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ENERGY PRODUCTION AND HEALTH EXTERNALITIES: EVIDENCE FROM OIL REFINERY STRIKES IN FRANCE

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ABSTRACT

This paper examines the effect of energy production on newborn health using a recent strike that affected oil refineries in France as a natural experiment. First, we show that the temporary reduction in refining lead to a significant reduction in sulfur dioxide (SO2) concentrations. Second, this shock significantly increased birth weight and gestational age of newborns, particularly for those exposed to the strike during the third trimester of pregnancy. Back-of-the-envelope calculations suggest that a 1 unit decline in SO2 leads to a 196 million euro increase in lifetime earnings per birth cohort. This externality from oil refineries should be an important part of policy discussions surrounding the production of energy.

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1. Introduction

Meeting the continued increased demand for energy is a major issue faced by nearly all countries. While there is much interest in developing renewable sources of energy, oil remains the predominant source given its relative price. Its portability also makes it particularly attractive for mobile sources, suggesting a reprieve in energy demand is unlikely in light of the tremendous growth in automobile ownership and travel throughout the world.

Despite the price advantage of oil, its production poses a health risk. The point source emissions include several pollutants linked with numerous health impacts, most notably sulfur dioxide (SO_2). In some countries, such as France, nearly 20 percent of ambient SO_2 emissions come from oil production (Soleille, 2004). Evidence links SO_2 with a wide range of respiratory effects, and as such is regulated under environmental policies throughout the world. The optimal design of energy policy must consider this production externality when comparing its full costs to those from renewable energy production.

In this paper, we estimate the health effects from oil production by exploiting the pension reform strikes in France in October, 2010 that lead to a major disruption in the production of oil. These strikes provide an ideal natural experiment for overcoming the typical biases that arise when estimating the health effects of pollution. Amid nationwide protests over pension reform that involved raising the retirement age, striking workers blocked fuel supplies to oil refineries, which resulted in a complete cessation of operations at several major refineries for nearly a month. As Figure 1 demonstrates, this lead to a sharp reduction in SO_2 in areas close to the refineries when the strike began, that quickly dissipated once the strike was resolved and production resumed, while areas far from the refineries experienced no change in SO_2 levels. We exploit this temporal event by estimating difference-in-differences models, using areas far from the refineries as a control group. We focus on the health of newborns as the outcome of interest, both because this is a particularly sensitive group with much policy interest and because birth outcomes are strong predictors of a wide range of future outcomes (Black et al., 2007; Currie, 2009).[3]

While this is not the first pollution-health study to use the closing of an industrial process or other exogenous event as a natural experiment[4], there are several important features of our design that make this an important contribution, mostly centered on parameter identification. First, a common concern in such analyses is that individuals sort into residential locations based, in part, on the amount of air pollution and the employment opportunities in the area, making pollution exposure an endogenous variable.[5] A permanent change in pollution levels can lead to a temporary disequilibrium in the housing market whereby there is no sorting at the time the shock occurs, but sorting is likely to resume as time from the shock passes. If the "post-shock" period includes a long enough time period, then sorting, and hence the endogeneity of pollution, remains a potential concern. In our case, the closure of the refineries was a temporary event – lasting approximately one month – making it unlikely that households relocated in search of new employment opportunities or because of preferences for air quality.

Second, seemingly exogenous events, such as a strike, may lead to unobserved behavioral changes in the treatment group that affect health, potentially invalidating the research design. Two features make this unlikely in our setting. One, although the variation in pollution is due to

[3] As noted in Joyce et al. (1988) and Chay and Greenstone (2003), focusing on infants also offers a methodological benefit because cumulative exposure can be readily assigned, circumventing issues around mobility and prior exposure.
[4] While there are a wide range of studies on this topic using quasi-experimental techniques (see the review in Graff Zivin and Neidell, 2013), the most closely related are Ransom and Pope (1995), Hanna Oliva (2011), and Currie et al. (2012), who all focus on the closing of industrial processes.
[5] The link between employment opportunities and pollution endogeneity arises because industry creates both jobs and pollution.

the closure of refineries at specific locations, the strike that caused this was a nationwide one centered on pension reforms, with the oil refineries an "unlucky recipient" of the protests. Therefore, any common responses to the strike are accounted for by including a control group. For example, changes in time allocation or activity choice because of the strike affected not only refinery workers but nearly all workers throughout the country.[6] Two, France has universal health coverage independent of employment status, so the strike did not result in a change in health insurance status. Therefore, the use of prenatal care, an important predictor of infant health (Currie and Gruber, 1996; Hanratty, 1996; Chou et al., 2011), would not have differentially changed for pregnant mothers in the treatment group during the strike, further reducing the scope for omitted variable bias.

Third, studies that examine the effect of prenatal insults often seek to uncover the distinct effects from different stages of the pregnancy in order to encourage the optimal use of prenatal care. In particular, shocks that occur early in pregnancy, specifically for women who are not yet aware they are pregnant, may leave little opportunity to engage in health-promoting behaviors (Almond and Currie, 2011). In the case of pollution, relatively simple behaviors, such as altering the amount of time spent outside, can yield significant improvements in health (Neidell, 2009).[7] Reliably estimating the separate contribution from each trimester is complicated by the fact that pollution levels are often highly correlated across the three trimesters of pregnancy, resulting in severe multicollinearity. Because the strike led to a sharp decrease in pollution for roughly one month, upon which it returned to baseline levels almost immediately after, our research design

[6] Note that this strategy does not account for avoidance behavior, i.e., changes in time allocation in direct response to the changes in pollution (Neidell, 2009). This does not introduce a bias *per se* but changes the interpretation of estimates, so that our estimates reflect the effect of the strikes net of avoidance behavior. See Graff Zivin and Neidell (2013) for more details.
[7] For example, air quality alerts, which seek to warn the public of dangerous air quality levels, are particularly targeted at pregnant women.

allows us to overcome this multicollinearity concern to more precisely investigate the separate effects by trimester.

Lastly, the handful of quasi-experimental economic studies examining the impact of emissions from energy sources typically focus on the consumption of energy (Currie and Walker, 2011; Beatty and Shimshack, 2011; Moretti and Neidell, 2011; Schlenker and Walker, 2011). While this consumption side represents an important externality, the production externality is empirically distinct, but has received limited attention.[8] More reliable estimates of the health impacts from energy production are an important component in the development of policies surrounding energy production (Parry and Small, 2005) and the siting of industrial plants.

Using this natural experiment, we first demonstrate that although SO_2 is considerably higher in areas close to the refineries, it falls significantly during the strike compared to areas far from the refineries, with regression results supporting the pattern in Figure 1. We find no evidence of changes in two other pollutants, particulate matter and nitrogen dioxide, around the time of the strike, a finding consistent with the change in SO_2 coming from the oil refineries. Turning to health outcomes, we find that birth weight and gestational age of newborns living in the same census tracts as the refineries increased by over 3 and 1.5 percent, respectively, during the strike. Nearly all of the improvement in weight gain can be attributed to the increase in gestation. Furthermore, these effects are primarily driven by exposure during the third trimester of pregnancy, a time when most fetal weight gain occurs. Overall, our estimates suggest that the effects from oil production that accrue to newborns alone are quite sizeable and should be an important part of policy discussions surrounding the production of energy.

[8] Furthermore, the common pollutants from energy consumption are carbon monoxide and particulate matter.

2. Background: Refineries, Air pollution and Health

2.1. Pollution and the refinery closure

Refineries are responsible for 20 percent of SO_2 release in France (Soleille, 2004). Oil refineries convert crude oil to everyday product like gasoline, kerosene, liquefied petroleum. Crude oil contains relatively high quantity of sulfur, which leads to the creation of sulfur dioxide when crude oil is heated at the refinery to produce fuel. The refining process also releases a large number of chemicals such as benzene, chromium and sulfur acid into the atmosphere, which limits our ability to conduct a proper instrumental variable analysis.

France has 11 refineries that produce 89 million tons of petrol every year. The main 4 refining companies operating in France are Total, Shell, Esso and Ineos, located in the regions of Haute Normandie, Provence Alpes Côtes dAzur, Rhône-Alpes, Nord-Pas-de-Calais, Pays-de-la-Loire, Ile de France and Alsace. Total refineries are allowed to emit up to 3,500 tons of sulfur dioxide per year which corresponds to 9.6 tons a day.

Due to protests over pension reform, protesters successfully ceased production in October, 2010 by mass picketing and the creation of physical blockades around fuel depots. As a result, production was reduced to a minimum or completely ceased for nearly 18 days until the strike was resolved. Closing a refinery is a complex process that requires anywhere from 2 days to one week according to the size of the refinery, and a comparable time period to re-open. Thus, the reduction in SO_2 is likely strongest between mid October and the beginning of November. We focus on the 4 refineries that completely shut down as a result of the strike.[9]

2.2. Pollution and health

[9] These refineries are Donges, Feyzin, Gonfreville l'Orcher and Petite Couronne.

Sulfur dioxide (SO_2) is one of a group of highly reactive gasses known as oxides of sulfur (SOx). The largest sources of SO_2 emissions are from fossil fuel combustion at power plants and other industrial facilities (EPA 2011). SO_2 is a colorless gas with a very strong smell. In France, the threshold for SO_2, fixed by the European Act of 2002-13 related to air quality, is 132 parts per billion (ppb) per hour; violations occur when this standard is exceed more than 24 times a year. In comparison, the Clean Air Act in the United States set the one-hour SO_2 standard at 75 ppb, where a violation occurs if the 99th percentile of 1-hour daily maximum concentrations, averaged over 3 years, exceeds this value. This standard was recently strengthened in June 2010, suggesting the need for reliable estimates of the relationship between SO_2 and health.

Given the rapid stages of development that a fetus goes through in a short period of time, negative shocks can results in both immediate and latent effects (Almond and Currie, 2011). Pollution is one potential shock because it can impair the health of the mother, indirectly compromising fetus health, or cross the placenta, directly affecting the health of the fetus. Slama et al. (2008) describe more extensively possible biological mechanisms by which air pollutants may affect birth outcomes: SO_2, in particular, can harm the fetus by impacting blood viscosity and endothelial function. These changes can affect placental blood flow, transplacental oxygen and nutrient transport, all of which may affect fetal health.

Furthermore, while there is a growing consensus that prenatal exposure to pollution affects birth outcomes, there is little understanding about the most susceptible periods of prenatal exposure. While the fetus experiences important organ developments in the first trimester, suggesting a particularly vulnerable stage, the fetus also gains the most weight during the third trimester, suggesting another crucial stage. Evidence from the fetal origins hypothesis suggests that exposure to negative shocks during early pregnancy has no effects at birth but latent impacts later in life (Almond et al., 2009), while exposure during late pregnancy is more likely to affect birth outcomes (Stein et al. 2003; Schultz, 2010). Consistent with this, Deschenes et al. (2009) find that the sensitivity of birth weight to temperature is concentrated almost entirely in the second and third trimesters of the pregnancy.

Whether these same patterns hold for pollution is largely unknown. While not focused on SO_2 per se, several economic studies have found robust evidence that prenatal exposure to pollution affects infant health (Currie et al., 2009; Sanders and Stoecker, 2011; Currie and Walker, 2011). While most of these studies focus on the effect from exposure during the entire pregnancy, an important contribution of our study is the ability to precisely estimate the effects from exposure during each trimester. Furthermore, previous studies typically focus on pollution stemming from vehicular or industrial emissions, such as particulate matter and carbon monoxide, and our focus on oil refining is more relevant for SO_2.

3. Data and empirical strategy

3.1. Data sources

Health data are drawn from the French National Hospital Discharge Database (PMSI) from 2007 to 2011. The key variables for our analysis are the year and month of birth, the census tract of residence of the patient, and the birth weight and gestational age at birth. Panel A of table 1 shows the birth weight and the gestational age by month, year and census tract. We also consider low birth weight (<2500 grams) and short gestational age (<37 weeks) as two clinically relevant outcomes. We observe from table 1, panel A that the birth weight and gestational age are lower in census tracts with refineries (the treatment group) than in census tracts without refineries (the control group) for all periods of the study, hinting at potential effects from living near a refinery. Figure 2 shows the distribution of birth weight. Unlike the US, there is much less variation in birth weight in France, a finding consistent with universal access to health care.

Air quality is monitored throughout France by 38 approved air quality monitoring associations (AASQA). The French monitoring station system has approximately 700 measurement monitors equipped with automatic instruments. Figure 3 shows the location of monitoring stations, departmental boundaries (one of the three levels of government below the national level, between the region and the commune), and major cities throughout France. Not surprisingly, monitors are more highly clustered in major cities. The monitors also show broad coverage of the country, with nearly every department having at least one monitor.

We obtain daily measure of ambient air pollution concentrations in microgram per cubic meter ($\mu g/m^3$) for all air quality monitors in France for 2007-2010 from the Ministry for Ecology, sustainable development and spatial planning (ADEME) database. We also know the exact geographic location of each monitor. Since our main focus is on SO_2, we only include monitors that continuously measured SO_2 during this time period. This leaves us with 187 monitors that span 57 departments and 2864 census tracts. Monthly pollution concentration data are presented in Panel B of Table 1. The most notable aspect of this panel is that SO_2 levels are nearly 4 times higher in areas near the refinery, while the levels are virtually identical for PM10, NO_2 and slightly higher for benzene.[10]

We also present the fraction of days in which the values recorded at the monitors exceeded health standards for SO_2 and PM_{10}.[11] While the number of exceedances is quite low for

[10] Note that we dropped one inexplicably high measure of benzene (18.44) in order to make the scale of Figure 5 (below) easier to interpret. This measure occurred in a treated census tract on September 25, 2011, so including it would further reinforce the idea that the refineries may affect benzene levels as well.
[11] There is no 24 hour air quality standard for benzene and NO_2. Although there is an hourly standard for NO_2, we were only able to obtain daily data.

SO_2 (occurring less than 1% of the time), census tracts with refineries are nearly 10 times more likely to have a violating monitor, consistent with higher SO_2 levels. The rate of exceedances for particulates is much higher on average, occurring nearly 5% of the time, though the rate of violations is quite similar across areas.

Since weather has direct effects on health and also affects pollution formation, we also include meteorological data in our analysis. Our weather data come from Meteo France, the French national meteorological service. There are 100 monitors, one in each department. We also have daily measures at each monitor, along with data on the geographic location. We use average and maximum temperature, precipitation, maximum speed wind, prevailing wind direction, and maximum and minimum relative humidity. Summary statistics for daily and monthly measures of weather are presented in Panel C of Table 1.

Although we include census tract fixed effects in our regression, which controls for all time invariant characteristics, we also include one measure of economic well-being to capture time varying factors: the unemployment rate. We use the quarterly rate of unemployment from the National Institute of Statistics and Economic Studies, which is available at the census tract level. Panel D of Table 1 also presents summary statistics for this variable.

3.2 Merged data

Using the exact location of pollution and meteorology monitors and the census tract of residence for the birth outcomes, we assign pollution to census tracts in a two-step procedure. When a census tract has a pollution monitor in it, we assign that pollution concentration to the census tract. When it does not, we assign pollution using an inverse distance weighted average (IDWA) of pollution, similar to Currie and Neidell (2005). To do this, we compute the centroid of each census tract, and then compute the distance from the centroid to each monitor within the department. We then take the weighted average of pollution measurements from all monitors within a certain distance from the census tract centroid, using the inverse of the distance as weights. We vary the cutoff distance to assess the sensitivity of our results to our assignment of pollution.

Although we have a daily measure of pollution and meteorology, health outcomes are only observed at a monthly level. We begin by aggregating pollution and meteorology at a monthly level. Since we only know the month of discharge for newborns, and their average length of stay in the hospital is 5.5 days, we must approximate their date of birth, and thus exposure to the strike. We assume all births occurred on the 1^{st} day of the month, and assign pollution and meteorology from the previous 9 months (we also assess the sensitivity of results by assuming the 15^{th} of the month). For example, an infant discharged in November is born anywhere from October 25^{th} to November 25^{th}, and we assume the birth date is November 1. We then assign exposure to this infant as the mean for the months from February through October, breaking it into 3 month intervals for examining trimester effects.

3.3 Empirical Methodology

Our goal is to assess the impact of oil production on both pollution levels and health outcomes at birth. We estimate difference in difference models to exploit the unexpected shutdown in production as a result of the strike in October 2010, using areas close to the refineries as the treatment group and areas far from the refineries as the control group. We implement this by estimating the following equation:

(1) $$Y_{cm} = \beta * strike_m * close_c + \delta * X_{cm} + \sigma_m + \alpha_c + \varepsilon_{cm}$$

where Y is either ambient pollution concentrations or birth outcomes in census tract c at month m. '*strike*' is an indicator variable for the October 2010 period when the strike occurred, and '*close*' is an indicator variable for whether the refinery is in the same census tract as the air pollution monitor or patient's residence. β is the difference-in-difference parameter. X_{cm} is a vector of census tract controls that include weather controls and the quarterly unemployment rate. We control for seasonal and temporal patterns by including month dummies and year dummies in σ_m. We include census tract fixed effects (α_c) to control for time-invariant characteristics of the census tract. ε_{cm} represents the error term, which consists of an idiosynchratic component and a term clustered on the department and month.

As with any difference in difference design, the key underlying assumption for identification is that the control group serves as a valid counterfactual for the treatment group with parallel trends. Although we can not explicitly verify this assumption, we feel this threat is limited in this setting for several reasons. Because the strike was nationwide, and not just for the workers at oil refineries, any changes in response to the strike likely happened on a global scale that would have affected both the treatment and control groups. Moreover, the strike was a temporary condition, making it unlikely that workers relocated in search of new employment opportunities. Furthermore, because workers in France have health insurance regardless of employment status, there was unlikely to be a change in prenatal care consumption during the time of the strike.

Figure 4 provides evidence to support the parallel trends assumption. Since there is little economic data available at such high temporal and spatial resolution, we plot the unemployment rate, which is available quarterly at the census tract, over time for the treatment and control groups. Although the unemployment rate is lower in census blocks with refineries, there is no trend difference between census blocks with refineries and their counterparts, supporting our contention that there are no differential trends across the two groups.

4. Results

4.1 Refinery closures and pollution levels

We start by examining the effect of strikes on air pollution. The previously mentioned Figure 1 provides a daily graph of adjusted SO_2 pollution from September to December, 2010 for the treatment and control groups, with SO_2 adjusted by X_{cm} and σ_m. Prior to the strike, SO_2 levels are considerably higher in census tracts with refineries. However, during the strike, SO_2 dramatically falls in refinery areas to levels comparable to non-refinery areas. Immediately after the strike, SO_2 levels in refinery areas again exceed those of non-refinery areas. This visual display clearly demonstrates a strong, temporal effect of the strike on SO_2 levels.

Table 2 provides regression estimates of (1), which are largely analogous to this Figure. In order to gauge the extent of confounding, we successively add more time-varying controls, namely the weather variables and the unemployment rate. Consistent with Figure 1, the strike causes a statistically significant drop in SO_2 levels for areas close to refineries. SO_2 levels drop during the strike by roughly 15 $\mu g/m^3$. Adding controls for weather (column 2) and unemployment (column 3) has no noticeable effect on our estimates.

The second and third panels explore the effect from different approaches for assigning pollution from monitors to census tracts. Limiting the sample to census tracts within 8 km of a monitor, shown in panel 2, leads to a slight increase in the effect of the strike on SO_2 levels. We see a much bigger increase, though still not a statistically significant difference, when we limit to census tracts with 2 km of a monitor. This increase is consistent with a more precise measure of pollution from using a closer monitor. Overall, the results from Table 2, supporting the findings from Figure 1.

Figure 5 presents the same plot as Figure 1 for three additional pollutants: NO_2, PM_{10}, and benzene. While NO_2 and PM_{10} do not appear to change in response to the strike, Benzene shows a pattern consistent with being affected by the strike, though less stark than that for SO_2. While these patterns suggest SO_2 is the pollutant most affected by the strike, the possible relationship for other pollutants precludes us from conducting a proper instrumental variable (IV) analysis where we instrument SO_2 levels using the strike, though we cautiously provide IV estimates.

4.2. Refinery closures and birth outcomes

Given that we have found a relationship between the oil refinery strikes and pollution levels, we now turn our attention to the impacts of the strikes on health at birth. Tables 3 and 4 present results of the impact of exposure to the strikes anytime during pregnancy on birth weight and gestation, respectively. The top panel explores the effect on birth weight using the continuous measure and the low birth weight indicator, whereas the bottom focuses on gestational age and short gestation. Within each of the 4 dependent variables, we also explore sensitivity to controls as with the SO_2 results, as well as sensitivity to monitor-census tract distance assumptions.

For birth weight, we find that birth weight increases by roughly 75 grams during the strike. This result is also insensitive to the addition of weather variables and unemployment. Compared to the mean birth weight of 3228 grams, this represents a 2.3 percent increase in birth weight. If we assume that the only pollutant affected by the refinery is SO_2, we can compute the effect of SO_2 on birth weight by dividing the effect of the strike on birth weight by the effect of the strike on SO_2 as shown in Table 2, akin to instrumental variables (IV). This procedure suggests that a 1 $\mu g/m^3$ decrease of SO_2 for one month increases birth weight by 5 grams, though we must interpret this with caution because, as noted above, the refineries may have affected other pollutants, such as benzene, which would make IV valid.

Using an indicator for low birth weight, we find that the strike lowered this rate by roughly 2 percentage points, which is also statistically significant and robust to additional controls. When we limit the distance from pollution monitor to the census tract to 8 km, our estimates change minimally, as with the SO_2 results. Limiting to 2 km leads to a larger improvement in birth weight, though the difference is again not statistically significant.

For gestational age, we find similar qualitative results. Using all census tracts, regardless of distance to a pollution monitor, we find the strike increased gestational age by roughly 0.37 weeks, or 2.5 days, which is a 1% change from the baseline mean. This yields an IV estimate of a 1 $\mu g/m^3$ decrease of SO_2 for one month increases gestational length by 0.18 days. The strike reduces the probability of short gestation by .08. These results are again insensitive to additional controls. While the results do not become larger when limiting to a shorter distance from the census tract to the pollution monitor, the differences are again not statistically significant.

To compare the estimates for birth weight and gestation, we perform the following calculation. Since the fetus gains about 200 grams in weight per week in the final month of pregnancy (Cunningham et al., 2010), the 0.37 week increase in gestation translates into an extra 74 grams in weight, which is nearly identical to our estimate on the impact on birth weight. Therefore, it appears that the reduction in birth weight is solely due to shorter gestation, rather than growth retardation.

Since the strike only lasted for less than one month, as previously mentioned one of the advantages of our study is the ability to more precisely isolate the effects by trimester. Table 5 presents results by including exposure to the strike by trimester. We focus solely on census tracts less than 8 km from a monitor and with the meteorological and economic covariates included, though results are robust to different assumptions regarding these choices.

We find that almost all of the effects from pollution are due to exposure during the third trimester. Birth weight increases by roughly 150 grams when the strike occurred during the third trimester, which represents a 4.6 percent increase. The effects from the first and, in particular, second trimesters are much smaller and not statistically significant. Turning to the incidence of low birth weight, we find reasonably similar effects across the trimesters, but the third is the largest (and comparable to the estimate for the overall pregnancy) and the only one that is statistically significant.

For gestational age, we also find that exposure to the strike in the third trimester has the biggest effect: it increases gestational age by roughly 0.85 weeks, a roughly 2.2 percent increase. This longer gestation translates into roughly 170 grams, which again explains all of the estimated effect on birth weight from third trimester exposure. The effects in the first and second trimester are again much smaller and not statistically significant. Turning to the incidence of short gestation, we again find the third trimester has the biggest effect, but the first and second also appear significantly related to short gestation.

As previously mentioned, we do not know the exact date of birth of the child, only the month of discharge from the hospital. In Table 6, we present results assuming the date of child's birth is on the 15th of the month instead of the 1st, again focusing solely on the census tracts within 8 km of a monitor. Our results from this specification are virtually identical to the main results, suggesting the lack of knowledge about the exact birth date is not hindering inference.

Since pollution and other environmental confounders often show strong seasonal patterns, we want to ensure that our results are not driven by this phenomenon. To assess this, we present estimates from a falsification test where we assign the date of the strike to have occurred on October, 2009, a year before the actual strike occurred. Shown in Table 7, we find that the placebo strike is neither associated with SO_2 levels or any of the birth outcome measures. Of the 17 coefficients shown, only 1 is statistically significant (at the 10% level), which is almost exactly what we expect given the chance of a Type I error.

5. Conclusion

The goal of this paper was to examine an externality from energy production, focusing on health impacts as measured by birth outcomes. To account for the endogeneity of pollution exposure, we exploit the oil refinery strike that occurred in October 2010, which led to a sharp, temporary reduction in SO_2 in areas close to the refineries. This reduction led to a robust increase in birth weight and gestation of infants, particularly those who were exposed during their third trimester of pregnancy.

To gauge the magnitude of these estimates, we perform the following illustrative calculations, similar to Currie et al. (2009). We value the improvements in birth weight by computing the percentage change in birth weight from the change in pollution in October, 2010 by dividing the estimated impact of third-trimester SO_2 on birth weight from Table 5 (140) by the mean birth weight in our sample (3220) from table 1. We multiply this by the estimated elasticity between birth weight and earnings of 0.1 from Black et al. (2007) to obtain the percentage change in earnings during the month of strikes. We then multiply this by the average gross annual earnings of all full time workers (33,168 euros) from the Directorate for Research, Studies, and Statistics in 2010 in France. Finally, we multiply by the total number of births in 2010 (832,799) to get the change in earnings per year. This gives an estimated increase in nationwide earnings of 120 million euros. Assuming a 40 year working career with 3 percent annual rise in earnings and a 6 percent discount rate, this amounts to 2.933 billion euros per cohort. If we attribute all of the estimated 15 unit decline in SO_2 to the strike, this implies that a 1 unit decrease in SO_2 increases future earnings of a given birth cohort by 196 million euros per year.[12] While only meant to be illustrative, these estimates suggest that the externalities from oil production that accrue to newborns alone are potentially quite sizeable and should be an important part of policy discussions surrounding the production of energy.

[12] Clearly, these estimates understate the full benefits from a decrease in SO_2 because they only capture the earnings impacts for a birth cohort and only capture the effects on births. A 3% (4%) discount rate would yield an earnings increase of 328 (272) million euros per 1 unit change in SO_2.

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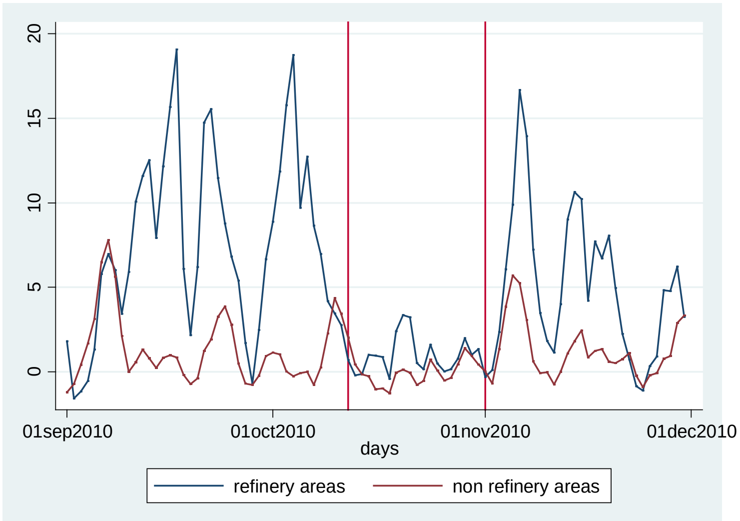
Figure 1: Adjusted SO_2 levels by proximity to refineries



Notes: SO_2 levels are adjusted by weather variables, the local unemployment rate, and month and year dummy variables. The red lines indicate the approximate dates of the strike. 'Refinery areas' are census tracts where refineries are located, and 'non refinery areas' are census tracts without refineries.

Figure 2: Birth weight distribution

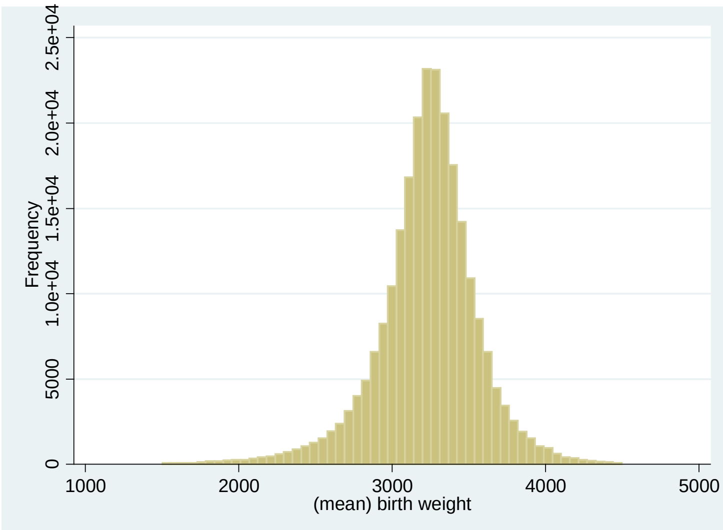


Figure 3: Air quality monitoring stations and department boundaries in France

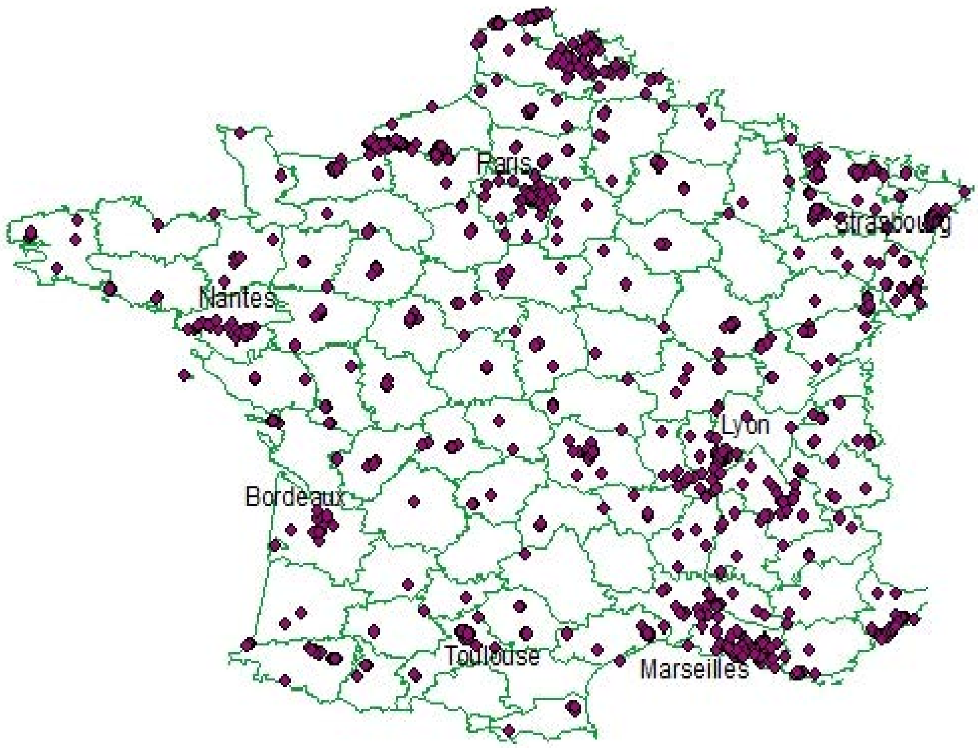
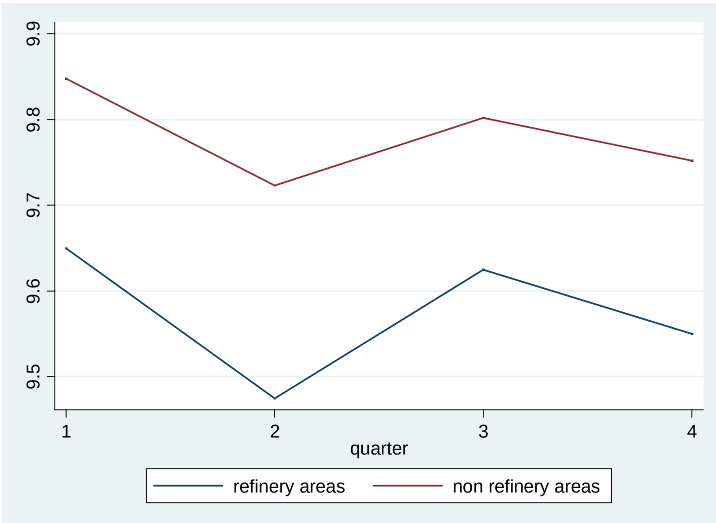
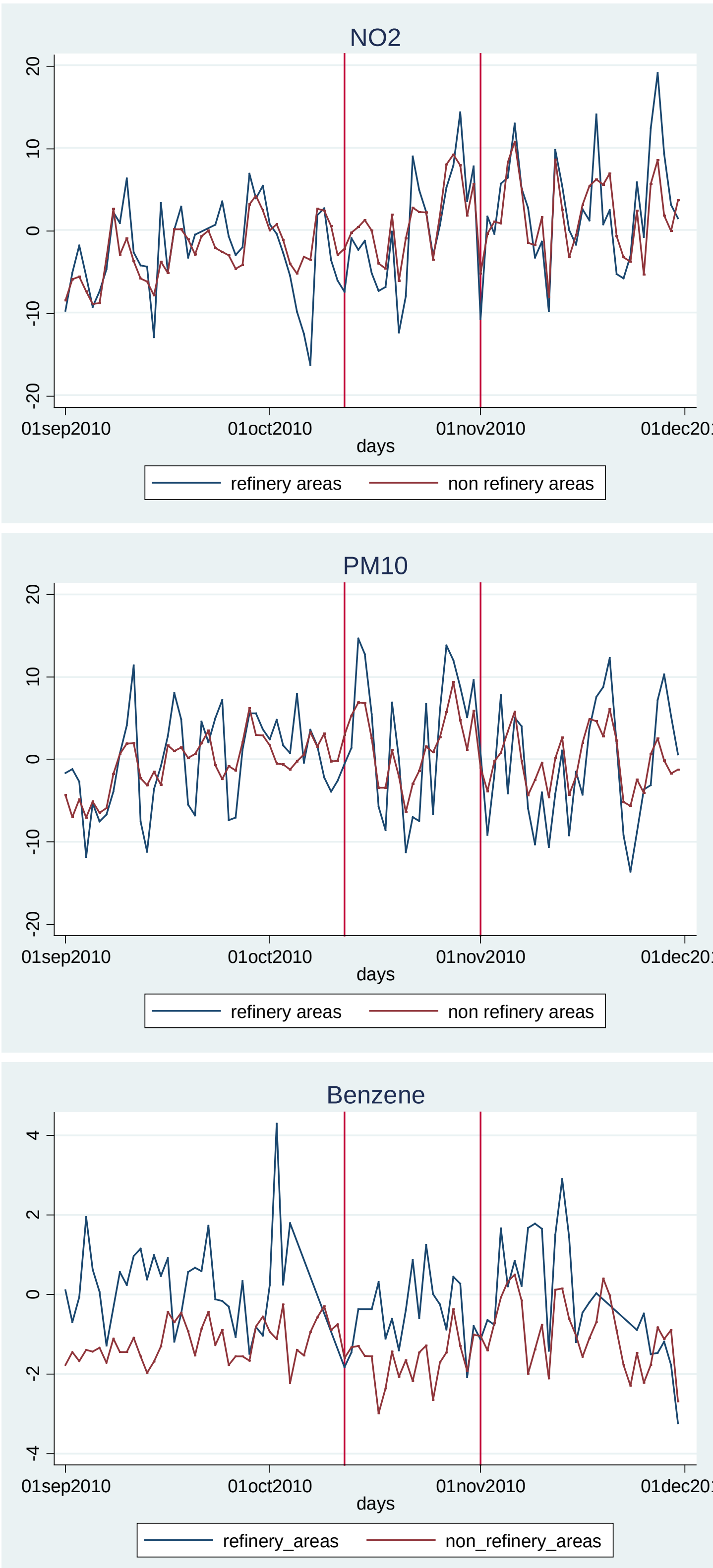


Figure 4: Unemployment distribution by proximity to refineries



Notes: Unemployment rates are available at the quarterly level for each census tract. 'Refinery areas' are census tracts where refineries are located, and 'non refinery areas' are census tracts without refineries.

Figure 5: Adjusted NO_2, PM_{10}, and Benzene by area



Notes: Pollution levels are adjusted by weather variables, the local unemployment rate, and month and year dummy variables. The red lines indicate the approximate dates of the strike.

Table 1. Summary statistics

	All	Treatment group (all time periods)	Control group (all time periods)
A. Outcomes			
birth weight (grams)	3228 [353]	3220 [272]	3228 [354]
birth weight < 2500 grams	.03 [.17]	.02 [.13]	.03 [.17]
gestational age (weeks)	38.86 [1.50]	38.78 [1.31]	38.86 [1.50]
gestational age < 37 weeks	.08 [.27]	.08 [.27]	.08 [.27]
B. Pollution			
SO_2 - monthly average ($\mu g/m^3$)	3.82 [4.53]	12.87 [10.86]	3.63 [4.10]
SO_2 - % days exceeding AQS	.15 [3.89]	1.284 [1.13]	.12 [.35]
NO_2 - monthly average ($\mu g/m^3$)	24.22 [14.81]	23.35 [12.27]	24.23 [14.83]
PM_{10} - monthly average ($\mu g/m^3$)	22.55 [7.45]	22.52 [6.76]	22.56 [7.45]
PM_{10} - % days exceeding AQS	4.55 [2.09]	5.85 [2.35]	4.47 [2.07]
Benzene - monthly average ($\mu g/m^3$)	1.86 [.80]	2.78 [.74]	1.54 [.25]
C. Covariates			
mean temperature (°C)	11.86 [5.91]	11.74 [5.65]	11.86 [5.92]
max. temperature(°C)	16.57 [6.76]	16.34 [6.55]	16.57 [6.76]
precipitation (mm)	2.19 [1.44]	2.28 [1.30]	2.19 [1.44]
wind speed (m/sec)	6.94 [1.45]	6.96 [.97]	6.95 [1.45]
wind direction (wind rose)	208.4 [40.4]	205.8 [38.1]	208.4 [40.4]
min. humidity (%)	55.07 [12.03]	56.32[12.50]	55.07 [12.03]
max. humidity (%)	92.7 [4.13]	93.19 [4.02]	92.6 [4.13]
unemployment rate (%)	8.71 [2.22]	8.50 [1.10]	8.71 [2.22]

Notes: Reported values are means with standard deviations in brackets. The number of observations is 151,624. Air quality standard (AQS) for SO_2 is 0.04 ppm (105 μg/m3) for every 24 hour period and for PM_{10} is 50 μg/m3 for every 24 hour period.

Table 2. The effect of the strike on SO_2 levels

	1	2	3
A. All census tracts			
strike	-15.24*	-15.30*	-15.27*
	(8.796)	(8.799)	(8.772)
Observations	151,624	151,624	151,624
R-squared	0.758	0.758	0.758
B. Census tracts < 8km from monitor			
strike	-16.48*	-17.06*	-16.63*
	(9.020)	(9.065)	(8.713)
Observations	16,945	16,945	16,945
R-squared	0.757	0.758	0.758
C. Census tracts < 2km from monitor			
strike	-26.49**	-28.86**	-25.22**
	(11.23)	(11.30)	(10.79)
Observations	5,652	5,652	5,652
R-squared	0.756	0.757	0.757
weather	n	y	y
local economic conditions	n	n	y

Note: This table provides the coefficient estimates of the effect of strike on Sulfur Dioxide (SO_2). All specifications include census tract fixed effects, year and month dummy variables, with standard errors clustered at the month and department level in parenthesis. The weather variables include average and maximum temperature, precipitation, minimum and maximum humidity, wind speed and direction. The unemployment rate is our measure of local economic conditions. Statistical significance is denoted by: *** p<0.01, ** p<0.05, * p<0.1 .

Table 3. The effect of the strike over the entire pregnancy on birth weight

	1	2	3	4	5	6
		birth weight (g)			birth weight < 2500 g	
A. All census tracts						
strike	73.61*	76.47*	76.44*	-0.020*	-0.021*	-0.021*
	(44.61)	(44.75)	(44.73)	(0.011)	(0.011)	(0.011)
Observations	121,157	121,157	121,157	121,157	121,157	121,157
R-squared	0.053	0.053	0.053	0.066	0.066	0.066
B. Census tracts <8km from a monitor						
strike	71.87	74.87*	74.03*	-0.019*	-0.020*	-0.019*
	(44.50)	(44.91)	(44.83)	(0.011)	(0.012)	(0.012)
Observations	14,169	14,169	14,169	14,169	14,169	14,169
R-squared	0.043	0.044	0.045	0.066	0.067	0.067
C. Census tracts <2km from a monitor						
strike	92.38*	99.43**	99.03**	-0.025*	-0.026*	-0.026*
	(47.21)	(48.41)	(48.41)	(0.014)	(0.014)	(0.014)
Observations	4,962	4,962	4,962	4,962	4,962	4,962
R-squared	0.055	0.059	0.060	0.049	0.054	0.054
weather	n	y	y	n	y	y
local economic conditions	n	n	y	n	n	y

Note: This table provides the coefficient estimates of the effect of exposure to the strike at any time during pregnancy on birth weight. All specifications include census tract fixed effects, year and month dummy variables, with standard errors clustered at the month and department level in parenthesis. Statistical significance is denoted by: *** p<0.01, ** p<0.05, * p<0.1.

Table 4. The effect of the strike over the entire pregnancy on gestation

	1	2	3	4	5	6
		gestation (wks)			gestation < 37 wks	
A. All census tracts						
strike	0.361*	0.382*	0.383*	-0.091***	-0.094***	-0.094***
	(0.194)	(0.196)	(0.195)	(0.029)	(0.029)	(0.029)
Observations	90,134	90,134	90,134	90,134	90,134	90,134
R-squared	0.071	0.071	0.071	0.075	0.075	0.075
B. Census tracts <8km from a monitor						
strike	0.366*	0.373*	0.373*	-0.088***	-0.087***	-0.087***
	(0.196)	(0.197)	(0.197)	(0.030)	(0.030)	(0.030)
Observations	10,761	10,761	10,761	10,761	10,761	10,761
R-squared	0.081	0.083	0.083	0.087	0.089	0.089
C. Census tracts <2km from a monitor						
strike	0.375	0.407*	0.400*	-0.062*	-0.066*	-0.065*
	(0.243)	(0.242)	(0.241)	(0.037)	(0.036)	(0.036)
Observations	3,849	3,849	3,849	3,849	3,849	3,849
R-squared	0.111	0.120	0.120	0.111	0.121	0.121
weather	n	y	y	n	y	y
local economic conditions	n	n	y	n	n	y

Note: This table provides the coefficient estimates of the effect of exposure to the strike at any time during pregnancy on gestation. All specifications include census tract fixed effects, year and month dummy variables, with standard errors clustered at the month and department level in parenthesis. Statistical significance is denoted by: *** p<0.01, ** p<0.05, * p<0.1.

Table 5. The effect of the strike on birth weight and gestational age by trimester of pregnancy, census tracts within 8 km of pollution monitor

	1 birth weight (g)	2 birth weight < 2500 g	3 gestation (wks)	4 gestation < 37 wks
strike - 3rd trimester	151.2***	-0.024**	0.847***	-0.110***
	(50.15)	(0.012)	(0.226)	(0.031)
strike - 2nd trimester	10.63	-0.019	0.133	-0.082***
	(66.14)	(0.012)	(0.300)	(0.030)
strike - 1st trimester	60.02	-0.015	0.138	-0.069**
	(78.78)	(0.012)	(0.250)	(0.033)
Observations	14,169	14,169	10,761	10,761
R-squared	0.045	0.067	0.083	0.089
weather	n	y	y	n
local economic conditions	n	n	y	n

Note: This table provides the coefficient estimates of the effect of strike on birth weight and gestation by trimester of pregnancy when the distance from the census tract to the pollution monitor is less than eight kilometers. All specifications include census tract fixed effects, year and month dummy variables, with standard errors clustered at the month and department level in parenthesis. Statistical significance is denoted by: *** p<0.01, ** p<0.05, * p<0.1.

Table 6. Estimates using alternative measure of strike exposure, census tracts within 8 km of pollution monitor

	1 birth weight (g)	2 birth weight < 2500 g	3 gestation (wks)	4 gestation < 37 wks
A. Entire pregnancy				
strike	73.50	-0.0193*	0.347*	-0.0839***
	(44.83)	(0.0114)	(0.198)	(0.0298)
Observations	14,169	14,169	10,769	10,769
R-squared	0.045	0.067	0.083	0.089
B. By trimester				
strike - 3rd trimester	148.1***	-0.0224*	0.815***	-0.106***
	(49.92)	(0.0118)	(0.225)	(0.0306)
strike - 2nd trimester	8.323	-0.0184	0.110	-0.0810***
	(66.62)	(0.0121)	(0.307)	(0.0298)
strike - 1st trimester	63.69	-0.0171	0.111	-0.0643*
	(79.75)	(0.0121)	(0.249)	(0.0336)
Observations	14,169	14,169	10,769	10,769
R-squared	0.045	0.067	0.083	0.089

Note: This table provides the coefficient estimates of the effect of strike on birth weight and gestation assuming all births occurred on the 15th of the month (as opposed to 1st). All specifications include census tract fixed effects, year and month dummy variables, weather, and local economic conditions, with standard errors clustered at the month and department level in parenthesis. Statistical significance is denoted by: *** p<0.01, ** p<0.05, * p<0.1.

Table 7. Effect of placebo strike in October, 2009, census tracts within 8 km of pollution monitor

	1 SO_2	2 birth weight (g)	3 birth weight < 2500 g	4 gestation (wks)	5 gestation < 37 wks
A. Entire pregnancy					
strike	0.112	44.02	0.023	-0.149	0.050
	(1.608)	(68.54)	(0.038)	(0.379)	(0.071)
Observations	16,945	14,169	14,169	10,761	10,761
R-squared	0.619	0.045	0.067	0.083	0.089
B. By trimester					
strike - 3rd trimester		69.28	-0.013	0.044	0.040
		(95.03)	(0.009)	(0.350)	(0.115)
strike - 2nd trimester		65.82	-0.018*	0.186	0.049
		(96.34)	(0.010)	(0.437)	(0.112)
strike - 1st trimester		-3.07	0.101	-0.676	0.060
		(151.70)	(0.107)	(0.903)	(0.113)
Observations		14,169	14,169	10,761	10,761
R-squared		0.045	0.068	0.083	0.089

Note: This table provides the coefficient estimates of the effect of a placebo strike occurring October, 2009 on SO_2, birth weight and gestation. All specifications include census tract fixed effects, year and month dummy variables, weather, and local economic conditions, with standard errors clustered at the month and department level in parenthesis. Statistical significance is denoted by: *** p<0.01, ** p<0.05, * p<0.1.