Agriculture Expansion, Mechanization and Environmental Regulations:
On the impact of sugar-cane's field-clearing fires over child health

Opportunities for investment in child health come by in specific "windows". Researchers across the social sciences have raised the point that returns to early childhood investments are very significant and, most likely, higher than in any other phase of a child's life [Carneiro and Heckman, 2003 and Conti et al., 2009]. This is compatible with observations of strong intergenerational correlations in health and income unfolding early in the life cycle [Case et al., 2002]. The argument is reinforced by the literature that relates *in utero* conditions to health and socioeconomic outcomes in adulthood [see Currie, 2011; and Almond and Currie, 2010]. These findings suggest that more attention needs to be paid to early investments in human capital and on the design and evaluation of policies that (directly or indirectly) affect conditions under which pregnancies are carried.

One particular underexplored aspect in this literature is the environmental impact of rapid economic growth over birth outcomes in developing countries. On the one hand the impact of environmental control regulations over birth outcomes have been extensively studied in developed nations, while on the other hand most analyses using developing country data center on information derived from food shortages, disease outbreaks, natural disasters and armed conflicts. While I acknowledge the importance of investigating dramatic impacts of extreme events, these studies face identification challenges that are not trivial, particularly with regards to "selection of the most fit" on the analysis of long run outcomes. Most importantly however, due to the cheer size of effects, they do not provide estimates that can be easily employed to support a cost-benefit analysis of various policies. With these observations in mind, my contributions in the present article are threefold. First I focus on environmental consequences of an economic expansion, not a downturn, with particular focus on the expansion of agricultural production of commodities. Second, I analyze environmental policy interventions coupled with technological innovation in production that can induce important environmental improvements. Finally, the level of detail in the data employed provides important additional robustness to the impact evaluation performed.

In the present article I combine administrative data from approximately 4 million birth records in the state of Sao Paulo (Brazil) between 2002 and 2009 with satellite imaging of sugar-cane field fires in order to examine the impact of exposure to biomass burning over birth outcomes. The period covered in the analysis illustrates a major expansion of the Brazilian agricultural frontier, with particular strong increase in the sugar-cane production relative to all other cultures (Figures 1 and 2). The expansion occurs in specific locations within the state and does provide a large variation in exposure to sugar-cane production in my data set (Figures 3 and 4), with sizeable sugar-cane specialization trends among some municipalities. Together with the production expansion driven by domestic subsidies and international prices, the period covered by my data also encompasses changes in environmental regulations as well increased mechanization of harvesting that are both conducive to reduction in the use of fires for filed-clearing operations. These changes provide additional identification variation both on geographic and temporal dimensions.

Figure 5 presents the seasonal pattern of fires' incidence across the state. More importantly, however, Figure 6 examines the pattern of potential smoke exposure in different weeks of the year and also in different locations. It is noticeable that both higher occurrence levels and earlier onset of fires are observed in sugar-cane producing locations. Fires are intensively used in most non-mechanized productive units in the state, since they represent a factor of 3 increase in the amount of product harvested by a laborer. The earlier onset nicely follows sugar-cane's April-October harvesting cycle.

Focusing on my main dependent variable (I also use prematurity indicators, and APGAR scores), Figure 7 summarizes the distribution of birth-weight in my data. Figure 8 depicts the average birth-weight of children born in Sao Paulo according to the calendar-week of birth. The features emerging from the data confirms seasonal patterns found elsewhere [Currie and Schwandt, 2013, and references therein] and are suggestive of favorable environments for children conceived during the summer months and unfavorable for those whose mothers were exposed to harsher (extremely dry and mildly cold) winter conditions in the last trimester of the pregnancy. This pattern as well most of my results are robust to the presence of maternal unobserved characteristics. This is confirmed employing family fixed-effects estimation on approximately 350 thousand sibling pairs in the linked version of birth records I construct from the original source.

Figure 9 presents the intuition for my preliminary results. Contrasting birth-weight of children born in different weeks of the year and also on locations differentially exposed to biomass burning smoke the indication is that birth outcomes are less likely to dramatic improve for kids conceived during summer months. This is in accordance with the early onset of field-clearing fires in these locations, which coincides with the last trimester of pregnancy for those mothers. This is apparent even considering the fact that different locations have dramatically different average levels in the dependent variable.

My research design directly deals with two major potential confounders of these analyses: the seasonal variation in birth outcomes due to the agricultural business cycle and the intra-year weather variations. I do so by exploring detailed geocoding of both births and fires combined with information on direction and velocity of winds (50 meters above the ground) to define exposure to biomass burning smoke. In this case localized variation in smoke exposure do occur even for people that are equally exposed to weather conditions and the cycle in economic activities associated to agriculture. The strategy is summarized in an example depicted in Figure 10. Consider the center of the circle as representing a birth. Taking into consideration the wind direction, if fires have occurred during a specific window of time before birth in the Northeast corner of this circle that mother was not affected. Yet, if fires have occurred in the non-Northeast section of the circle, pregnancies are likely exposed to smoke. Since I can find moms in different treatment statuses, even relative to the same fire event, I have exposed and unexposed pregnancies carried over during approximately identical economic and weather conditions. This is one important element in my causal inference analysis. This strategy can also be further tested by looking at this exact same location before and after mechanization, under fire and non-fire harvesting techniques, but yet again under similar weather and business cycles.

Finally, 2.9 million birth records in these data (and all the sibling pairs) are also linked to school records that allow the investigation of the early impacts of birth outcomes or even direct exposure to smoke over the accumulation of human capital also in the form of education.

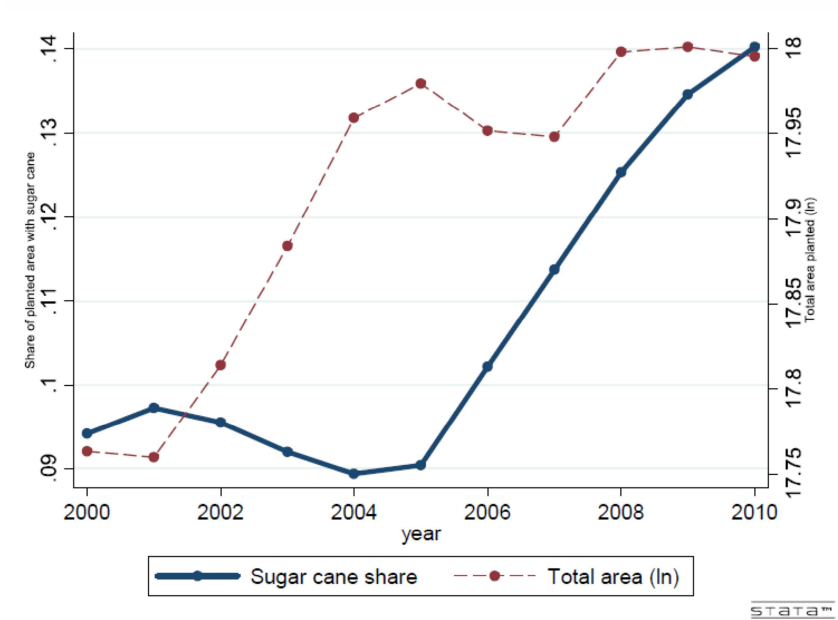

Figure 1: Expansion of Total Agricultural Land and Sugar-Cane Production (Brazil)

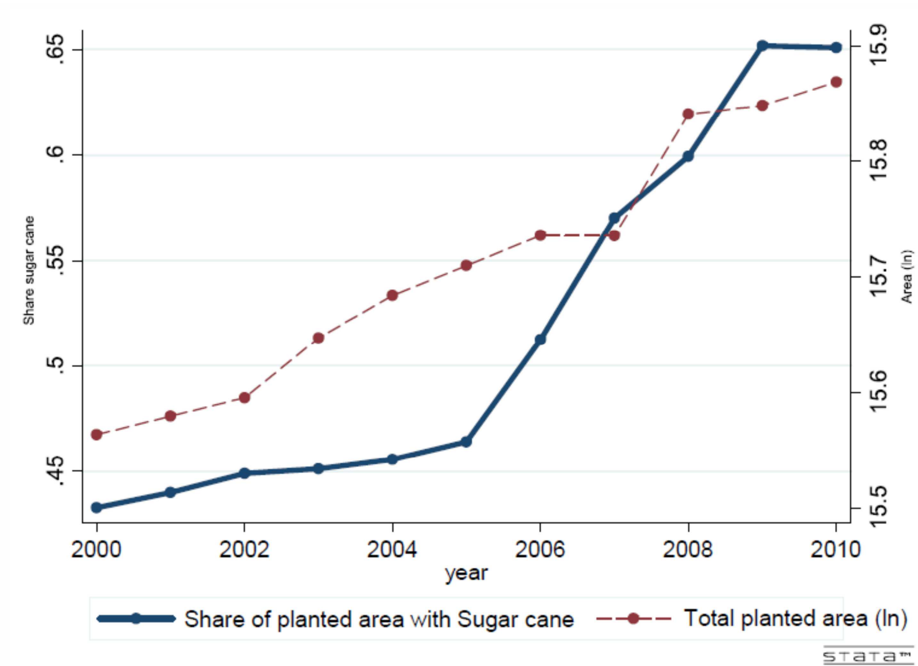

Figure 2: Expansion of Total Agricultural Land and Sugar-Cane Production (Sao Paulo)

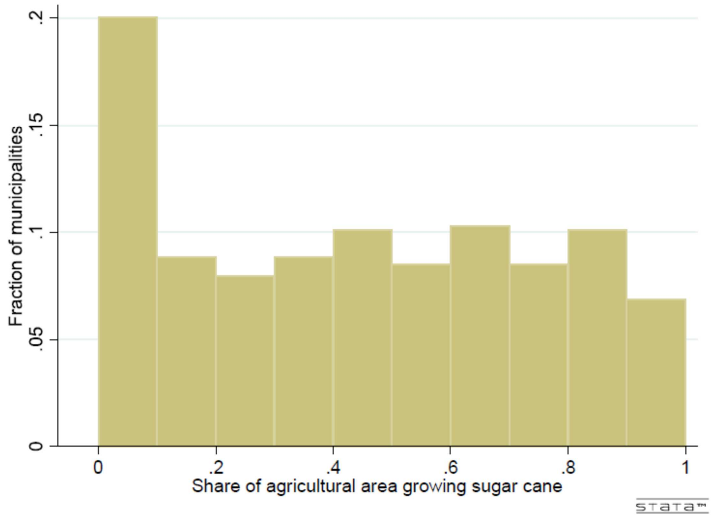

Figure 3: Share of area dedicated agricultural production that grows sugar-cane in Sao Paulo (Aggregate figures 2000-2010)

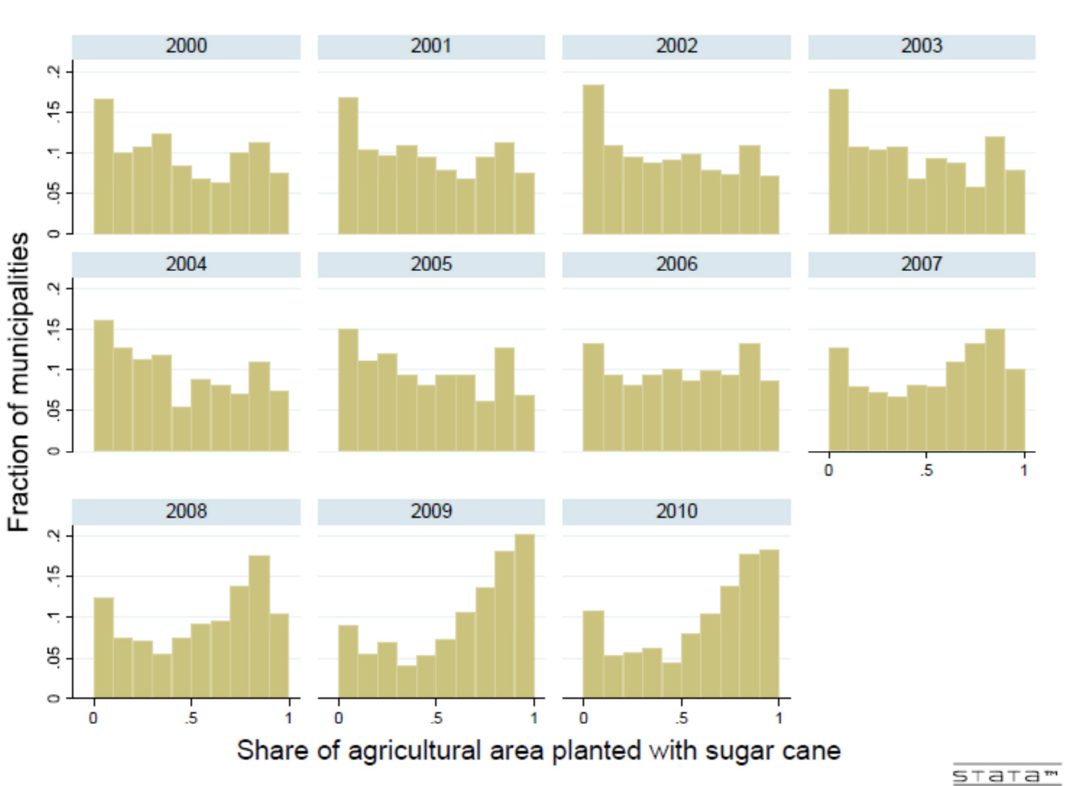

Figure 4: Time variation in the share of area dedicated agricultural production that grows sugar-cane across municipalities in Sao Paulo

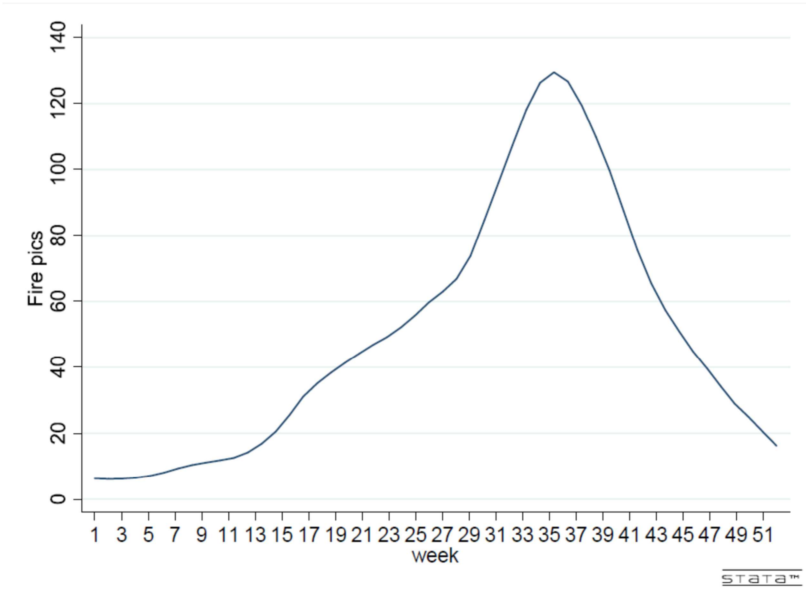

Figure 5: Incidence of Fires (satellite picture detection), 2001-2008

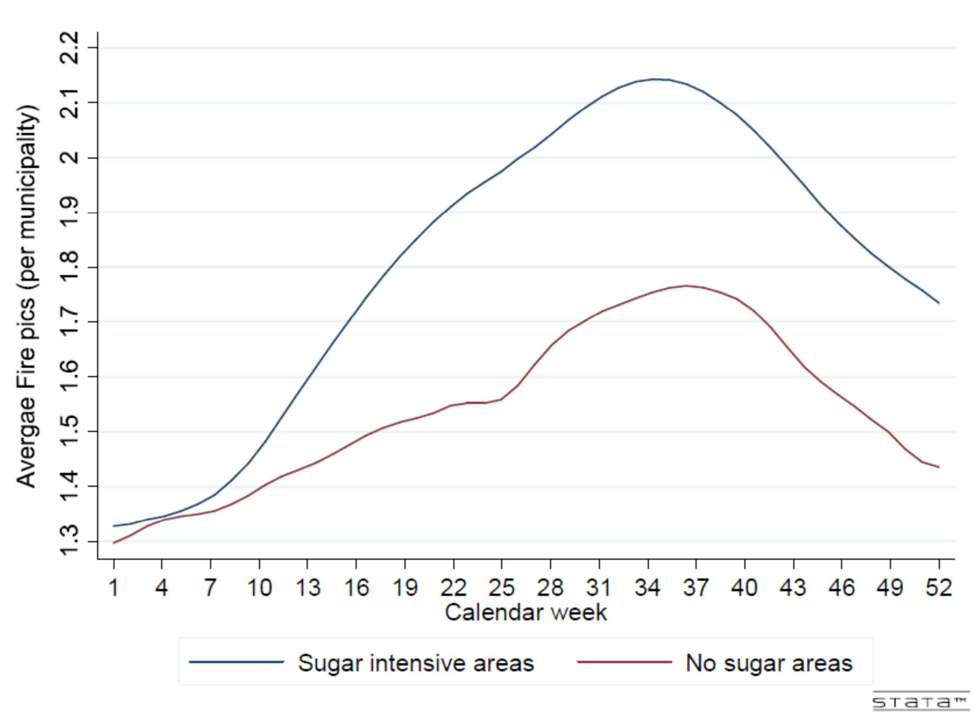

Figure 6: Fire Incidence in Sugar-Cane and Non-Sugar-Cane locations (2001-2008)

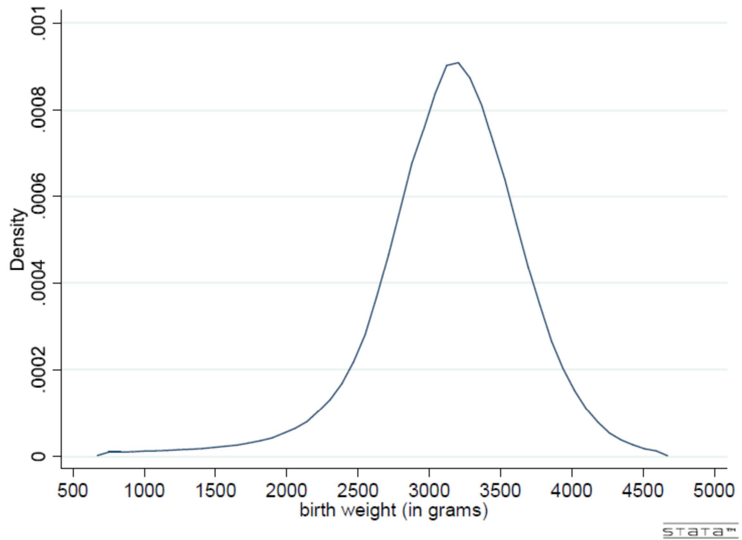

Figure 7: Distribution of birth-weight in Sao Paulo (2002-2009)

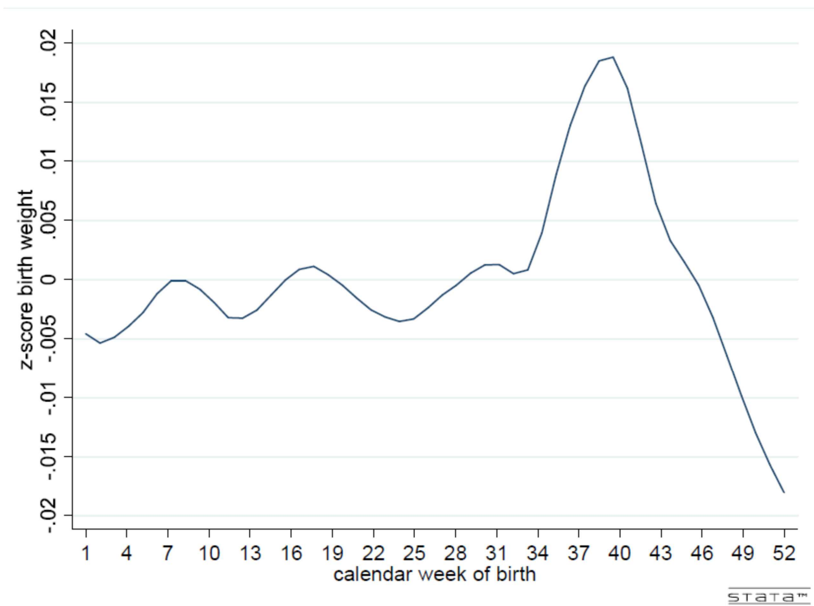

Figure 8: Birth-weight by calendar week of birth in Sao Paulo (2002-2009)

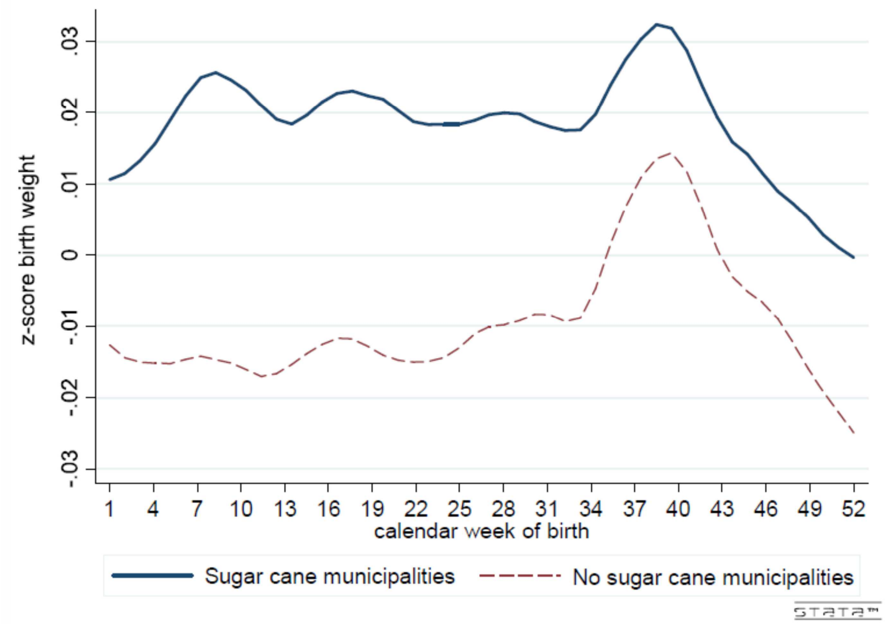

Figure 9: Birth-weight by calendar week of birth for sugar-cane municipalities in non-sugar-cane municipalities in Sao Paulo (2002-2009)

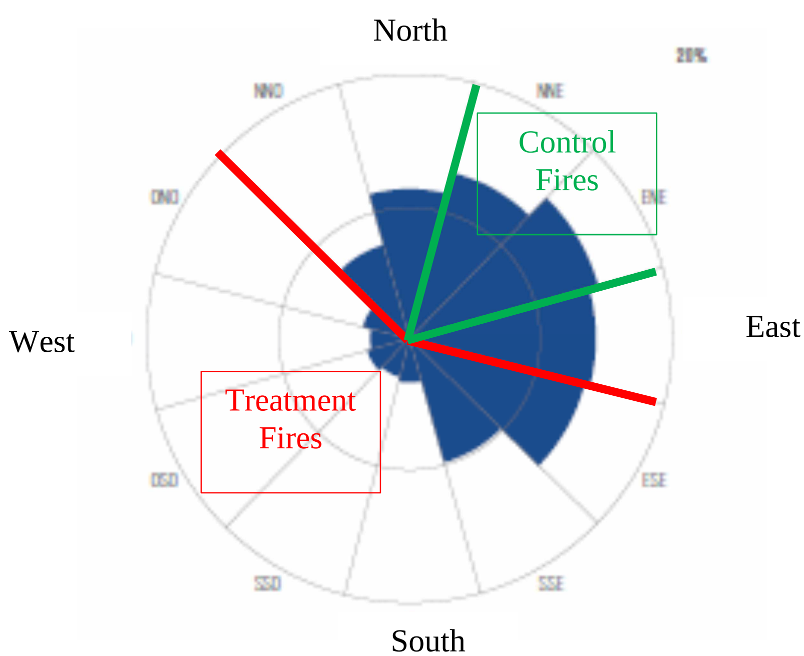

Figure 10: Identification Strategy Based on Wind Direction
(reproduced with editions from *Atlas Eolico do Estado de Sao Paulo*, 2012)