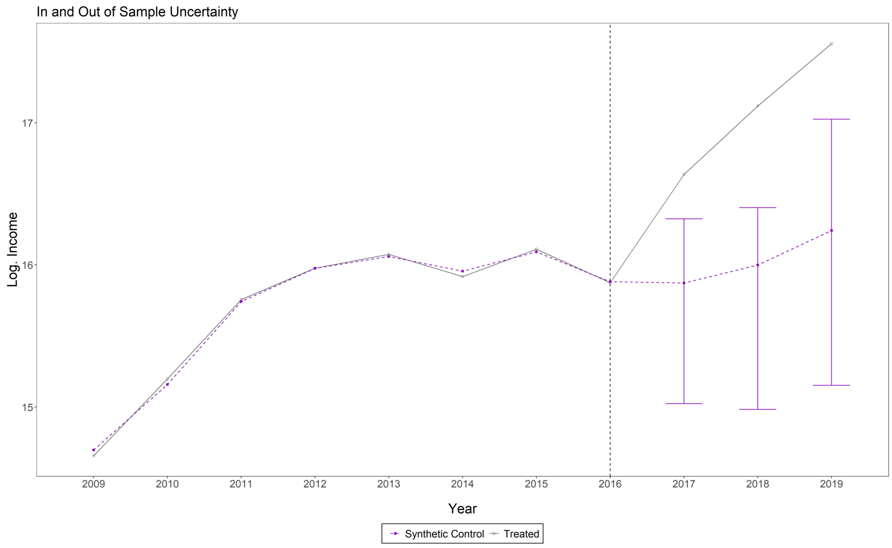


Figure 11: Costs and expenses of companies

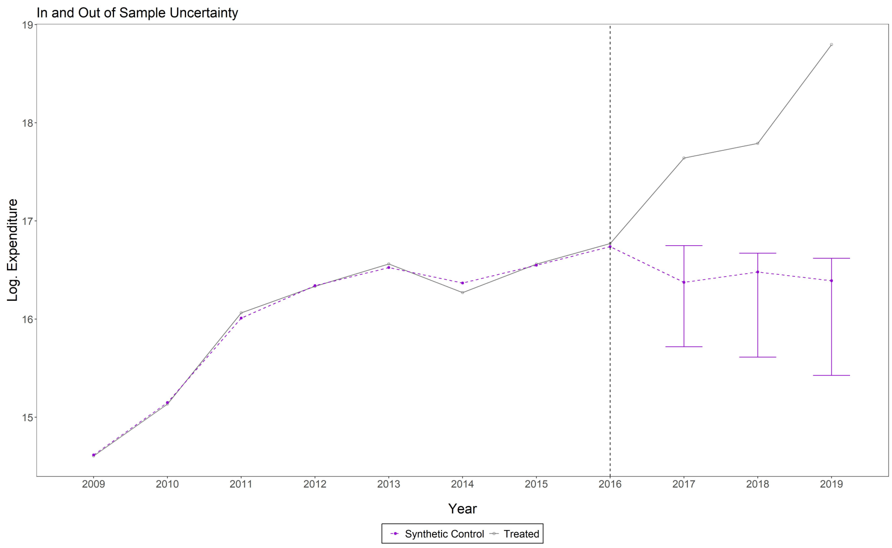
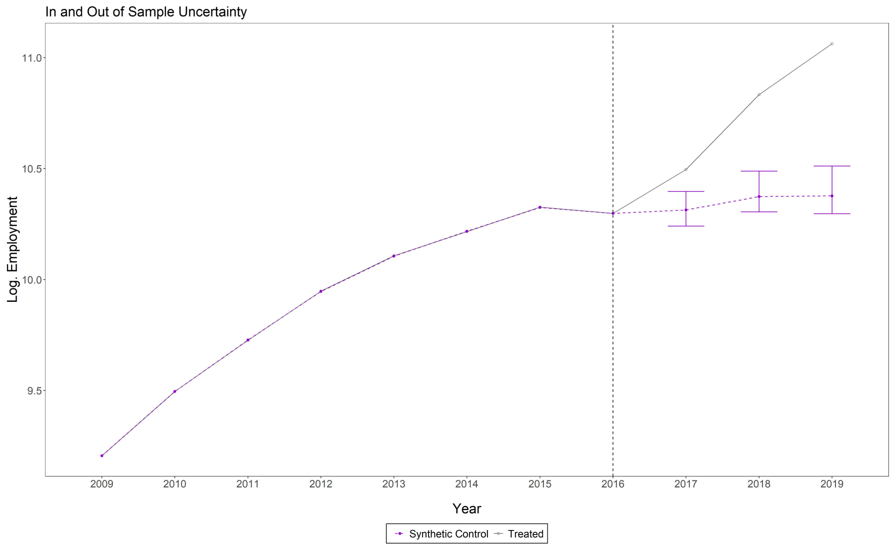


Figure 12: Formal employment



Secondly, we observe that canton Yantzaza had better outcomes than the synthetic control during the entire postprogram period. This result suggests that Fruta del Norte positively impacted businesses' performance because, in the absence of that investment project, Yantzaza would have had a slower business income growth rate, while business expenses and employment would have stalled. Based on the mean results and the prediction interval, the differences between those outcomes in canton Yantzaza and the synthetic control can be attributed to the project impact of Fruta del Norte. In terms of the magnitude of the program effects, we highlight that over the period 2017–2019 business income was 1.07 times higher, expenses were 1.66 times higher, and employment increased by 44.3 percent as the result of the Fruta del Norte mining project in canton Yantzaza.

5.2 Education-level variables

Similar to what we did to quantify the impact of Fruta del Norte on business performance, we use the results in figures 13, 14, and 15 to explain how the project impacted school enrollment in canton Yantzaza. First of all, note that as was the case with the business performance outcomes, the three synthetic controls associated to the school enrollment outcomes match the preprogram dynamics of canton Yantzaza quite well. Again, that result suggests that by using data from those synthetic controls, we can reliably answer the counterfactual question.

Directing attention to Figure 13, observe that the postprogram dynamics in preschool enrollment are not that different between canton Yantzaza and the synthetic control. In addition, the prediction intervals in all three years indicate that the preschool enrollment in the synthetic control during the postprogram period might be comparable with Yantzaza canton. Combined, the evidence suggests that Fruta del Norte did not affect school enrollment at preschool level.

Note that in Figure 14, as with preschool enrollment, the preprogram trend in elementary school enrollment in the synthetic control also matches that of the Yantzaza canton quite well. Estimates for the postprogram period, however, suggest that the project reduced enrollment in elementary education. Regarding the magnitude of those effects, Fruta del Norte induced a 9.3 percent decrease in elementary school enrollment in the Yantzaza canton. While the latter result is somehow puzzling, it lends itself to several interpretations. An increase in labor supply leads to children being unattended when school schedules are inconsistent with labor market demands. Another is that children dropping out at the elementary level supply the increasing demand for labor (that they fulfill as child workers) within the household.

Figure 15 shows that, while the match in the preprogram dynamics of high school enrollment of canton Yantzaza and the SC is quite good, the drop in high school enrollment was more pronounced in the Yantzaza canton during the postprogram period. That impact appears to be concentrated in the first two years of the postprogram period. On average, over the period Fruta del Norte negatively impacted high school enrollment, reducing it by 8.2 percent. This result is consistent with the improvement in the business performance indicators, in particular with that of employment. A higher level of economic activity increases the demand for labor and thus, high school students, whose opportunity costs of staying in school are low, especially those at the margin of dropout, leave school to join the labor force. Whether they work in the formal or informal sector, we cannot ascertain from the data. Still, the stronger demand for labor in the formal sector we document above would have also generated dynamism in the informal sector, dragging workers to both sectors.

Figure 13: Preschool enrollment

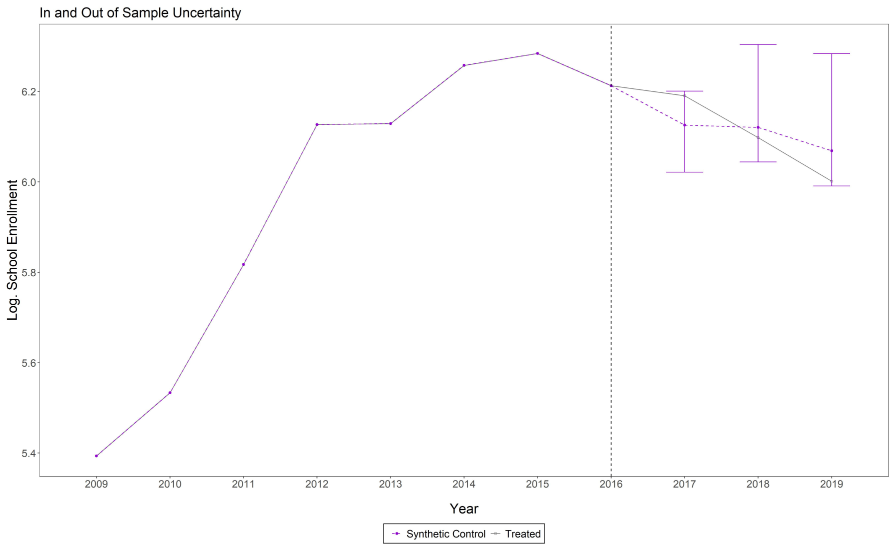


Figure 14: Elementary school enrollment

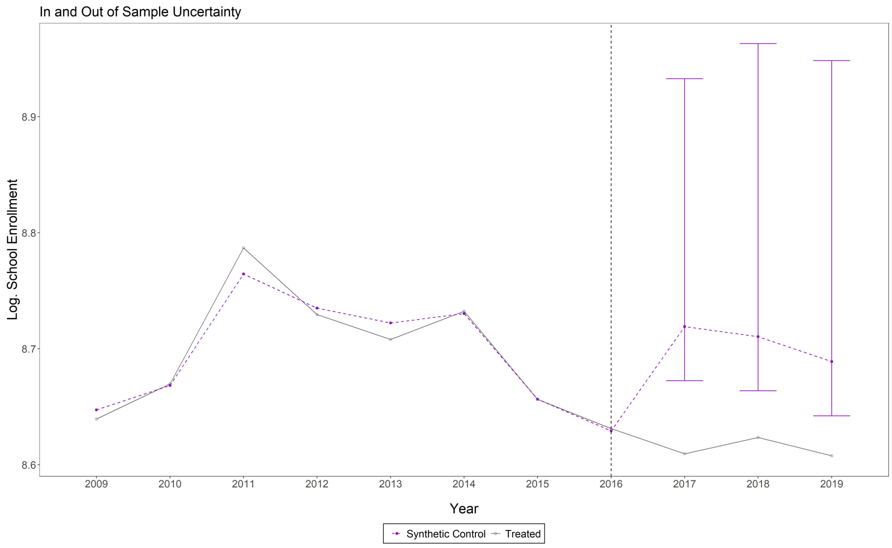
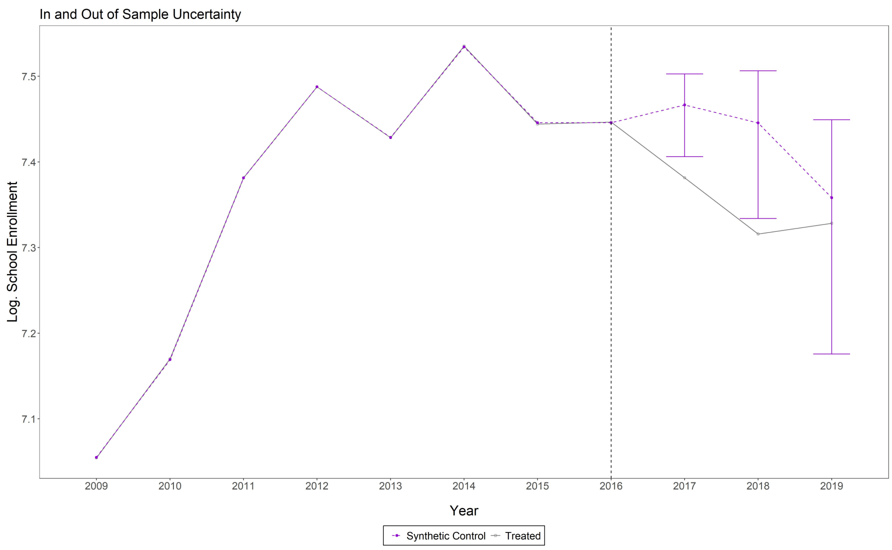


Figure 15: High school enrollment



5.3 Health variables

In this subsection, we turn our attention to Figures 16, 17, 18, 19, and 20 which present the results related to the impact of Fruta del Norte on four health outcomes: overall mortality, neonatal mortality, teen pregnancy, and percentage of new births assisted by medical professionals. We study these outcomes because it is reasonable to expect that the local revenues generated by the Fruta del Norte project could have increased public resources available for investment in human capital at the local level, eventually rendering better health outcomes for Yantzaza canton residents than what they would have experienced in the absence of the project. Furthermore, health outcomes in Yantzaza could have also changed as people responded to changes in their incentives to invest in health, form families, and work that resulted from Fruta del Norte. The combined effect of the project's operating on health-related outcomes on those two mechanisms (possibly others, as well) is summarized in the figures.

The first observation that we highlight is that the weak systematic pattern relating mortality rates in Yantzaza and in the synthetic control in Figure 16 contrasts with a clear pattern of a decrease in neonatal mortality in Figure 17. While the data do not support the conclusion that Fruta del Norte impacted mortality rates in the Yantzaza canton either positively or negatively, the result masks the fact that neonatal mortality apparently decreased because of the project.

Our second observation is driven by the combined evidence presented in Figures 18, 19 and 20. The graphs strongly suggests that while teen pregnancy increased in the Yantzaza canton as the result of Fruta del Norte, the quality of medical care received by women in labor also improved, hand in hand with a positive impact on birth rates.

5.4 Discussion

The results presented in this section suggest that the Fruta del Norte project positively impacted local economic activity in canton Yantzaza. The local economic dynamism spurred by the project positively affected local formal employment, an outcome that improved the quality of life in canton Yantzaza in a way that otherwise would not have been observed.

Those positive economic impacts of the project on the local economy would have affected the economic incentives that motivate school enrollment, especially among teenagers. As the data show, teenagers dropped out of high school more often than in the counterfactual state; their decisions possibly responded to better opportunities foreseen in the labor market in the short term with the identification of economic gains from a revitalized local economy. In parallel, teen pregnancy increased, and we conjecture that this pattern also influences the rate of school dropout.

The finding of a duality of positive economic effects with potentially negative externalities is not uncommon in the development literature. Public attention needs to be directed toward the design of programs to address those negative externalities. On-the-job training and schooling for teenagers, family planning, and home visiting programs with educational schooling content are policies that can counterbalance those effects. There is a need to ensure that young people acquire fungible skills that facilitate their transitions across jobs (language, computing, coding, etc.). It is imperative to design family planning interventions because teenage pregnancy precludes longer-term positive outcomes for women and perpetuates intergenerational poverty.

Figure 16: Mortality rate

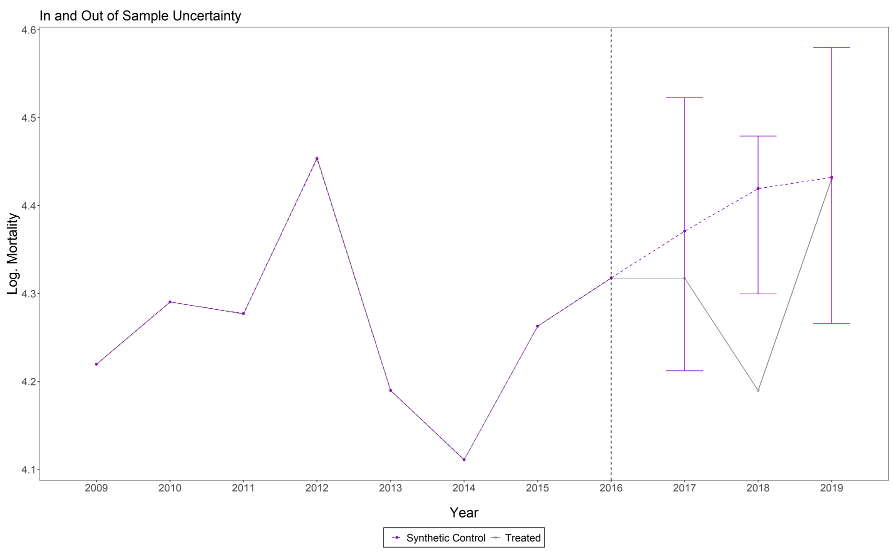


Figure 17: Neonatal mortality rate

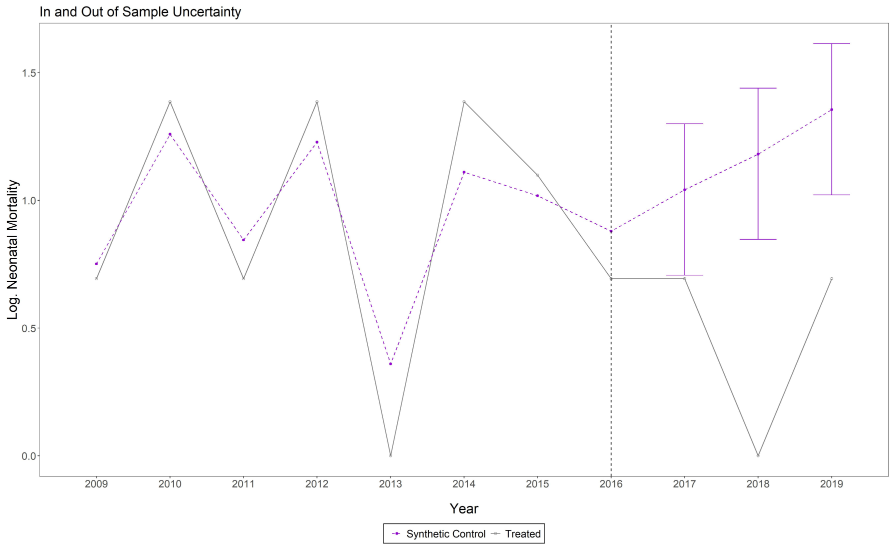


Figure 18: Teenage pregnancy rate

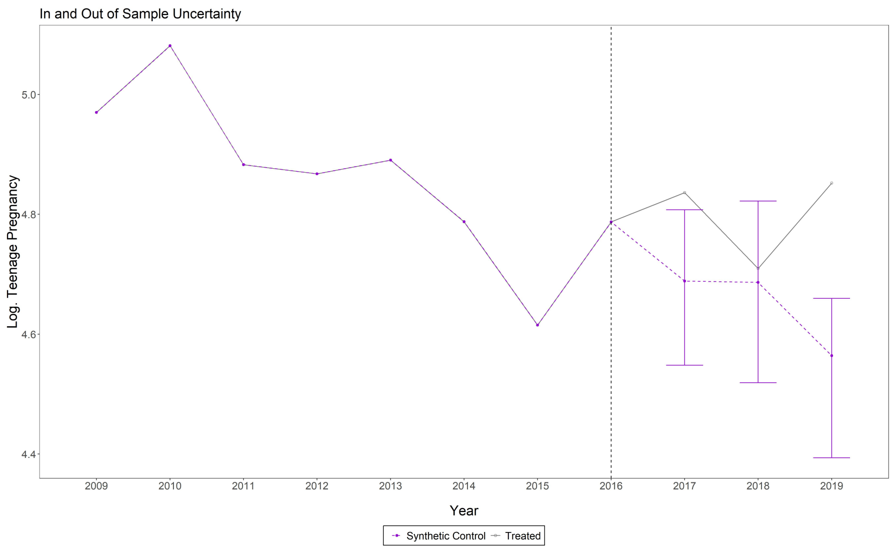


Figure 19: Medically assisted births

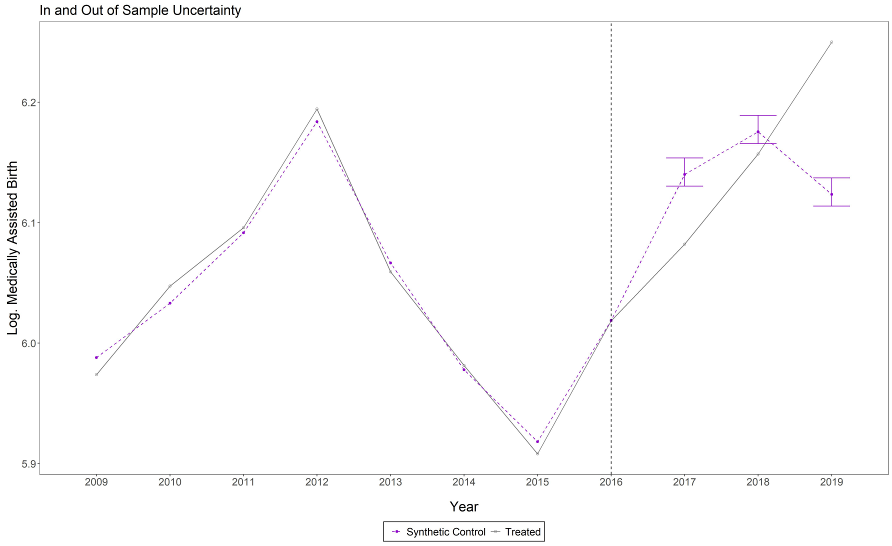
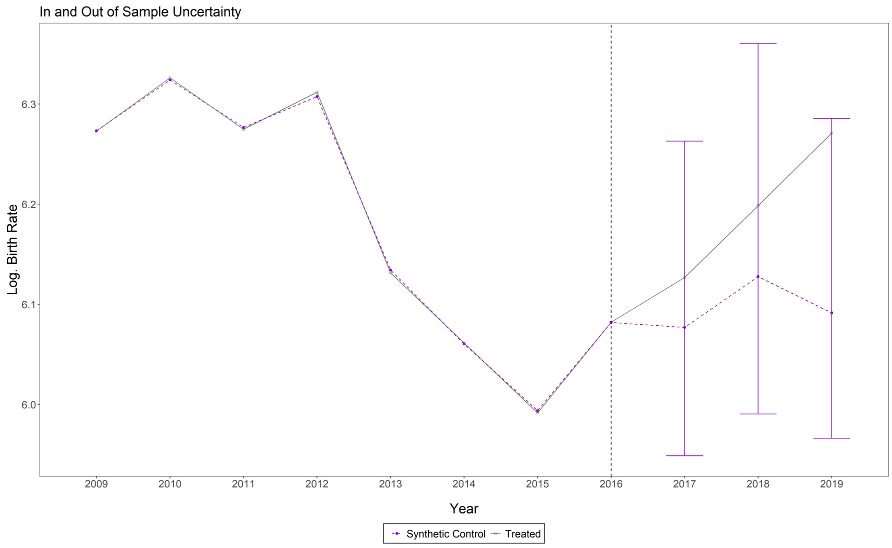


Figure 20: Birth rate



5.5 Robustness checks

Results with DP2 and DP3

Figure 21: Business income, DPs 2 & 3

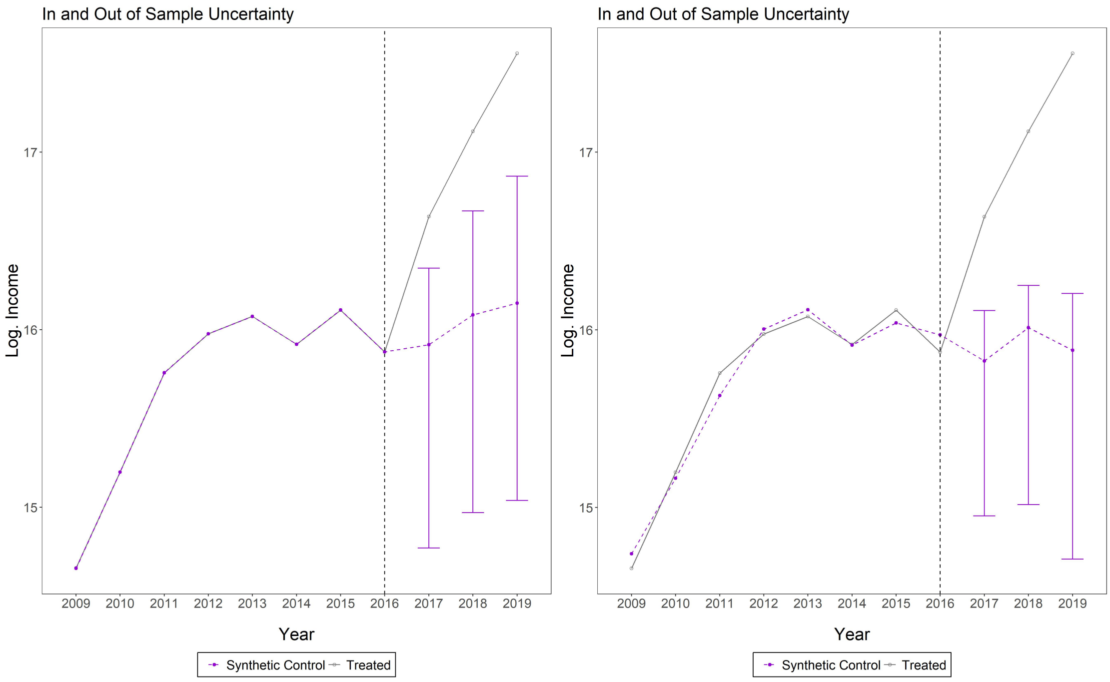


Figure 22: Costs and expenses of companies, DPs 2 & 3

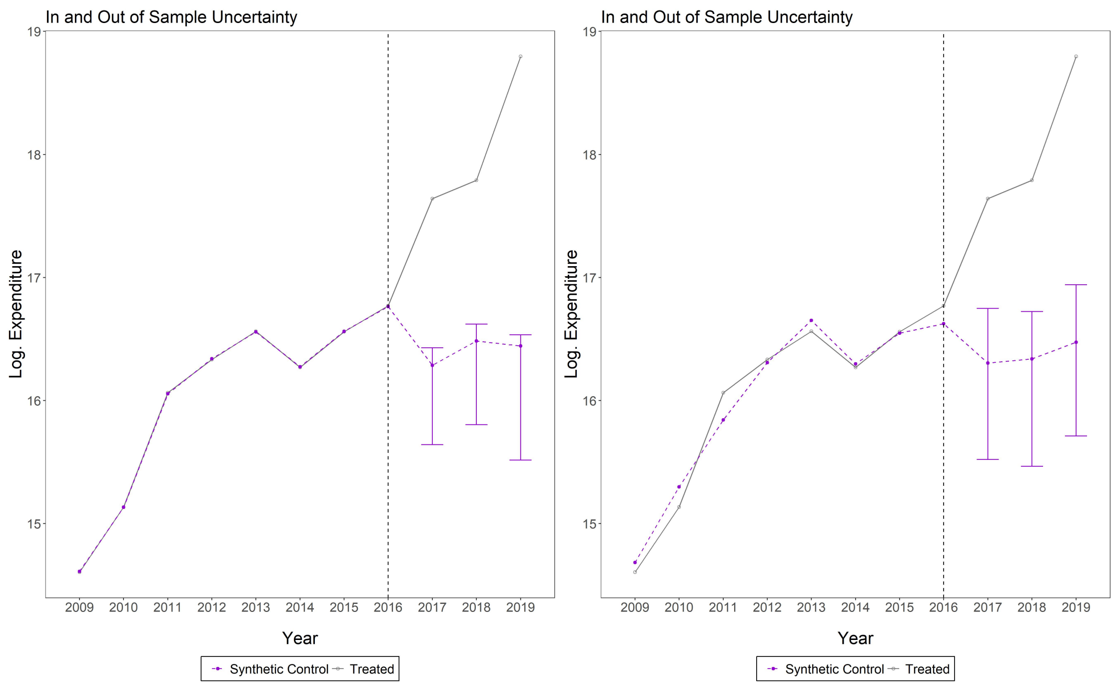


Figure 23: Formal employment, DPs 2 & 3

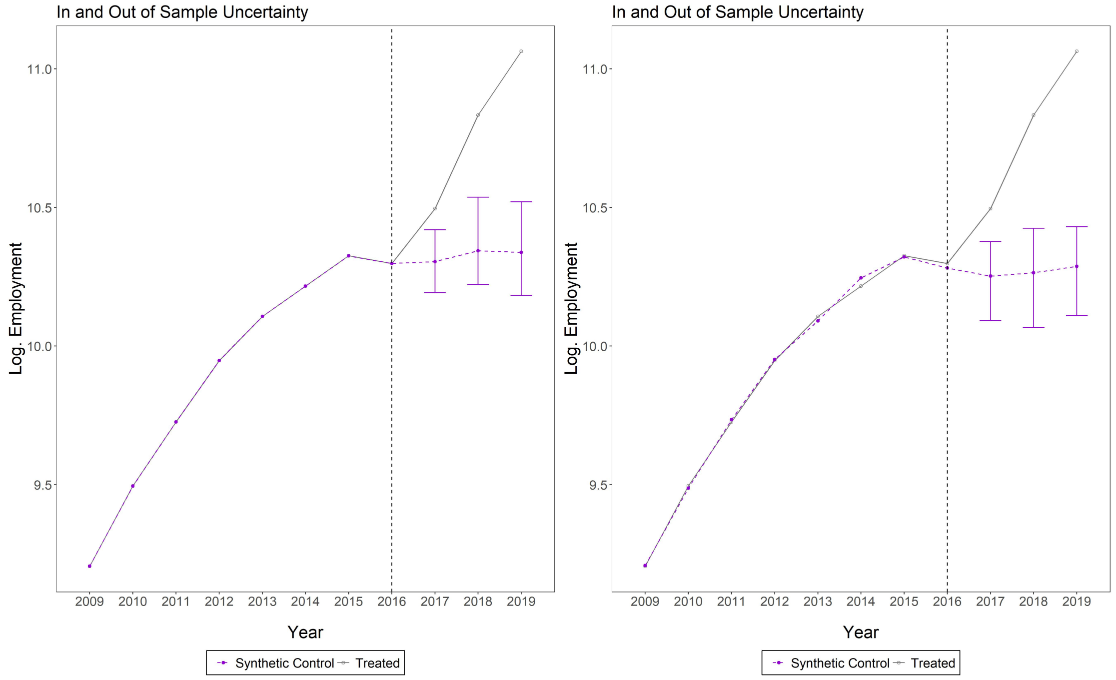


Figure 24: Preschool, DPs 2 & 3

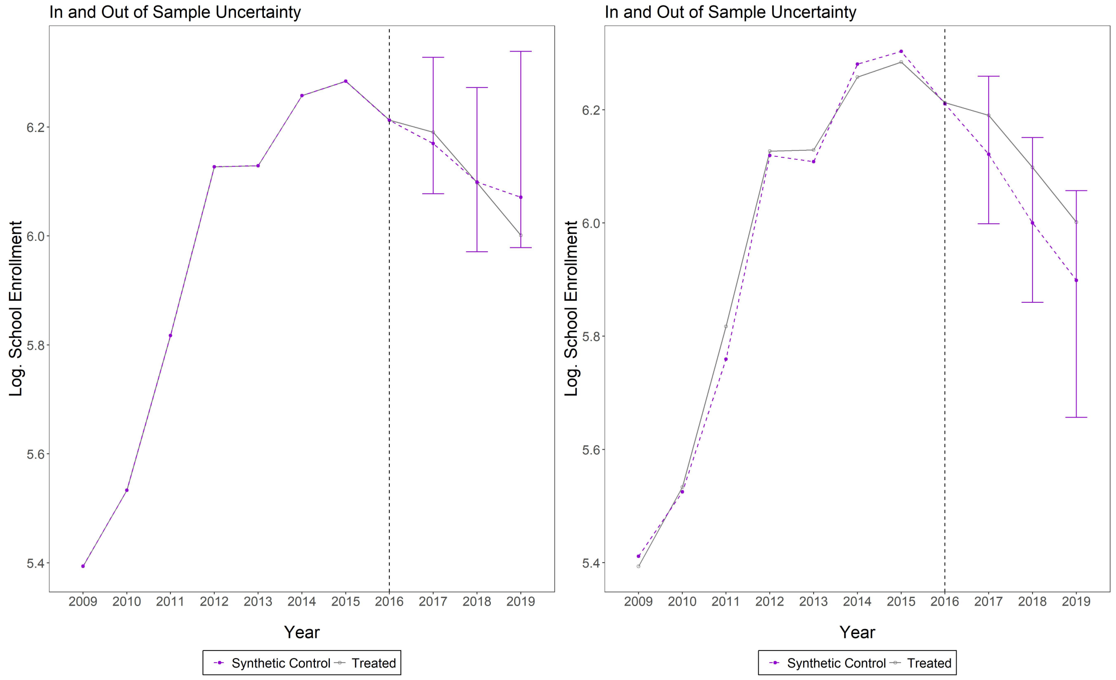


Figure 25: Elementary school, DPs 2 & 3

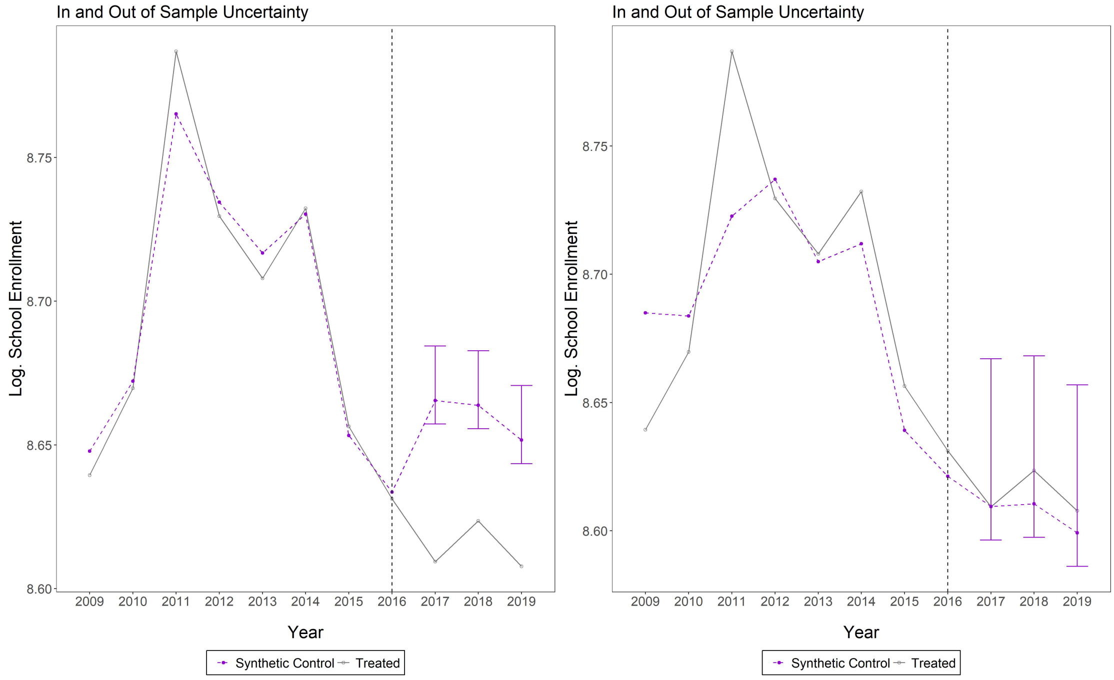


Figure 26: High school, DPs 2 & 3

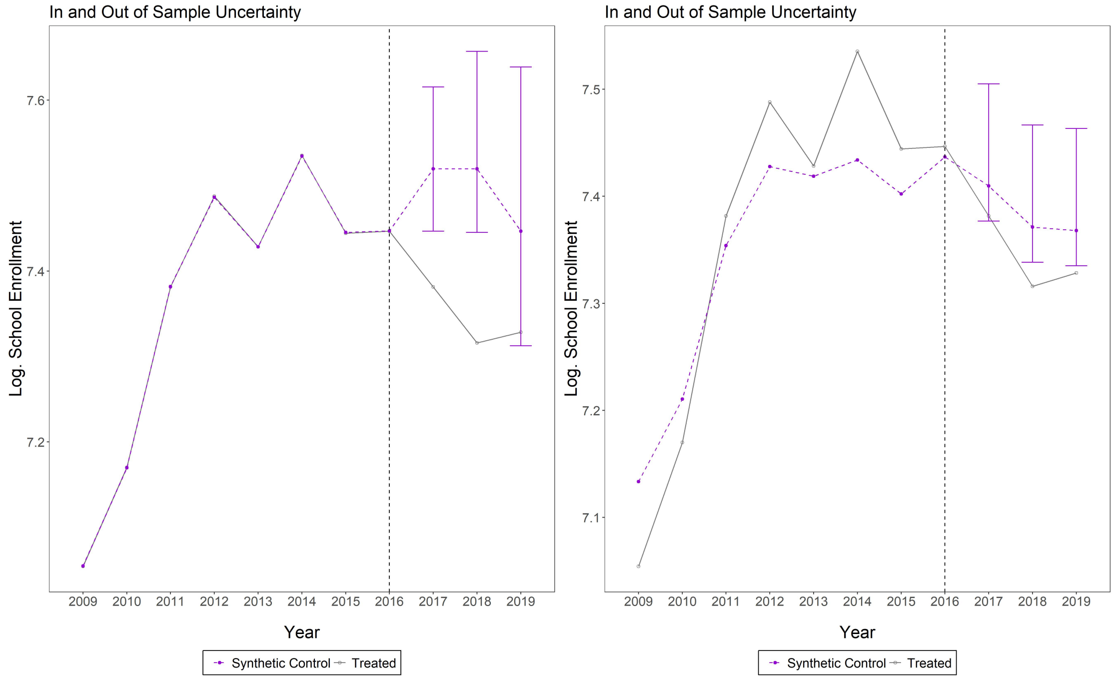
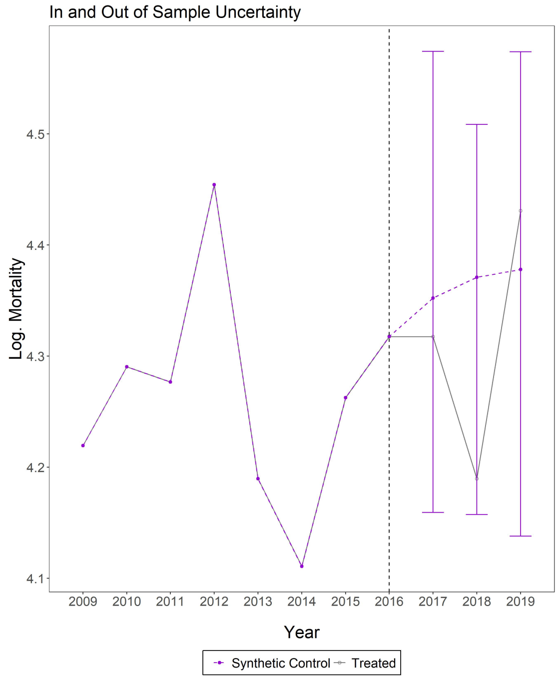


Figure 27: Mortality rate, DPs 2 & 3



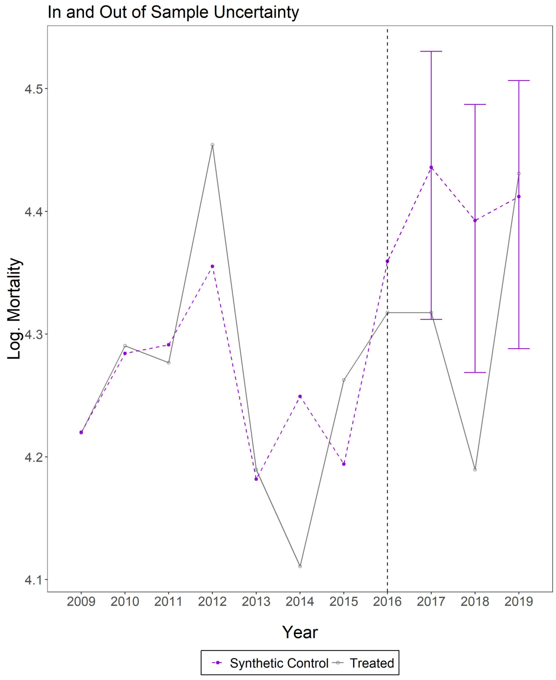


Figure 28: Neonatal mortality rate, DPs 2 & 3

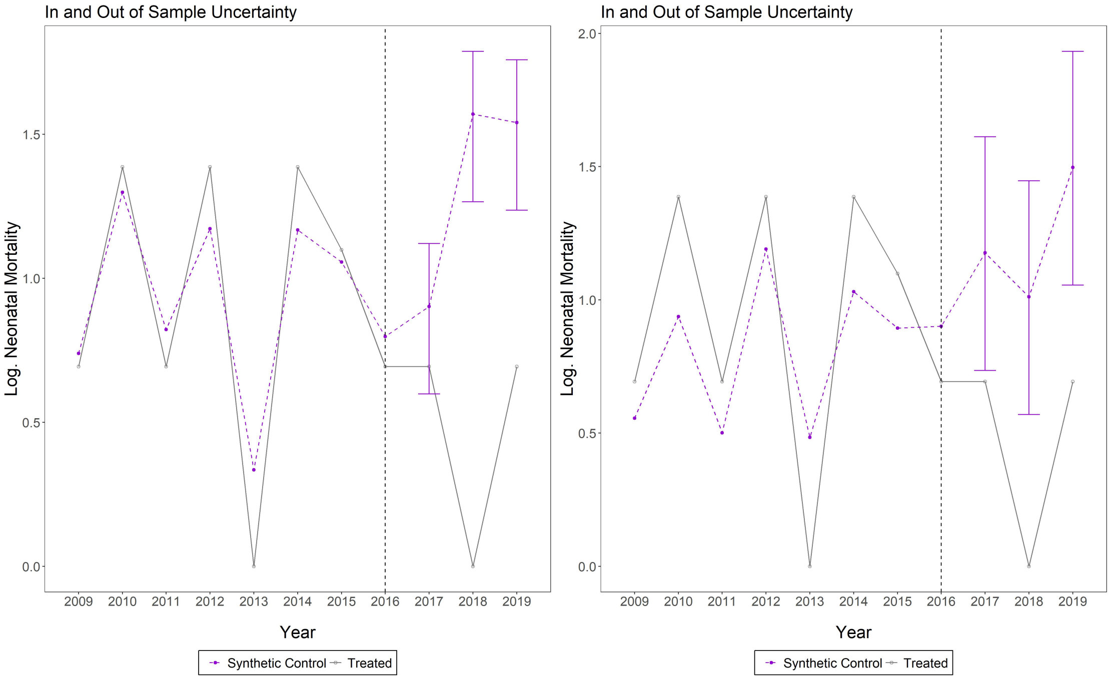


Figure 29: Teenage pregnancy rate, DPs 2 & 3

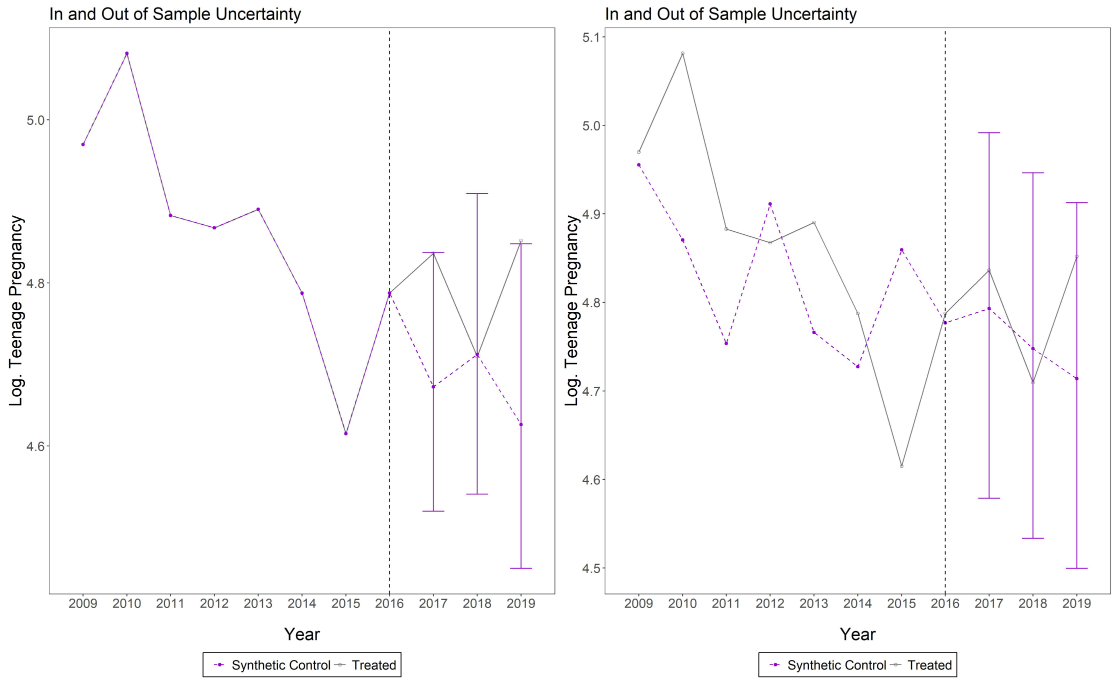


Figure 30: Medically assisted births, DPs 2 & 3

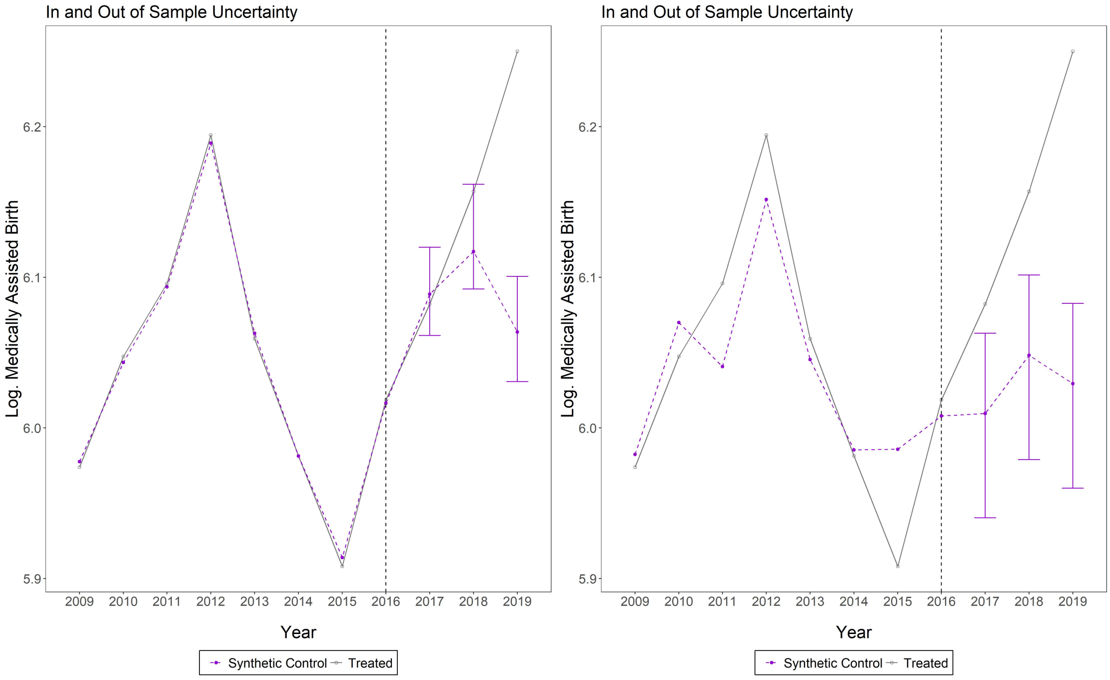
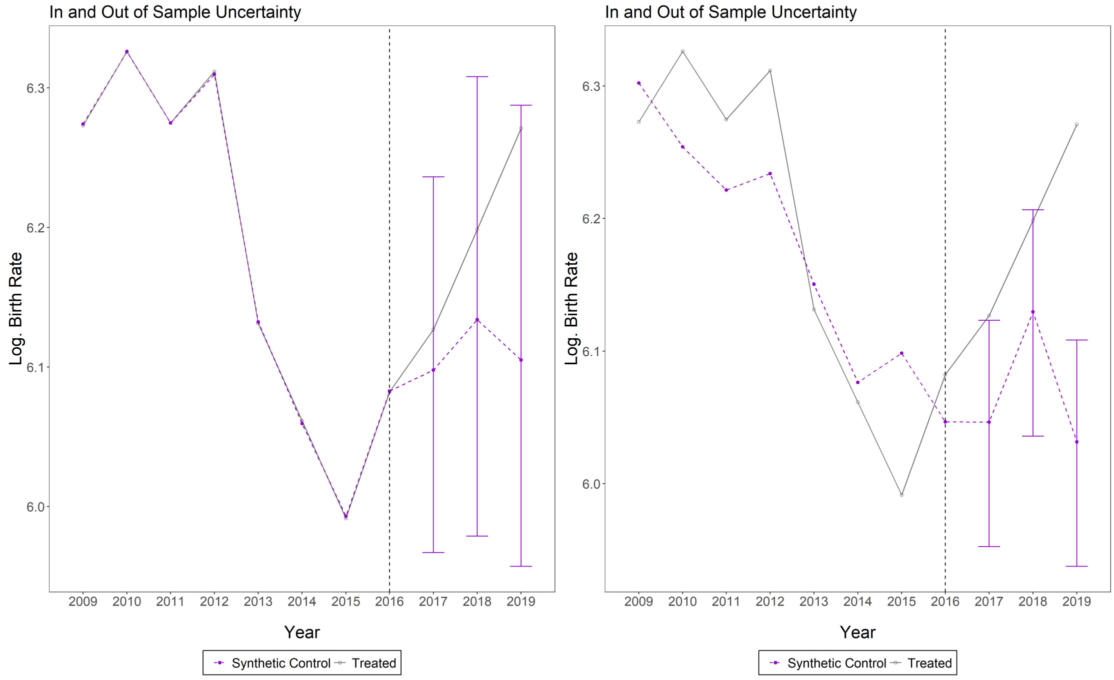


Figure 31: Birth rate, DPs 2 & 3



6 Conclusions

In this paper, we provide empirical evidence on the impacts of the Fruta del Norte project, a large-scale mining project in the Ecuadorian Amazon region, on several socioeconomic indicators at the canton level. Overall, our results suggest that Fruta del Norte had a positive impact by leveraging local economic activity in the Yantzaza canton. This dynamism led to increases in local economic dynamism and employment. In parallel, the project appears to have driven some increases in the rates of school dropout and teen pregnancy, which we hypothesize result from teens joining the labor force and forming families.

One key policy lesson our research highlights is that investments in large-scale mining projects might need to be accompanied by a portfolio of government-led public policies to mitigate some of the negative social externalities such projects can generate. The big investments that large-scale mining projects make have impacts on local economic dynamics and redefine incentives for the labor force participation of youth. Because youth anticipate that they can gain more, by using their time to work instead of staying in school, the governments must set policies based on the incentive structure that underlies the labor supply decision of those youth. For instance, there is ample ground for designing and implementing cost-effective youth work programs to foster the acquisition of human capital for those youth while "on the job." Thinking creatively about public-private partnerships to design and implement programs tailored to the mining industry's needs for human talent might enable the local population to maximize their productive enjoyment of the economic benefits of large-scale mining in Ecuador.

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Appendix

Weight matrices, DP 1

- Business income:

DP 1: 88 cantons
Active donors: 9 cantons

Cantonal codes	**Weights**
1116	0.006
1213	0.009
1503	0.027
1509	0.013
1602	0.228
1701	0.025
2102	0.29
2401	0.096
406	0.306

- Costs and expenses of companies:

DP 1: 88 cantons
Active donors: 6 cantons

Cantonal codes	Weights
1113	0.069
1604	0.088
1701	0.167
2102	0.384
307	0.024
608	0.268

- Formal employment:

DP 1: 88 cantons
Active donors: 21 cantons

Cantonal codes	Weights
1110	0.022
1111	0.057
1206	0.018
1210	0.064
1211	0.104
1301	0.003
1701	0.025
1802	0.007
1803	0.025
1806	0.088
1807	0.008
1808	0.058
1809	0.123
2002	0.045
2105	0.01
2201	0.001
2302	0.163
2401	0.016
303	0.067
304	0.066
610	0.028

- Preschool:

DP 1: 88 cantons
Active donors: 24 cantons

Cantonal codes	Weights
1209	0.011
1213	0.003
1301	0.022
1507	0.047
1601	0.02
1602	0.001
1701	0.01
1901	0.415
2003	0.004
2103	0.027
2105	0.001
2106	0.09
2203	0.008
302	0.001
303	0.008
306	0.06
401	0.038
402	0.066
404	0.001
405	0.05
406	0.005
606	0.001
607	0.03
609	0.082

- Elementary school:

DP 1: 88 cantons
Active donors: 8 cantons

Cantonal codes	Weights
1116	0.001
1201	0.033
1806	0.038
2202	0.117
2301	0.018
2302	0.585
307	0.159
403	0.049

- High school:

DP 1: 88 cantons **Active donors:** 25 cantons	
Cantonal codes	**Weights**
1105	0.006
1110	0.011
1112	0.003
1201	0.18
1204	0.002
1209	0.002
1211	0.002
1601	0.133
1701	0.044
1901	0.017
2107	0.132
2202	0.074
2204	0.012
2402	0.001
303	0.043
305	0.004
307	0.029
403	0.101
404	0.002
602	0.001
603	0.046
605	0.079
606	0.001
609	0.065
610	0.009

- Mortality rate:

DP 1: 88 cantons
Active donors: 18 cantons

Cantonal codes	Weights
1105	0.073
1112	0.041
1209	0.003
1503	0.014
1507	0.083
1602	0.022
1603	0.071
1604	0.12
1701	0.163
1804	0.02
1805	0.026
2103	0.151
2202	0.084
2302	0.035
2403	0.003
305	0.023
406	0.068
609	0.001

- Neonatal mortality rate:

DP 1: 88 cantons
Active donors: 6 cantons

Cantonal codes	Weights
1807	0.35
2105	0.113
302	0.162
305	0.095
405	0.169
610	0.111

- Teenage pregnancy rate:

DP 1: 88 cantons
Active donors: 18 cantons

Cantonal codes	Weights
1105	0.057
1106	0.045
1107	0.097
1108	0.028
1111	0.028
1212	0.032
1301	0.045
1701	0.155
1804	0.006
1805	0.227
2105	0.038
2201	0.022
2203	0.026
2302	0.027
602	0.004
608	0.071
609	0.016
610	0.076

- Medically assisted births:

DP 1: 88 cantons
Active donors: 9 cantons

Cantonal codes	Weights
1202	0.237
1212	0.02
1901	0.11
2105	0.217
2204	0.016
2401	0.07
2402	0.205
302	0.095
608	0.03

- Birth rate:

DP 1: 88 cantons
Active donors: 13 cantons

Cantonal codes	Weights
1110	0.068
1114	0.053
1115	0.147
1206	0.01
1209	0.016
1212	0.007
1301	0.002
1604	0.202
1701	0.151
2002	0.003
2105	0.098
602	0.166
606	0.077