Seasonality in Birth Defects, Agricultural Production and Urban Location

by

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Abstract

This paper tests whether the strength of the so-called "spring spike" in birth defects is related to agricultural production and urban location using Texas Birth Defects Registry data for the period 1996-2007. We find evidence of a spike in birth defects among children conceived in the spring and summer, but it is more pronounced in urban non-agricultural counties than in other types of counties. Furthermore, the spike lasts longer in urban non-agricultural counties as compared to other types of counties.

1. Introduction

Pesticide use by farmers is highest after planting, which typically occurs early in the growing season (Kellog et al., 2002). As a consequence, pesticide residues in surface and ground water are highest during the spring and the first months of summer (Winchester et al., 2009).

A number of researchers have hypothesized that this seasonal variation in pesticide contamination is linked in a causal sense to certain types of birth defects. Consistent with this hypothesis, Winchester et al. (2009) found that children conceived in the months of April through July were more likely to be born with birth defects such as cleft lip, clubfoot, and Down Syndrome than children conceived in other months; using data from Minnesota birth certificates, Garry et al. (1996) found a so-called "spring spike" in birth defects in regions where wheat was the predominant crop and the use of chlorophenoxy herbicides was common.

The current study tests whether the magnitude of the spring spike in birth defects is related to levels of agricultural production in Texas. Based on the results of Winchester et al. (2009) and Garry et al. (1996), we hypothesize that, all else equal, the spring spike in birth defects will be most pronounced in counties with the highest levels of agricultural production. Because farms are common in many urban counties of Texas (Langlois et al., 2010), we are able to jointly take into account the influences of both urbanization and agricultural production.

Our results provide evidence of a spike in birth defects among children conceived in the spring and summer, but it is more pronounced in urban non-agricultural counties than in other types of counties. Furthermore, the spike lasts into the fall in urban non-agricultural counties as compared to other types of counties. Because information on pesticide use by county in Texas is unavailable, our ability to explore the mechanisms at work is limited.

2. Data and definitions

2.1. Births and birth defects data

As noted above, the current study builds upon the work of Garry et al. (1996) and Winchester et al. (2009), who used birth certificate data available through the National Vital Statistics System (NVSS). One drawback to using birth certificate data is that there is no agreed-upon national standard for recording birth defects. In fact, despite the fact that not all congenital anomalies are apparent at birth (Stillerman et al., 2008) and are therefore not recorded on birth certificates (Watkins et al., 1996; DiGiuseppe et al., 2002), some states do not "actively assess birth defects up to the first year of life, which is the best method for fully ascertaining birth defects" (Stillerman et al. 2008, p. 632).

Our analysis draws on data from the Texas Birth Defects Registry (TBDR) data for the period 1996-2007.[1] The TBDR is an active birth defects surveillance system; its staff routinely reviews medical records from birth hospitals, referral hospitals and specialty clinics. All birth defects diagnosed prenatally or within the first year after delivery are entered into its web-based system which contains multiple human and computer checks to ensure that consistent surveillance procedures are followed throughout Texas (Sheu et al., 2011). Birth defects records from the TBDR were combined with Texas birth certificate data for the years 1996-2007. Crucially, these data include estimates of the month of conception for each birth, based on both the stated date of last menstrual period as well as the estimated gestational age at birth. These data also include the mother's county of residence at the time of delivery.

[1] Access to this data was granted after review by the IRB of the Texas Department of State Health Services.

2.2. Agricultural production data

Measures of agricultural production by county for the years 1995-2007 were obtained from the National Agricultural Statistics Service (NASS). Specifically, the NASS provided acres planted by county and year for the 6 major cash crops in Texas: cotton, corn, wheat sorghum, soybeans and rice. These, along with the total land area of each county, were merged with the birth certificate and birth defects data based on mother's county of residence at delivery.

2.3. Designation of agricultural vs. non-agricultural counties

Texas is composed of 254 counties. Counties were designated as agricultural if, on average, 9.8% of their total area was planted with cotton, corn, wheat, sorghum, soybeans or rice during the period under study. Eighty-nine Texas counties met this criterion, which is equivalent to being above the 65^{th} percentile of acres planted in these 6 crops. Eighty-nine counties were below the 35^{th} percentile of planted acres. That is, less than 1.2% of their total area was planted with the 6 major cash crops in Texas. These counties were designated as non-agricultural. Births to mothers from the 76 counties between the 35^{th} and 65^{th} percentile were dropped from the analysis, although their inclusion does not substantially alter the results reported below.

2.4. Designation of urban vs. non-urban counties

Counties were designated as urban if, based on 2003 Rural-Urban Continuum Codes, they belong to a metropolitan area of at least 1 million residents. One advantage of using the TBDR data is that Texas agricultural production is not highly correlated with urban/rural status (Langlois et al., 2010). As a consequence, comparing counties with high agricultural production

to those with low agricultural production does not simply reduce to a (potentially confounded) comparison of urban versus rural.

Of the 178 counties that contributed data to the analysis, 18 were designated as urban. Table 1 shows the relationship between this designation and the agricultural designation described above. Urban counties are evenly divided between agricultural and non-agricultural counties, as are non-urban counties. To be clear, the same threshold (greater than 9.8% of acres planted on average each year) was used to determine agricultural counties in both urban and non-urban settings. Non-agricultural urban counties averaged 10.4 births per 100 acres for the period 1996-2007, while agricultural urban counties averaged 7.8 births per 100 acres.

2.5. Descriptive statistics

Figure 1 plots the birth defects per 1000 births by month of conception for the entire state of Texas. We observe an increase in birth defects between April and May, with a peak in June. The birth defect rate remains elevated through August, and then declines. The magnitude of this spike is similar to that documented for the entire country by Winchester et al. (2009), as is its timing. While this is typically referred to as a "spring spike," it could more appropriately be called a "spring spike that lasts through the summer."[2]

Figure 2 plots birth defects per 1000 births separately for agricultural and non-agricultural counties. The birth defect rate is clearly higher in agricultural counties than non-agricultural counties. The spring spike, however, appears to be more pronounced in non-agricultural counties.

[2] The terminology in part is due to the fact that some studies have used data of last menstrual period (LMP), as opposed to date of conception, which occurs about 2 weeks later. These studies find a spike that runs April-July rather than May through August (e.g., Winchester et al., 2009).

In Table 2, we present means for the full sample and by the agricultural designation. Again, birth defect rates are highest in agricultural counties. Although only 10 percent of the counties in the sample are urban, a little over half of the 2,209,303 births in the sample occurred in urban counties. Almost 33 percent of births to mothers living in agricultural counties are also classified as urban and almost 70 percent of births to mothers living in non-agricultural counties are classified as urban. Births in agricultural counties are less likely to be to black mothers, and more likely to be to white or Hispanic mothers, than those in non-agricultural counties.[3] Births in agricultural counties are also more likely to occur to mothers who have obtained at least some post-secondary education.

Table 2 shows that residents of agricultural counties differed, on average, from residents of non-agricultural counties in ways that could have affected birth outcomes. Our empirical analysis below focuses on whether the seasonal spike in defects is more pronounced in agricultural counties.

In Table 3, we report observation counts by birth defect classification. Of the 2,209,303 births in our sample, 79,594 are recorded as having at least one birth defect.[4] Counts are reported for the following categories of birth defects: circulatory defects, chromosomal defects, selected musculoskeletal defects (limb reduction defects, talipes equinovarus/clubfoot, diaphragmatic hernia, omphalocele, gastroschisis), selected central nervous system defects (anencephaly, spina bifida without anencephaly, hydrocephaly without spina bifida, microcephaly), selected urogenital defects (hypospadias, renal agenesis/dysgenesis), oral clefts, and selected digestive defects (tracheoesophageal fistula/esophageal atresia, stenosis or atresia of

[3] Our results are virtually unchanged if black mothers are excluded from the sample.

[4] The Texas Birth Defects Registry monitors all major structural and chromosomal defects and records the defects using modified British Pediatric Association (BPA) codes.

large intestine, rectum or anal canal). There were 32,914 births with at least one defect not belonging to one of the 6 categories listed above; 9.35% of the 79,594 cases with at least one birth defect had defects from multiple categories.

3. The statistical analysis

Our basic specification is:

(1) $$BD_{imtc} = \beta_o + \beta_1 Spring_m + \beta_2 Urban_c + X_i\beta_3 + Year_t\delta_t + \varepsilon_{imtc}$$

where *BD* is an indicator for whether child *i* conceived in month *m*, year *t*, and county *c* had a birth defect.[5] *Spring* is an indicator that equals one for children conceived in May through August. *Urban* is an indicator for whether the county is designated as urban. The vector X_i includes controls for sex of child, mother's age, mother's race/ethnicity, mother's education, plurality of the birth and parity of the birth.[6] *Year* is a vector of year fixed effects. Standard errors are corrected for clustering at the county level.

The first two columns of Table 4 report estimates of the spring spike from equation (1) separately for agricultural and non-agricultural counties. There is evidence of a spring spike in birth defects among children born to mothers who lived in agricultural counties. Specifically, the probability of a birth defect increased by 0.0013 if conception took place in months of May, June, July, or August. However, the spring spike is twice this size when the sample is restricted to mothers who lived in non-agricultural counties: the probability of a birth defect increased by

[5] We estimate linear probability models in all of our analysis. For all models, approximately 3.7% of the sample has predicted probabilities outside the 0-1 interval.

[6] More specifically, mother's age is controlled for with a set of indicators for ages 20-24, 25-29, 30-34, 35-39, and 40 or older (the omitted category is composed of birth to mothers under the age of 20); mother's race/ethnicity is controlled for by indicators for black non-Hispanic, Hispanic, other non-Hispanic (the omitted category is composed of births to white non-Hispanic mothers); mother's education is controlled for by indicators for high school degree and greater than a high school degreee (the omitted category is composed of births to mothers with less than a high school degree). The regression also includes indicator variables for parity (up to 4th or higher birth), plurality (up to 3 or more) and for whether the infant was male.

0.0026 if conception occurred in May, June, July, or August. To provide a sense of magnitude, we note that the birth defect rate was 0.0407 when the sample was restricted to children born to mothers living in agricultural counties and 0.0316 when the sample was restricted to children born to mothers living in non-agricultural areas.

Column 3 combines the first two columns into:

(2) $$BD_{imtc} = \beta_o + \beta_1 Spring_m + \beta_2 Agric_c + \beta_3 Spring_m * Agric_c + \beta_4 Urban_c + X_i\beta_5 + Year_t\delta_t + \varepsilon_{imtc}$$

In this specification, β_1 estimates the spring spike in non-agricultural counties, β_2 estimates the difference in birth defect rates between agricultural and non-agricultural areas for months other than May through August, and β_3 estimates the difference in the spring spike between agricultural and non-agricultural areas. The negative coefficient on *Spring*Agric* in column 3 indicates that the spring spike is smaller in agricultural areas than non-agricultural areas. The difference is significant at the 10 percent level (p-value = 0.057).

Finally, in column 4 of Table 4, county fixed effects are added to (2), which causes the indicators *Agric* and *Urban* to drop out of our model:

(3) $$BD_{imtc} = \beta_o + \beta_1 Spring_m + \beta_2 Spring_m * Agric_c + X_i\beta_5 + Year_t\delta_t + County_c\lambda_c + \varepsilon_{imtc}$$

The column 3 results are highly robust to the addition of county fixed effects.

Table 5 reports results separately by birth defect classification. Equation (3) is estimated replacing the birth defect indicator with indicators for each of the birth defect categories given in Table 3. For each of these categories, the sample is restricted to observations that reported a birth defect in that category or no birth defect. We find evidence of a spring spike for circulatory defects, selected defects of the central nervous system, selected urogenital defects, selected digestive defects, and defects not elsewhere classified. For five all of these categories, the coefficient on the *Spring*Agric* interaction is negative but statistically insignificant at

conventional levels. The point estimates provide suggestive evidence that the spring spike is smaller in agricultural counties than in non-agricultural counties, but the lack of statistical significance means we cannot formally reject the hypothesis that there is no difference in the spring spike between agricultural and non-agricultural areas.

3.1. Seasonal variation by urban vs. agricultural designation

A 1997 EPA report found that roughly 28% of annual pesticide use in the United States is by residential, commercial, industrial or public entities (Aspelin, 1997). A 1999 report on pesticide use in Texas cited this EPA report, but found that there was not sufficient reporting or monitoring of pesticide use in Texas to generate comparable statistics for the state (Texas Center for Policy Studies, 1999). The Texas report did, however, cite evidence that contamination from non-agricultural pesticide use was likely a concern. For example, the report stated:

> The widespread use of the insecticide diazinon on lawns and other urban settings has affected water quality in the Trinity River basin. Wastewater from a number of city sewage treatment plants…can fail monthly toxicity tests because diazinon has reached the system through runoff and is not removed by the treatment plant (p.17)

The report also highlighted the use of pesticides by the Texas Department of Transportation in right-of-way maintenance for state highways, as well as the use of aquatic herbicides by the Texas Parks and Wildflife department, lake managers, golf courses and individual homeowners as other areas for concern.

While we know that agricultural pesticide usage is highest at the beginning of the growing season and drops off considerably by mid-summer, it is not clear whether this is true for commercial/residential pesticide usage where aesthetic concerns, turf preservation and insect

control may result in continued applications into fall. It is difficult to obtain any information on pesticide applications by month and reason for application, and none exists for Texas. California does, however, require registration of pesticide use. In the pesticide data from California, we find that a larger fraction of commercial/residential pesticide use occurs in the fall months compared to agriculture. Specifically, in the California data, 52% of all agricultural pesticide application occurs May through August, but only 16% occurs September through November. In contrast, 44% of all non-agricultural pesticide application occurs May through August, and 24% occurs September through November.[7]

In order to test whether the spring spike in non-agricultural counties is predominantly an urban phenomenon, we estimate the following extensions to models (1) through (3):

(4)

$$BD_{imtc} = \beta_o + \beta_1 Spring_m + \beta_2 Spring_m * Urban_c + \beta_3 Fall_m + \beta_4 Fall_m * Urban_c + \beta_5 Urban_c + X_i\beta_3 + Year_t\delta_t + \varepsilon_{imtc}$$

(5)

$$BD_{imtc} = \beta_o + \beta_1 Spring_m + \beta_2 Spring_m * Agric_c + \beta_3 Spring_m * Urban_c + \beta_4 Spring_m * Urban_c * Agric_c + \beta_5 Fall_m + \beta_6 Fall_m * Agric_c + \beta_7 Fall_m * Urban_c + \beta_8 Fall_m * Urban_c * Agric_c + \beta_9 Urban_c + \beta_{10} Agric_c + \beta_{11} Urban_c * Agric_c + X_i\beta_3 + Year_t\delta_t + \varepsilon_{imtc}$$

(6)

$$BD_{imtc} = \beta_o + \beta_1 Spring_m + \beta_2 Spring_m * Agric_c + \beta_3 Spring_m * Urban_c + \beta_4 Spring_m * Urban_c * Agric_c + \beta_5 Fall_m + \beta_6 Fall_m * Agric_c + \beta_7 Fall_m * Urban_c + \beta_8 Fall_m * Urban_c * Agric_c + X_i\beta_3 + Year_t\delta_t + County_c\lambda_c + \varepsilon_{imtc}$$

where *Fall* is an indicator for conception in the months September through November. Notice that our *Spring* indicator runs May through August and our *Fall* indicator runs September

[7] Calculations from California Pesticide Use Report (PUR) data.

through November, so it is not the case that there is an omitted Summer indicator. Equation (4) is estimated separately for agricultural and non-agricultural counties. Equation (5) combines the agricultural and non-agricultural counties into one model, and Equation (6) includes county fixed effects.

In equations (5) and (6), our key parameters of interest are β_2 and β_3. The estimate of β_2 corresponds to the difference in spring spikes between agricultural and non-agricultural counties restricting the comparison to non-urban counties; the estimate of β_3 is the difference in spring spikes between urban and non-urban counties restricting the comparison to non-agricultural counties. If the urban spring spike lasts into the fall, this will be reflected in the estimate of β_7.

Estimates of equation (4) are reported separately for agricultural and non-agricultural counties in the first two columns of Table 6. In column 1, the coefficient of *Spring* indicates that, among mothers living in non-urban agricultural counties, spring conceptions are associated with an increase of 0.0012 in the probability of a birth defect. The estimated coefficient of *Spring*Urban* represents the difference in spring spikes between urban and non-urban agricultural counties. However, this difference (0.0007) is not statistically significant at conventional levels.

When the sample is restricted to non-agricultural counties, the estimated coefficient of *Spring*, is a modest (and statistically insignificant) 0.0008. In contrast, the estimated coefficient of 0.0039 for the *Spring*Urban* interaction indicates that the spring spike is much larger in urban as compared to non-urban counties. Moreover, the coefficient estimate of 0.0027 for the *Fall*Urban* interaction indicates that the urban spike in birth defects persists into the fall. The

spring spike in non-agricultural areas reported in Table 4 is almost entirely an urban phenomenon that lasts into the fall.

Estimates from equations (5) and (6) are reported in the remaining columns of Table 6. The estimated coefficient of the *Spring*Agric* interaction is positive, but not statistically significant. In contrast, the estimated coefficient of the *Spring*Urban* interaction provides additional evidence that the spring spike is larger in urban non-agricultural counties than in non-urban non-agricultural areas. Specifically, the spring spike in urban non-agricultural counties is 0.0039 larger than in non-urban non-agricultural counties, a non-trivial difference given that the mean birth defect rate for non-agricultural counties is 0.0316 (Table 2). The estimated coefficient of the *Fall*Urban* interaction suggests that the urban non-agricultural spring spike persists on into the fall.

4. Discussion

Congenital anomalies, or birth defects, are the leading cause of death among children less than one year of age, accounting for more than one fifth of infant mortality in the Unites States (Kochanek et al., 2012).[8] In comparison, sudden infant death syndrome accounts for approximately 8 percent of infant mortality, and accidents account for approximately 4 percent (Kochanek et al., 2012). Children with birth defects who survive beyond their first year often must grapple with life-long disabilities, emotional distress, and pain.

According to the Environmental Protection Agency (EPA), a pesticide is "any agent used to kill or control undesired insects, weeds, rodents, fungi, bacteria, or other organisms" (EPA, 2012). Every year, approximately 5 billion pounds of herbicides, insecticides and fungicides are

[8] According to Wigle et al. (2008, p. 406), two to three percent of children in the United States are born with a defect, which can be "physical or biochemical" in nature and "inherited or environmentally induced."

used in the Unites States (Grube et al., 2011). Although the majority of birth defects cannot be linked to a specific cause, researchers have hypothesized that prenatal exposure to pesticides could increase the risk of being born with a defect (Stillerman et al., 2008).

Evidence for this hypothesis comes from a variety of sources. Shaw et al. (1999), Rull et al. (2006), and Nordby et al. (2005) found that living near farms that use pesticides is associated with increased risk of neural tube defects (NTDs). Having a parent who works in an agricultural occupation is also associated with increased risk of NTDs (Blatter et al., 1994; Blatter and Roeleveld, 1996; Garcia et al., 1999; Hanke and Jurewicz, 2004; Lacasaña et al., 2006), oral clefts (Hanke and Jurewicz, 2004; Romitti et al., 2007, and congenital heart defects (Garry et al., 1996; Shaw et al., 1999; Loffredo et al., 2001).

Winchester et al. (2009) used birth certificate data available through the National Vital Statistics System (NVSS) for the period 1996-2002. They found children whose mothers had their last menstrual period (LMP) during the months of April-July were more likely to have a birth defect than mothers whose LMP was in other months.[9] Moreover, they found that concentrations of atrazine, nitrates and other pesticides in surface waters were higher during the months of April-July.[10] However, any seasonal variation in birth defects could potentially be

[9] Conception occurs about two weeks after LMP. Therefore, the Winchester et al. (2009) result is consistent with our finding of a spring spike in birth defects for babies conceived May through August. While their main outcome of interest, like ours, is the presence of at least one birth defect, they also test individual birth defects. They find that spina bifida, circulatory/respiratory anomalies, tracheo-esophogeal defects, gastrointestinal defects, urogenital defects, cleft lip, adactyly, clubfoot, musculoskeletal anomalies, Down's syndrome and other birth defects were found to be significantly higher in April through July than in other months of the year.

[10] Because they could not rule out the possibility that a third factor was responsible for the increased risk of being born with a birth defect among children conceived in the spring and early summer, they conceded that "[a] causal link between birth defects and…pesticides is plausible but not proven from this present ecological study" (p. 667).

caused by factors such another type of environmental pollution, viral infections, selection into pregnancy, or even the use of decongestants such as pseudoephedrine.[11]

Garry et al. (1996) and Schreinemachers (2003) compared the spring spike across areas with different types of agricultural production or pesticide usage. Both focus on wheat production in the Midwest, which typically involves the application of chlorophenoxy herbicides. Using data from Minnesota birth certificates for the period 1989-1992, Garry et al. (1996) found a spring spike in birth defects in regions where chlorophenoxy herbicides and/or fungicides were frequently used. There was no evidence of a spring spike in regions with low or no reported use of chlorophenoxy herbicides/fungicides. [12]

Schreinemachers (2003) argued that a comparison of regions with high wheat production to low wheat production (and therefore low chlorophenoxy use) should be limited to a sample of rural, agricultural counties, so as not to improperly compare the high wheat producing areas to urban, non-agricultural areas. Analyzing a sample of rural counties with high agricultural production located in Minnesota, Montana, North Dakota, and South Dakota, she found that the spring spike in birth defects was equally as strong in low-wheat producing agricultural areas as the high-wheat producing areas, suggesting that other pesticides besides chlorophenoxy may play a role in the spring spike.

[11] Dolk et al. (2010) and Skinner et al. (2010) review the literature on environmental pollution and birth defects. Zhang and Cai (1993) and Acs et al. (2006) found that experiencing a cold in the first trimester of pregnancy was associated with a variety of birth defects. Shaw et al. (1998) found an association between illness resulting in fever and neural tube defects. Werler et al. (2002) found an association between the use of pseudoephedrine, a common decongestant, while pregnant and small intestinal atresia. Buckles and Hungerman (2013) found that births during winter are disproportionally to teenagers and single women.

[12] Chlorophenoxy herbicides are a class of weed killers developed in the 1940s and commonly used on wheat. See also Garry et al. (2002), who focused on birth defects among children born to male pesticide applicators living in the Red River Valley, Minnesota. Being conceived in the spring was associated with a sharp increase in the probability of having a birth defect.

Ours is the first study of the spring spike to jointly investigate agricultural production and urban status.[13] We find evidence of a spring spike in Texas birth defects, but this spike is more pronounced in urban non-agricultural counties than in other types of counties. Furthermore, we find that the spike lasts longer into the fall in urban non-agricultural counties as compared to other types of counties.

These results suggest that, if pesticides contribute to the spring spike in Texas birth defects, they do so in a manner that generates a larger spike in urban non-agricultural counties than in other counties. For example, pesticides used in agricultural production could lead to the contamination of urban water supplies, or the more pronounced spike in urban non-agricultural counties could be attributable to commercial and residential pesticide use. Better (e.g., monthly) data on pesticide applications and pesticide concentrations in watersheds is required to more definitively investigate this relationship.

5. Conclusion

It is possible that pesticide use by farmers can lead to birth defects. Prior research has, in fact, shown that there is an elevated risk of birth defects if conception took place in the spring, when pesticide use by farmers is highest (Garry, 1996; Winchester et al., 2009). However, it is also possible that this association is spurious—driven by seasonal fluctuations in other types of environmental pollution, viral infections, or even the use of decongestants such as pseudoephedrine.

Using data from the Texas Birth Defects Registry (TBDR) data for the period 1996-2007, the current study tests whether the magnitude of the spring spike in birth defects is related to

[13] Siffel et al. (2005) examined data from the Metropolitan Atlanta Congenital Defects Program for the years 1978-2001. These authors found little evidence of seasonality in birth defects.

levels of agricultural production. Prior researchers have tested whether the spring spike is more pronounced in agricultural areas than in non-agricultural areas, but these studies did not consider the role of urban status.

Our results provide evidence that the spring spike in birth defects is smaller in agricultural counties than in counties with low levels of agricultural production. Furthermore, we find evidence of a sizeable spring spike in urban non-agricultural counties relative to non-urban non-agricultural counties. The increased risk of birth defects observed in urban non-agricultural counties lasts into the fall. Our calculations using California pesticide data indicate that non-agricultural pesticide use in that state typically lasts later into the growing season than does pesticide use by farmers. If the same were true for Texas, this prolonged spring spike in urban areas would be consistent with a role for residential and commercial pesticide use. Monitoring of residential and commercial pesticide usage would provide the data needed to explore this relationship.

While the spring spike is larger in non-agricultural areas, birth defects remain more common in agricultural areas than non-agricultural areas. These results highlight the need for better monitoring of both agricultural and non-agricultural pesticide usage that would provide the data necessary to more definitively estimate the relationship between birth defects and pesticide use.

Finally, while the evidence presented here is clearly circumstantial, it may provide guidance to future researchers with access to detailed information on pesticide use and concentrations. With this information, it may be possible to identify what causes the spring spike in birth defects. Our results suggest that any alternative explanation cannot simply predict a spring spike but must also predict a larger spring spike in urban non-agricultural areas.

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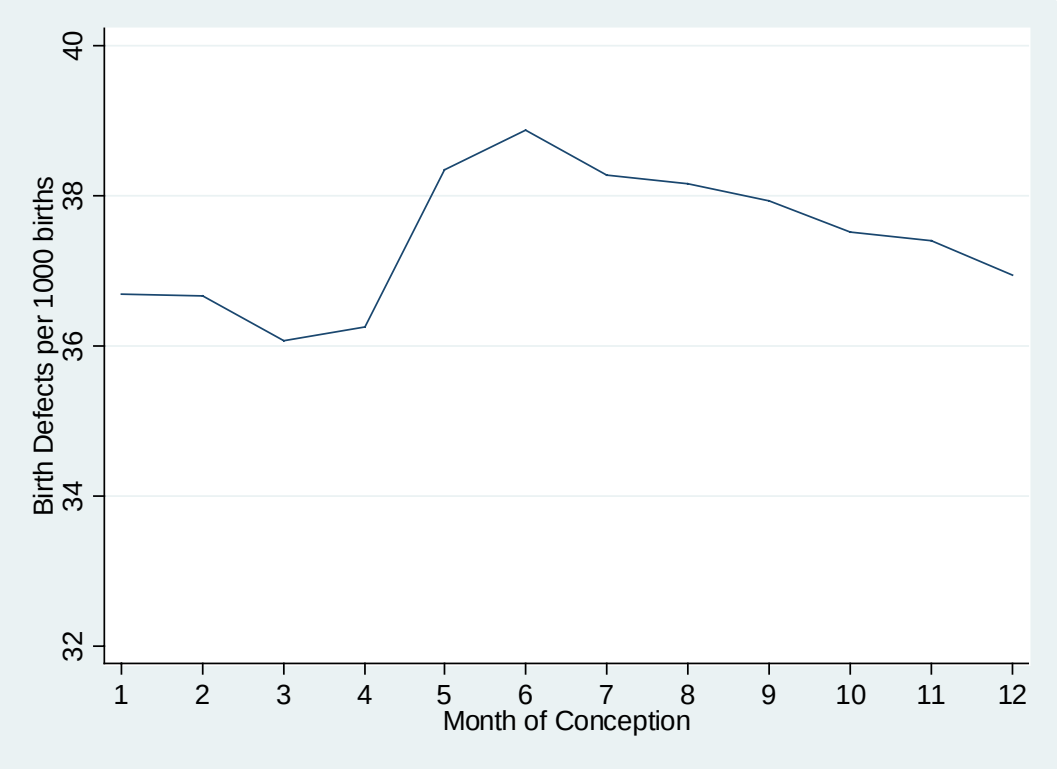

Fig 1: Seasonal Variation in Birth Defects, Texas, 1996-2007

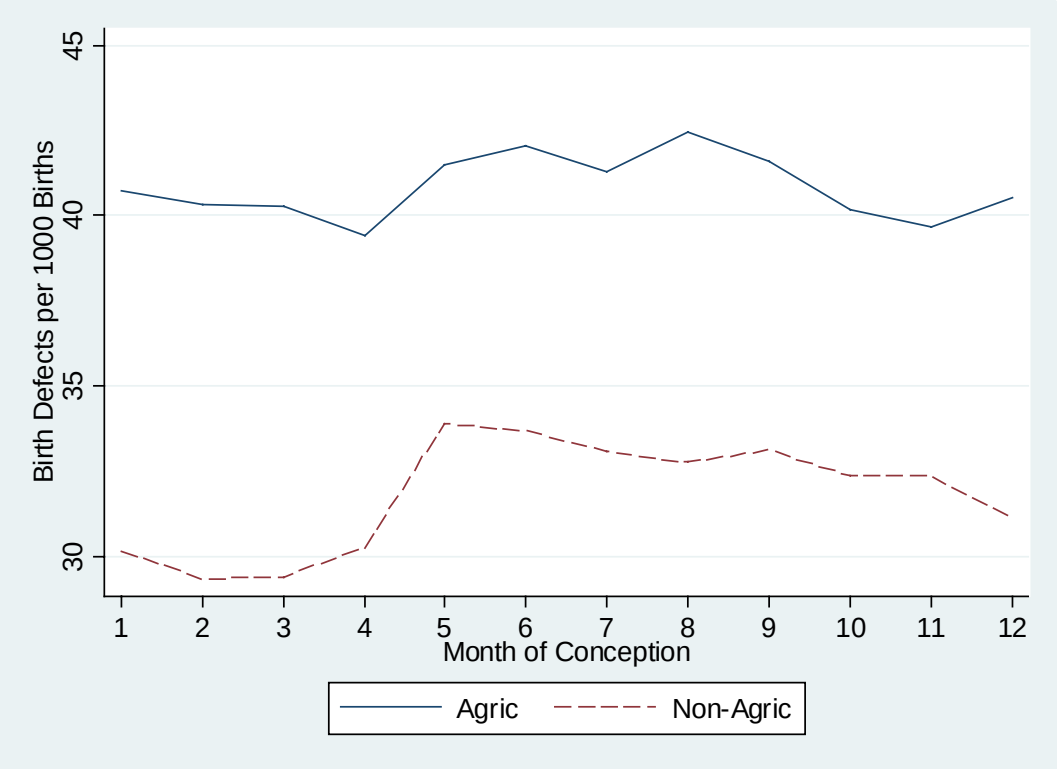

Fig 2: Seasonal Variation in Birth Defects, Agricultural vs. Non-Agricultural Counties

Table 1: Counties by Agricultural and Urban Designation

	Non-Urban Counties	Urban Counties	All Counties
Agric Counties			
N	80	9	89
Col %	50.0	50.0	50.0
Row %	89.9	10.1	100.0
Non-Agric Counties			
N	80	9	89
Col %	50.0	50.0	50.0
Row %	89.9	10.1	100.0
	160	18	178
	100.0	100.0	
	89.9	10.1	

Notes: The 89 Texas counties below the 35th percentile of agricultural production, as measured by average annual percent of acres planted are designated non-agricultural. The 89 Texas counties above the 6th percentile of agricultural production are designated agricultural. The remaining 76 counties between the 35th and 65th percentile are not included in the analysis. Urban counties are those in a metropolitan area containing at least 1 million residents.

Table 2: Sample Means by Agricultural Designation

	Full Sample	Agricultural Counties	Non-Agricultural Counties
% Birth Defects	0.0360	0.0407	0.0316
% Born May-Aug	0.235	0.239	0.231
% Born Sept-Nov	0.253	0.252	0.253
% Urban	0.518	0.326	0.697
% Male	0.511	0.511	0.511
% Mother age:			
<20	0.144	0.146	0.142
20-24	0.281	0.278	0.284
25-29	0.269	0.269	0.269
30-34	0.200	0.202	0.198
35-39	0.088	0.088	0.089
40+	0.018	0.017	0.019
% Mother's Race/Ethnicity:			
White non-Hispanic	0.384	0.408	0.362
Black non-Hispanic	0.104	0.064	0.142
Hispanic	0.476	0.494	0.459
Other non-Hispanic	0.036	0.034	0.037
% Mother's Education:			
<high school	0.322	0.291	0.350
high school	0.295	0.298	0.292
> than hs	0.384	0.411	0.358
% Plurality:			
1	0.972	0.971	0.972
2	0.027	0.028	0.027
3 or more	0.001	0.001	0.001
% Parity:			
1	0.389	0.389	0.387
2	0.315	0.318	0.312
3	0.181	0.180	0.180
4	0.073	0.071	0.074
5 or more	0.044	0.042	0.045
N	2,209,303	1,064,711	1,144,592

Notes: Agricultural and non-Agricultural counties are defined in the notes of Table 1. Sample is composed of births in the set of 178 analysis counties in 1996-2007 with non-missing data for the variables in the table.

Table 3: Observation Counts by Birth Defect Classification

Total # Births	2,209,303
Total # Births with at least 1 birth defect	79,594
Total # Births with a defect classified in:	
Circulatory	30,192
Chromosomal	4,278
Selected musculoskeletal defects	5,746
Selected central nervous system defects	3,844
Selected urogenital defects	6,888
Oral Cleft	3,422
Selected digestive defects	1,508
Defect not elsewhere classified	32,914

Sample is described in the notes of Table 2. Some categories are selected rather than comprehensive (e.g. Digestive does not contain all birth defects possibly categorized as digestive). Some births have birth defects from more than one category.

Table 4: Birth Defects by Season of Conception and County Agricultural Production

	(1) Ag Counties	(2) Non-Ag Counties	(3) Ag and Non-Ag Counties	(4) Ag and Non-Ag Counties with County FEs
Spring	0.0013**	0.0026***	0.0026***	0.0025***
	(0.0004)	(0.0006)	(0.0006)	(0.0006)
Agric			0.0084***	
			(0.0027)	
Spring*Agric			-0.0014+	-0.0013+
			(0.0007)	(0.0007)
N	1,064,711	1,144,592	2,209,303	2,209,303

Notes: Table reports coefficient estimates from equations (1)-(3). Sample is as described in the notes of Table 2. Coefficients are estimates from a linear probability model in which the dependent variable is an indicator for any monitored birth defect. Each specification also includes controls for urban location, mother's age, mother's race/ethnicity, mother's education and year, plurality, parity and sex of the birth. Standard errors are reported in parentheses and are clustered at the county level. +p-value<0.10, * p-value<0.05, ** p-value<0.01, ***p-value<0.001

Table 5: Birth Defects by Season of Conception and County Agricultural Production, by Birth Defect Classification

	Spring	Spring* Ag County	N
Circulatory	0.00063**	-0.00020	2,159,901
	(0.00023)	(0.00033)	
Chromosomal	0.00002	0.00006	2,133,987
	(0.00005)	(0.00009)	
Selected musculoskeletal defects	0.00001	-0.00002	2,135,455
	(0.00005)	(0.00011)	
Selected central nervous system defects	0.00016+	-0.00001	2,133,553
	(0.00009)	(0.00012)	
Selected urogenital defects	0.00019+	-0.00017	2,136,597
	(0.00012)	(0.00017)	
Oral Cleft	0.00022	-0.00013	2,133,131
	(0.00015)	(0.00018)	
Selected digestive defects	0.00008+	-0.00013	2,131,217
	(0.00005)	(0.00018)	
Defect not elsewhere classified	0.00163***	-0.00089	2,162,623
	(0.00043)	(0.00054)	

Notes: Each row of Table 5 reports estimates from equations (3) for a different birth defect category. Coefficients are estimates from a linear probability model in which the dependent variable is an indicator for a particular birth defect category. For each birth defect category, the sample is restricted to observations that either have either that defect or no defect. Each specification also includes controls for urban location, mother's age, mother's race/ethnicity, mother's education and year, plurality, parity and sex of the birth. Standard errors are in parentheses and are clustered at the county level.
+p-value<0.10, * p-value<0.05, ** p-value<0.01, ***p-value<0.001

Table 6: Birth Defects by Season of Conception, County Agricultural Production and County Urban Status

	(1) Agric Counties	(2) Non-Agric Counties	(3) Ag and Non-Ag Counties	(4) Ag and Non-Ag Counties /w County FEs
Spring	0.0012*	0.0008	0.0008	0.0007
	(0.005)	(0.0009)	(0.0008)	(0.0008)
Spring*Agric			0.0004	0.0005
			(0.0010)	(0.0010)
Spring*Urban	0.0007	0.0039***	0.0040***	0.0039***
	(0.0013)	(0.0009)	(0.0009)	(0.0009)
Spring*Urban*Agric			-0.0032*	-0.0033*
			(0.0016)	(0.0015)
Fall	0.0004	0.0007	0.0007	0.0007
	(0.0004)	(0.0008)	(0.0008)	(0.0008)
Fall*Agric			-0.0003	-0.0002
			(0.0009)	(0.0009)
Fall*Urban	0.0002	0.0027**	0.0028**	0.0028**
	(0.0015)	(0.0010)	(0.0009)	(0.0009)
Fall*Urban*Agric			-0.0025	-0.0026
			(0.0017)	(0.0017)
Agric			0.0085**	
			(0.0032)	
Urban	-0.0029	-0.0038**	-0.0038**	
	(0.0041)	(0.0014)	(0.0013)	
Urban*Agric			0.0007	
			(0.0044)	
N	1,064,711	1,144,592	2,209,303	2,209,303

Notes: Table reports estimates from equations (4)-(6). Sample is as described in the notes of Table 2. Coefficients are estimates from a linear probability model in which the dependent

variable is an indicator for any monitored birth defect. Each specification also includes controls for mother's age, mother's race/ethnicity, mother's education and year, plurality, parity, and sex of the birth. Standard errors are reported in parentheses and are clustered at the county level. +p-value<0.10, * p-value<0.05, ** p-value<0.01, ***p-value<0.001