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RICHARD T. ELY LECTURE

Inequality at Birth: Some Causes and Consequences

By Janet Currie*

Economists have long been interested in the origins of inequality between individuals and between groups. Richard Ely, the founder of the American Economic Association and the person honored by these lectures, was certainly concerned about the "…share of the total product of industry that is received by each section of the community" (Richard T. Ely, Thomas S. Adams, Max O. Lorenz, Allyn A. Young 1910, p. 542). In his 1910 *Outlines of Economics*, he concluded the chapter on the personal distribution of wealth with a call to action: "Society must, therefore, take measures to better the environment of the poor. They must be taught to live wisely, and their children must be given a fair chance in life" (Ely et al. 1910, 550). In calling for reform, he explicitly rejected the view that poverty simply reflected the distribution of native abilities in the population and was therefore immutable.

Today, the same debate is often framed in terms of "nature versus nurture." Endowments at birth are thought of as representing "nature" and differences in achievements between similarly endowed groups reflect "nurture." In this lecture, I will explore the possibility that differences that are often thought to be innate may, in fact, reflect the effects of "nurture" or interactions between "nature and nurture," and, like Ely, I will focus on the importance of giving children a fair chance in life.

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The first part of the lecture will review some of the evidence about the determinants of health at birth. I argue that individuals may start with very different endowments at birth because of events that happened to them during a critical period: the nine months that they were *in utero*. In turn, endowments at birth have been shown to be predictive of adult outcomes and of the outcomes of the next generation.

This focus on the prenatal period suggests that differences that appear to be innate may in fact be the product of environmental factors. While summarizing several influences on health at birth, I will give considerable attention to one particular example of an environmental influence: prenatal exposure to pollution. A large literature outside of economics advocates for "environmental justice," arguing that poor and minority families are disproportionately exposed to environmental hazards. But issues of data quality and weaknesses in methodology leave this assertion open to debate (William Bowen 2002).

I provide new evidence on this question, showing that children born to less educated and minority mothers are indeed more likely to be exposed to pollution *in utero*. The gradients in pollution exposure by maternal race and education are clear-cut when we use data at a fine enough level of geographic disaggregation. More strikingly, I show that these gradients can arise quickly following changes in environmental conditions, and that white, college educated mothers are particularly responsive to these changes.

These results shed light on some of the mechanisms underlying the perpetuation of lower socioeconomic status. Poor and minority children are more likely to be in poor health at birth, partly because their mothers are less able to provide a healthy fetal environment. Poor health at birth is associated with poorer adult outcomes, which in turn provide less than optimal conditions for the children of the poor. This conclusion suggests that policymakers attempting to

TABLE 1—SUMMARY STATISTICS FOR DEMOGRAPHIC GROUPS: 1989 AND 2006
(*Singleton births only*)

	Low birth weight (<2,500g)		Premature (<37 weeks)	
	Mean	SD	Mean	SD
Year: 1989				
All mothers	**0.060**	0.237	**0.097**	0.296
White mothers	**0.045**	0.208	**0.072**	0.258
Black mothers	**0.137**	0.344	**0.191**	0.393
Hispanic mothers	**0.058**	0.233	**0.110**	0.313
White mothers with college or more	**0.032**	0.176	**0.058**	0.234
White mothers with <HS education	**0.074**	0.262	**0.106**	0.308
Black mothers with <HS education	**0.144**	0.352	**0.214**	0.410
Hispanic mothers with <HS education	**0.056**	0.230	**0.114**	0.318
Year: 2006				
All mothers	**0.065**	0.246	**0.111**	0.314
White mothers	**0.083**	0.276	**0.121**	0.326
Black mothers	**0.149**	0.357	**0.188**	0.391
Hispanic mothers	**0.067**	0.249	**0.125**	0.331
White mothers with college or more	**0.038**	0.191	**0.079**	0.269
White mothers with <HS education	**0.084**	0.278	**0.128**	0.334
Black mothers with <HS education	**0.138**	0.344	**0.189**	0.391
Hispanic mothers with <HS education	**0.058**	0.234	**0.116**	0.320

Notes: For birth outcomes (LBW rates, premature rates), the units of analysis are individual birth records for all singleton births in 1989 and 2006. There were 3,948,042 singleton births in 1989 and 4,121,898 in 2006.

ameliorate inequalities among children cannot afford to ignore mothers, since what mothers do even before they know they are pregnant may have profound consequences.

I. Endowments at Birth and Future Outcomes

This section provides an overview of the literature on health at birth with the aim of establishing five important points: First, there are large and persistent inequalities in health at birth. Second, the persistence of disparities cannot be taken as evidence that the source of disparities is "genetic." Indeed, the sharp distinction that is often made between nature and nurture is now outdated and unhelpful. Third, health at birth is surprisingly malleable and reflects the influences of a wide range of individual and social factors. Fourth, health at birth is a useful predictor of important future outcomes such as earnings, education, and disability, although the long-term effects of health at birth are themselves amenable to environmental influences. Fifth, there is increasing evidence of intergenerational transmission of poor infant health at birth.

A. *Endowments at Birth, Genes, and the Epigenome*

Table 1 shows data calculated using singleton births from the US National Individual-Level Natality Data.[1] This database contains information about virtually all of the approximately 4 million births per year in the US. The table illustrates huge inequality in health at birth. For example, the incidence of low birth weight (birth weight less than 2,500 grams) is more than three times higher among children of black high school dropout mothers than among children of white college educated mothers. Although this lecture will focus on low birth weight as the measure of health at birth, disparities are also present if we look at alternative indicators such as prematurity.[2]

[1] I focus on singleton births because multiple births are much more likely to be low birth weight and many multiple births result from assisted reproductive technologies (ART). If one looks at all births, the fraction of low birth weights among white college educated mothers has increased more than Table 1 suggests, because these mothers are more likely than others to use ART.

[2] Disparities are also seen in APGAR scores. The APGAR score is a rating from zero to ten of the infant's

I focus on birth weight because it has been measured over a long period of time and is widely available. Moreover, while the limitations of birth weight as a summary measure are increasingly well understood (see Douglas Almond, Kenneth Y. Chay, and David S. Lee 2005), little progress has been made toward finding an alternative, superior measure. Thus, for the time being we must look under the lamppost, while hoping that a better light source will soon become available.

Table 1 indicates that differences in endowments at birth have been relatively stable over time. There has been a tendency to view this stability as indicative of group-level genetic differences (Richard J. Herrnstein and Charles Murray 1994). Yet the emerging science of epigenetics suggests that a much subtler interplay of genes and the environment is at work. Arturas Petronis (2010) argues that "it is difficult to visualize how highly stable DNA sequences can account for heritability which is malleable and context-dependent" (p. 722).

A puzzle brought to light by the sequencing of the human genome is that human beings have so few genes—approximately 23,000, about the same number as a fish or a mouse. It seems that there are too few genes to explain the complexity of humankind. Moreover, we now know that unrelated individuals share over 99 percent of their DNA and that those genetic variations (polymorphisms) that have been identified explain little of the variation observed in the population (Lars Feuk, Andrew R. Carson, and Stephen W. Scherer 2006).

For example, height, an important predictor of future outcomes, is strongly heritable; that is, the height of children tends to resemble the height of their parents. Genome-wide association studies (GWAS) have detected 40 areas of the DNA that affect height. However, variations in these regions of the genome can explain less than 5 percent of the heritability of height in humans (Brendan Maher 2008).[3] Moreover, economic historians have shown that the average height of human populations can change rapidly with improvements in health and nutrition (Richard H. Steckel 1995). Anne Case and Christina Paxson (2008, 2010) argue that height is in fact an indicator of early deprivation.

These puzzles suggest that genes cannot be the whole story, and much recent work in genetics focuses on the epigenome, which literally means "above the genome." The epigenome determines which genes are expressed. It can be thought of as a series of switches that turn parts of the genome on and off. Another metaphor is that it is the "software" that corresponds to the genetic "hardware" and tells the "hardware" what to do. Perhaps the best example of epigenetics at work is the development of an infant from a single cell. A person's skin, blood, and hair all start from a single cell and have the same DNA. These tissues are differentiated from each other as a series of epigenetic switches are "thrown" over the course of development.

One process by which parts of the gene are expressed or silenced involves a methyl molecule that attaches to a part of the DNA. The part of the DNA that is "methylated" is hidden from the cell and is not expressed. Another process involves a chemical tag that attaches to the histone, which is the protein that the DNA wraps around, and changes its shape, thus changing the functioning of the gene. These switches can be triggered by environmental factors, and changes in the arrangement of the switches can be passed from parents to their offspring.

Thus, epigenetics offers an elegant theory of how environmental factors can rapidly "get under the skin." For example, some mice have a gene that causes them to have a yellow coat and to be prone to obesity and disease. If pregnant mice with this "agouti" gene are fed diets high in folic acid and B-12, their offspring are thin and brown (Craig A. Cooney, Apurva A. Dave, and George L. Wolff 2002). The diet enables

health 5 minutes after birth. Wanchuan Lin (2009) shows that while there was no convergence in the incidence of low birth weight from 1983 to 2000, gaps in APGAR scores and infant mortality declined, largely due to improvements in medical care at the time of child birth.

[3] There is a great deal of controversy in genetics about the "missing heritability." GWAS studies use stringent significance levels to avoid false positives. Jian Yang et al. (2010) argue that, taken as a group, variations in the genome (more technically, the approximately 300,000 single nucleotide polymorphisms, or SNPs, that have been identified) can explain over half of the heritability of height, even if few single SNPs are significantly associated with height. However, statistically one might expect to be able to explain a large fraction of the variation in the variable of interest, given such a large number of potential explanatory variables. The controversy about the measurement of heritability in genetics makes the evidence regarding rapid changes in the height of human populations over time in response to environmental factors even more important.

mothers to create methyl molecules that attach to the agouti gene in key locations and "silence it" in their offspring. Experiments like these suggest that the variation in human characteristics that we see results from complex interactions between genes and the environment.

B. *The Malleability of Health at Birth*

We do not need to look for evidence at the molecular level to find evidence that health at birth is malleable. Many recent studies in economics show that birth weight is affected by a wide range of factors.[4] Today it is perhaps unsurprising to hear that tobacco, alcohol, and illegal drug use during pregnancy have negative effects, or that good nutrition and better access to medical care have positive effects on fetal health. Damage due to fetal alcohol syndrome (FAS) provides an instructive early example of a condition that was falsely attributed to "genetics," even though it was environmental in origin. The facial features and behaviors typical of FAS had been recognized for a long time but had been attributed to heredity. For example, Henry H. Goddard's (1912) monograph about the Kallilak family of "congenital idiots" was subtitled, "A Study in the Heredity of Feeble-mindedness." However, Robert J. Karp et al. (1995) show that FAS offers an excellent explanation of the characteristics Goddard describes.

More recently, economists have helped to quantify the magnitude of these effects (Currie and Jonathan Gruber 1996; William N. Evans, Jeanne S. Ringel, and Diana Stech 1999; Currie and Matthew Neidell 2005; Kelly Noonan et al. 2007; Currie, Neidell, and Johannes F. Schmeider 2009; Angela R. Fertig and Tara Watson 2009; David S. Ludwig and Currie 2010). For example, Currie, Neidell, and Schmeider (2009) use confidential data from birth certificates on 1.5 million births in New Jersey between 1989 and 2003 in which births to the same mother can be linked. They compare births to the same mother in pairs in which the mother smoked during one pregnancy but not during the other. These fixed effects estimates of negative effects of smoking on birth weight are smaller than ordinary least squares (OLS) estimates, but are still substantial: at the mean number of cigarettes smoked per day (ten), they estimate that smoking increases the probability of low birth weight by 0.018 percentage points on a baseline of 0.089 (compared to an OLS estimate of 0.067 percentage points).

The introduction of social programs such as the Supplemental Feeding Program for Women, Infants, and Children (WIC) and Food Stamps in the 1970s (Hilary W. Hoynes, Marianne E. Page, and Ann Huff Stevens 2009; Almond, Hoynes, and Diane Whitmore Schanzenbach, forthcoming) have also been shown to affect birth weight. For example, Hoynes, Page, and Stevens (2009) find that among mothers who were high school dropouts, and mothers in high poverty counties, the introduction of WIC reduced the proportion of births that were of lower birth weight by 1 to 2.5 percent.

Currie and Enrico Moretti (2003) investigate the effect of increases in maternal education on infant health outcomes. While there is a large literature on this topic, it is difficult to find an instrument that affects education without possibly having an independent effect on infant health. Currie and Moretti (2003) use data on college openings in the woman's county of birth in the year in which she turned 17. College openings are shown to have had a significant effect on the education of white mothers, though they had no effect on black mothers (who may have faced other constraints on college attendance) or men (who were presumably less geographically constrained). Children of women induced to attend college by the openings were significantly healthier: the estimates suggest that an additional year of college education reduces the incidence of low birth weight by 10 percent. These positive results may be because college education dramatically reduces smoking, increases the probability that a woman gets timely prenatal care, and increases the probability that she is married at the time of the birth.[5]

[4] Almond and Currie (2011) and Currie (2009) offer more detailed overviews of factors that have been shown to influence birth weight, and of policies that have been shown to be effective in ameliorating the long-term consequences of low birth weight.

[5] Subsequent studies using laws affecting the compulsory schooling of high school educated mothers have not shown positive impacts on birth weight (Maarten Lindeboom, Ana Llena-Nozal, and Bas van der Klaauw 2009; Justin McCrary and Heather Royer 2011). Gabriella Conti et al. (forthcoming) reconcile these findings using data from the 1970 British Cohort Study and showing that the women most likely to

A fourth strand of the recent literature in economics examines the effects of pollution on health at birth. Cross-sectional differences in ambient pollution are usually correlated with other determinants of fetal health. For example, fetuses exposed to lower levels of pollution may also receive higher quality medical care. Failing to account for these relationships leads to upwardly biased estimates of the effects of pollution. Epidemiological studies typically have few (if any) controls for these potential confounders.[6]

Chay and Michael Greenstone (2003a, b) address the problem of omitted variables by focusing on "natural experiments" provided by the implementation of the Clean Air Act of 1970 and the recession of the early 1980s. Both the Clean Air Act and the recession induced sharper reductions in airborne particulates in some counties than in others, and they use this exogenous variation in levels of air pollution at the county-year level to identify its effects. They estimate that a one-unit decline in particulates caused by the implementation of the Clean Air Act (or recession) led to between five and eight (four and seven) fewer infant deaths per 100,000 live births. They also find some evidence that the decline in total suspended particles (TSPs) led to reductions in the incidence of low birth weight. However, only TSPs were measured at that time, so that they could not study the effects of other pollutants. And the levels of particulates studied by Chay and Greenstone (2003a, b) are much higher than those prevalent today; for example, PM10 (particulate matter of 10 microns or less) levels have fallen by nearly 50 percent from 1980 to 2000.

Several recent studies consider natural experiments at more recently encountered pollution levels. For example, the Currie, Neidell, and Schmieder (2009) study discussed above focuses on a sample of mothers who lived near pollution monitors and shows that infants exposed *in utero* to higher levels of carbon monoxide (which comes largely from vehicle exhaust) suffered reduced birth weight and gestation length relative to siblings, even though ambient CO levels were generally much lower than current Environmental Protection Agency (EPA) standards. The estimates suggest that moving from an area with high levels of CO to one with low levels of CO would have an effect larger than getting a woman who was smoking ten cigarettes a day during pregnancy to quit![7] Moreover, CO exposure increases the risk of death among newborns by 2.5 percent. The negative effects of CO exposure are five times greater for smokers than for nonsmokers, and there is some evidence of negative effects of exposure to ozone and particulates among infants of smokers. Katja Coneus and C. Katharina Spiess (2010) adopt similar methods using German data, and also find large effects of CO on infant health.

Currie and Reed Walker (2011) exploit the introduction of electronic toll collection devices (E-ZPass) in New Jersey and Pennsylvania. Since much of the pollution produced by automobiles occurs when idling or accelerating back to highway speed, electronic toll collection greatly reduces auto emissions in the vicinity of a toll plaza. They compare mothers near toll plazas to those who live near busy roadways, but farther from toll plazas, and find that E-ZPass increases birth weight and gestation. They obtain similar estimates when they follow mothers over time and compare siblings born before and after adoption of E-ZPass. E-ZPass reduced CO by about 40 percent in the vicinity of toll plazas and also reduced concentrations of many other pollutants found in vehicle exhaust. These reductions reduce the incidence of low birth weight by about one percentage point in the two kilometers surrounding the toll plaza and by as much as 2.25 percentage points in areas immediately adjacent to the toll plaza.[8]

select into higher education have higher returns to education in terms of both wages and smoking behavior. Clearly, one should be cautious about drawing inferences about the benefits of forcing would-be high school dropouts to stay in school from a study that focuses on the effects of giving women who wanted to go to college the opportunity to do so.

[6] There are some important exceptions. For example, Jennifer D. Parker, Pauline Mendola, and Tracey J. Woodruff (2008) study a natural experiment caused by the closure and reopening of a pollutant-emitting steel mill in a valley in Utah, and find that the closure reduced preterm birth.

[7] The standard for eight-hour CO concentrations is nine parts per million (ppm). The mean in our sample is 1.6ppm, but some areas had levels around four. Moving from an area with 4ppm to one with 1ppm in the third trimester would reduce the incidence of low birth weight by 2.5 percentage points, while going from ten to zero cigarettes per day would reduce low birth weight by 1.8 percentage points.

[8] In contrast to the results reported below, they did not find any impact of E-ZPass adoption on the demographic composition of births in the immediate vicinity of the

Currie and Schmeider (2009) focus on the effects of toxic emissions to the air as measured by the EPA Toxic Release Inventory (TRI), a program discussed further below. They distinguish between chemicals that are known to affect the developing fetus (developmental chemicals) and other toxins. They also distinguish between "fugitive releases" and releases that go up a smoke stack. The latter are less likely to be harmful to the plant's neighbors since stacks generally have "scrubbers" and disperse pollutants over a wide area. They find evidence of significant effects. For example, at the county level, a two-standard-deviation increase in releases of the heavy metal cadmium would increase the incidence of low birth weight by 1.2 percent, while a two-standard-deviation increase in emissions of toluene (a common volatile organic compound) would increase it 2.7 percent. Given that these are county-level average effects, it is likely that effects are much larger for those located close to the emitting facilities, as discussed further below.

Together these studies demonstrate that health at birth is sensitive to many environmental factors, including maternal behaviors like smoking (which in turn may be influenced by maternal education) and maternal exposure to pollution. They also indicate that health at birth is sensitive to maternal participation in social programs like WIC.

C. *Long-Run Consequences of Health at Birth*

In addition to showing that health at birth is influenced by many environmental factors, economists have been active in demonstrating that health at birth is predictive of future outcomes. This point is apparent in Figure 1, which is constructed using data on the children of the National Longitudinal Survey of Youth (NLSY). These are children of the original NLSY members who were 14 to 21 in 1978, and their children are now young adults. Figure 1 shows, as others have also shown (see Currie and Duncan Thomas 2001; Case and Paxson 2008, 2010; Flavio Cunha and Heckman 2008; Raj Chetty et al. 2010; Cunha, Heckman, and Susanne M. Schennach 2010; James P. Smith 2009), that indicators of human capital measured early in life are predictive of future outcomes.

What is more striking about Figure 1, is that the relationship between birth weight and future outcomes is almost as strong in this sample as the relationship between test scores and outcomes. Epidemiologists such as D. J. P. Barker (1998) have shown associations between health at birth and future health, but have not focused on measures of "economic" outcomes such as earnings and college attendance.

The association shown in the figure does not necessarily represent a causal relationship. Many omitted factors could be correlated both with negative birth outcomes and with lower future performance. Some of the most convincing studies indicating a causal relationship between health at birth and future outcomes use large national or state-level samples and show that within sibling or twin pairs, children of lower birth weight have worse adult outcomes in terms of schooling attainment, test scores, use of disability programs, residence in high-income areas, and wages (Sandra E. Black, Paul J. Devereux, and Kjell G. Salvanes 2007; Currie and Moretti 2007; Philip Oreopoulos et al. 2008; Royer 2009; Prashant Bharadwaj, Juan Eberhard, and Christopher Neilson 2010; Currie et al. 2010).

For example, extrapolated to the United States, the estimates in Black, Devereux, and Salvanes (2007) suggest that if the mean birth weight of high school educated women was increased to the mean birth weight of college educated mothers, the earnings of affected male children would increase by 2 percent, and the probability of high school graduation would increase by 1 percent among affected female children. It is important to note at this point that the long-term effects of low birth weight are themselves subject to environmental influence. Currie and Moretti (2007) find that women who were low birth weight are more likely to be poor (proxied by residence in a low income zip code at the time of their own child's birth) and have less education than other mothers. But most of this effect is accounted for by mothers who were also born in low income neighborhoods, and low birth weight has relatively little impact among women from better backgrounds.

Birth weight is the most widely available measure of fetal health, and is often treated as a

toll plazas in the three years before and after adoption. It is possible that mothers did not realize the health benefits associated with adoption, since CO is an odorless, colorless gas, and the negative health effects of ambient CO levels on fetal health are a subject of current research and therefore not widely known.

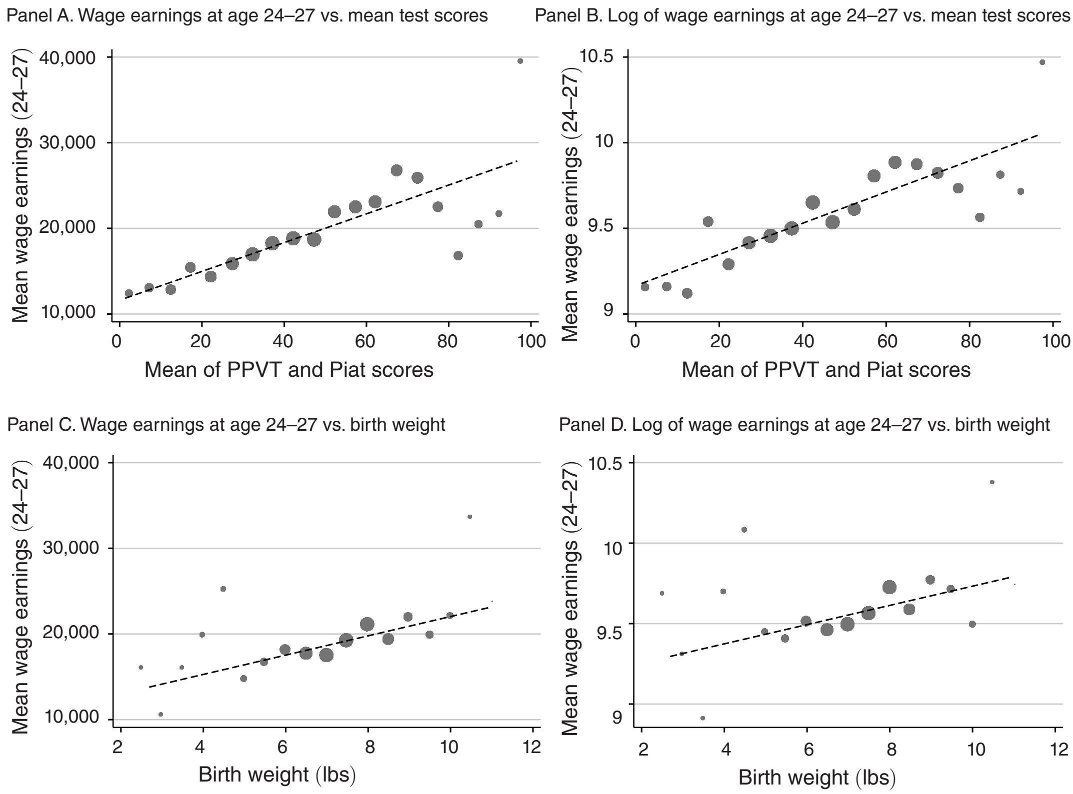

Figure 1. Correlation between Early Childhood Conditions and Adult Earnings

Notes: Plots of correlations between mean wage earnings from age 24 to 27 (in levels and logs) and early childhood conditions. Mean wage earnings are measured as the average of all reported wage earnings at age 24, 25, 26, and 27 (including zero earnings). Log wage earnings are measured as the natural log of mean wage earnings (excluding zero earnings). Mean test scores are measured as the mean of all valid PPVT, Piat Math, and Piat Reading Recognition test scores up to, and including, age six. Birth weight is measured in pounds, as reported by mothers. For these figures, test scores are divided into five-point bins (0–5, 6–10, etc.), and birth weight is divided into half-pound bins. Each data point represents the mean outcome for all observations in that bin, with the size of the point proportional to the number of observations in that bin. The dotted line represents the fitted values from an OLS regression of the earnings measure on the early childhood condition in the underlying data. Data are from the NLSY79 matched mother-child file. The sample is restricted to those born between 1980 and 1988 with valid observations for birth weight and PPVT and Piat test scores, at least one valid observation for wage earnings between age 24 and 27, and omitting those with very low and very high birth weights (<1,000 grams or >5,100 grams). The resulting sample sizes are 1,330 (panel A), 1,216 (panel B), 2,013 (panel C), and 1,825 (panel D).

summary measure. But there is reason to believe that it does not capture the full spectrum of fetal health effects (Almond, Chay, and Lee 2005). One important issue is that the fetus typically gains most of its weight in the third trimester, whereas studies often find that shocks in the first trimester are particularly harmful. Thus, birth weight may not be a sensitive measure of things that happen during the most critical period of fetal development.

Direct investigations of the long-term impacts of fetal health shocks often find large effects and enduring effects. For example, Almond, Lena Edlund, and Mårten Palme (2009) study the fallout from the Chernobyl nuclear disaster. Radiation affected some areas of Sweden but not others. By examining cohorts in affected and unaffected areas, and cohorts *in utero* just prior to the disaster and during the disaster, they are able to show that radiation exposure reduced the probability that affected children qualified for high school by 3 percent and reduced mathematics test scores by 6 percent. This result is despite the fact that, at the time, the amounts of radiation involved were considered to be so low as to be completely harmless.

Paradoxically, the long-term effects of an event like Chernobyl may be easier to identify than the effects of more severe shocks. Studies of the impact of health shocks *in utero* or early in life can come to conflicting conclusions depending on how the shock affects the probability of conception and the probability of survival for high and low income people (Carlos Bozzoli, Angus Deaton, and Climent Quintana-Domeque 2009). Migration can also make measurement of the childhood conditions of older cohorts difficult.

Two recent studies, by Yuyu Chen and Li-An Zhou (2007) and Almond et al. (2010) examine the long-term effects of the Chinese famine of 1959 to 1961 with designs that try to deal with these problems. Chen and Zhou (2007) rely on a small sample and pool children affected *in utero* with those affected in early childhood. They find evidence of significant negative effects on height, income, and labor supply. Almond et al. (2010) use data from the census, and find dramatic effects on children subjected to the famine *in utero*: affected men (women) were 9 percent (6 percent) more likely to be illiterate and 6 percent (3 percent) less likely to work. The finding of larger effects for men than for women is striking and not uncommon in the fetal effects literature. However, Robert S. Scholte, Gerard J. van den Berg, and Maarten Lindeboom (2010) examine the long-term effects of the Dutch "hunger winter" that took place during the Nazi occupation of the Netherlands in 1945 and find evidence of effects on health, but not on income or disability. They argue that long-term effects may be obscured by selection since the probability of surviving is lower for cohorts affected by the famine.

Almond (2006) studies the long run impact of the influenza epidemic of 1918 and finds that cohorts *in utero* during the peak of the epidemic had 6 percent lower income and were 1.5 percent more likely to be in poverty than those born just prior to the epidemic. Subsequent investigations have found both larger and smaller effects. Richard E. Nelson (2010) finds considerably larger effects of exposure to the 1918 epidemic using data from the Brazilian monthly employment survey. Those exposed *in utero* were 17.2 percent less likely to be employed than those in surrounding cohorts, 7.2 percent less likely to be literate, and 22.9 percent less likely to graduate from college. Elaine Kelly (2009) investigates the effects of the 1957 flu epidemic in Great Britain and finds that a one-standard-deviation increase in the severity of the epidemic reduced age 11 test scores of children who were *in utero* by 0.05 standard deviations. She also finds effects on birth weight but only for the children of the least healthy mothers. These varying findings suggest that the estimates do not only measure the biological impacts of flu—they also reflect the resources that were available to treat the afflicted, both at the time of the epidemic and afterward.

Jessica Reyes (2005) examines the phaseout of leaded gasoline in the US and finds that it led to a 3 to 4 percent decrease in low birth weight and infant mortality. The effects are identified using state-level variations in the timing of lead phaseouts. It is difficult, however, to use available US data to show evidence of a "first stage" in which the phaseouts affected ambient lead levels. J. Peter J. Nilsson (2009) investigates the long-term impact of banning leaded gasoline in Sweden during the 1970s and is able to make the connection between phaseouts and ambient lead using measures taken from moss samples. Identification comes from the fact that the ban had different impacts on different residential locations. One remarkable thing about his sample is that at the time of the phaseout, peak child blood levels in Sweden were already below the ten micrograms per deciliter that is the current "threshold for concern" in the US, so his results pertain to a level of lead emissions that is relevant for the US today. His estimates imply that reducing levels from ten to five micrograms per deciliter would increase high school graduation rates by 2.3 percent and increase mean earnings between ages 20 and 32 by 5.5 percent. He finds larger effects on children of lower socioeconomic status, even among those who grew up in the same neighborhood.

Nicholas J. Sanders (2010) builds on the work of Chay and Greenstone by asking whether high school students who were affected by the reductions in pollution caused by the recession of the early 1980s have higher test scores as a result. Sanders finds that a one-standard-deviation decrease in total suspended particles while the child was *in utero* is associated with an increase of 1.87 percent of a standard deviation in high school test scores.[9]

These studies illustrate the fact that health at birth is predictive of future outcomes. This relationship has been demonstrated in a wide range of settings and suggests that poor health at birth could be a cause of low socioeconomic status in adulthood. Moreover, direct estimates of the impact of fetal health shocks indicate that estimates based on birth weight could understate the magnitude of the harm.

D. *The Intergenerational Transmission of Shocks to Health at Birth*

While the papers discussed above emphasize that health at birth is important for an individual's outcomes, economists have also shown that a mother's health at birth affects her child's future health. For example, Dora L. Costa (1998) argues that much of the inequality in birth weight observed over the course of the twentieth century was due to differences in mothers' early health endowments.

The Currie and Moretti (2007) study discussed above uses a large sample of sisters drawn from California birth certificates from the 1960s to the 1990s. Birth certificates record the mother's state of birth. For mothers who were born in California during that interval, it was possible to go back and find the mother's birth certificate, and to identify mothers who were sisters. Thus, there is some information about both an infant's birth weight and the mother's birth weight, and there is information about maternal circumstances at the time of her infant's birth, as well as at the time of her own birth.

Sister comparisons using this dataset show that women who were low birth weight are more likely to deliver low-birth-weight infants, and this effect is greater if the women are living in a low income neighborhood. What these results indicate is that like height, low birth weight is transmissible for reasons that are not purely genetic, since low adult socioeconomic status compounds the negative impact of maternal low birth weight, and makes it more likely that the child will also be low birth weight.

It has been known for some time from animal studies that environmentally induced changes in the epigenome can be transmitted from parents to offspring. For example, R. J. C. Stewart et al. (1980) starved pregnant rats and found that it took several generations for the descendants of the starved rats to return to the size of the control, nonstarved rats, even when all descendants shared the same diet.

The social science study that comes closest to suggesting that a similar mechanism might be at work in explaining the transmission of low birth weight is Almond and Chay (2006). They build on previous work showing that the civil rights movement had a large effect on the health of black infants in some southern states, especially Mississippi, due to the desegregation of hospitals and increased access to medical care (Almond, Chay, and Greenstone forthcoming). For example, there was a large decline in deaths due to infectious disease and diarrhea in these cohorts. Because birth records include the mother's state of birth, it is possible to identify black women who benefited from these changes (the 1967 to 1969 cohorts) regardless of their state of residence as adults, and to compare the outcomes of their infants to the outcomes of infants born to black women in the 1961 to 1963 birth cohorts. The birth outcomes of white women in the same cohorts are examined as a control. Almond and Chay (2006) conclude that the infants of black women who had had healthier infancies as a result of the civil rights movement show large gains in birth weight relative to the infants of black women born just a few years earlier, and that these gains are largest for women from Mississippi—the most affected state.

To summarize, there are large inequalities in health at birth. Despite the stability of these inequalities over time, we know that health at birth is amenable to a range of interventions. Moreover, health at birth has a causal impact on a wide range of outcomes, both among affected individuals and among their children, though the extent to which it does so is itself mediated by environmental factors.

II. Health at Birth and Environmental Justice

The preceding discussion suggests that many differences that appear to be innate may in fact

[9] A caveat is that he does not actually observe where the children were *in utero*, and so must assume that they were born in the location of residence during high school. He proposes an instrumental variable based on a "shift-share" analysis projecting state-level changes in industrial composition to the local level based on initial local employment shares.

be the product of environmental factors. The papers reviewed above suggest that residential location may be a key determinant of an infant's environment. For example, we saw that high poverty neighborhoods, proximity to toxic releases, and proximity to toll plazas were all associated with worse health at birth.

One version of the environmental justice hypothesis holds that minorities are more likely to be exposed to pollution because new pollution sources are more likely to be located in minority neighborhoods, or because clean-ups are more likely to occur in affluent neighborhoods. However, recent investigations by environmental economists (Shreekant Gupta, George Van Houtven, and Maureen L. Cropper 1995; W. Kip Viscusi and James T. Hamilton 1999; Hilary Sigman 2001) show little support for this hypothesis. For example, a recent paper examining reductions in nitrogen oxide emissions in response to a mandated program found no evidence that changes in emissions varied with neighborhood demographic characteristics (Meredith Fowlie, Stephen P. Holland, and Erin T. Mansur 2009). Wayne B. Gray and Ronald J. Shadbegian (2002) actually find that plants with more nonwhites nearby emit less pollution.

Instead, the economics literature implicitly suggests that if poor and minority children are more likely to be exposed to pollution, this may be because their parents are less likely to move away from environmental hazards. If pollution depresses housing prices, polluted neighborhoods may become more attractive to poor families. Alternatively, perhaps some groups are less able to process and act on information about hazards. There have been surprisingly few attempts to test these conjectures directly by looking at residential mobility. Some tests along these lines are discussed below. A theme that emerges is that the answers to these questions are clearer when one has access to continuous data at a fine level of geographical disaggregation.

This section addresses two hypotheses arising from the environmental justice literature. The first question is whether the children of minority and less educated mothers are, in fact, more likely to be exposed to pollution *in utero*? There is a large literature outside of economics that addresses this issue. Many of these studies focus only on a particular town or area, so that it is difficult to generalize or to see regional patterns. By using individual-level data on millions of births from five large states, and the mother's exact residential location, I will address this question with more precision than has been possible previously.

The dataset used here combines individual-level information about 11 million births that took place in five large states (Florida, Michigan, New Jersey, Pennsylvania, and Texas) between 1989 and 2003 with information about two sources of pollution: Superfund sites and facilities listed in the EPA TRI. Given that the birth data include the mother's residential address, it is possible to calculate her distance from a Superfund or TRI site in meters. The sample is restricted to singleton births.[10]

In 1980, the outcry over the health effects of toxic waste in Love Canal, New York, resulted in the Comprehensive Environmental Response, Compensation, and Liability Act, which became known as Superfund. [11] Superfund was intended to provide a mechanism for initiating clean-ups at the most dangerous hazardous waste sites. More than 1,500 sites are eligible for cleanup nationally; our sample includes 426 sites. The Superfund data are similar to those analyzed in Greenstone and Justin Gallagher (2008), and in Currie, Greenstone, and Moretti (2011).[12]

The TRI was created by the Emergency Planning and Community Right to Know Act (EPCRA) in 1986, in response to the Bhopal disaster and a series of smaller spills of dangerous chemicals at Union Carbide plants in the US. Bhopal added urgency to the claim

[10] Multiple births are excluded because they are much more likely to have health problems. However, including multiple births does not alter the conclusions reported here.

[11] Love Canal is a neighborhood in Niagara Falls, New York, which became notorious when it was discovered that the neighborhood (including a school) was built on top of 21,000 tons of dangerous chemical wastes, including dioxin. Construction activity at the site released the wastes leading to severe health problems. Eventually, the federal government stepped in and evacuated the residents.

[12] The data were downloaded from the EPA Superfund Information Systems website (http://cfpub.epa.gov/supercpad/cursites/srchsites.cfm) on 9/17/2008. Each National Priorities List (NPL) site has its own webpage. The data on these webpages were parsed from HTML to comma-separated value format using a custom Python script. The initiation of the cleanup was coded using the starting date of the first "Remedial Action" after a "Record of Decision." The site's cleanup completed date was coded as the date for "Construction Complete." If no such date was listed, then the site was considered to be precompletion.

Table 2—Fraction within 2,000 Meters of a Toxic Release Inventory or Superfund Site

	TRI		Superfund	
	Mean	SD	Mean	SD
All mothers	**0.4691**	0.4990	**0.0174**	0.1310
White mothers	**0.4051**	0.4909	**0.0159**	0.1250
Black mothers	**0.6121**	0.4873	**0.0298**	0.1701
Hispanic mothers	**0.5153**	0.4998	**0.0137**	0.1161
White mothers with college or more	**0.3725**	0.4835	**0.0114**	0.1190
White mothers with <HS education	**0.4444**	0.4969	**0.0174**	0.1307
Black mothers with <HS education	**0.6701**	0.4701	**0.0367**	0.1881
Hispanic mothers with <HS education	**0.5630**	0.4960	**0.0139**	0.1172

Notes: Sample is singleton births from 1989 to 2003 in Florida, Michigan, New Jersey, Pennsylvania, and Texas. For Superfund, births conceived after the initiation of a cleanup are omitted. There are 11.4 million observations in the TRI sample, and 9.2 observations in the Superfund sample.

that communities had a "right to know" about hazardous chemicals that were being used or produced in their midst. EPCRA required manufacturing plants (those in Standard Industrial Classifications 2,000 to 3,999) with ten or more full-time employees that either use or produce more than threshold amounts of listed toxic substances to report releases to the EPA for public disclosure.[13]

A possible drawback to using data on births is that pollution could affect the probability of a conception or of a live birth. If we suppose that pollution abatement would lead to fewer fetal deaths, and more births, and that the marginal fetus lost due to pollution is more vulnerable and less healthy than others, then focusing on births will tend to understate the beneficial effects of abatement by increasing the number of less healthy infants whose birth weight is recorded. It is difficult to look at fetal deaths directly, given that they are not required to be reported in most states until after 20 weeks, whereas most fetal losses occur in the first trimester of pregnancy. Hence, the results below should be interpreted keeping this potential source of downward bias in mind.

Table 2 shows that in our five-state sample of births, nonwhites are in fact much more likely to live within 2,000 meters of a TRI or Superfund site. There is also a gradient by education within race, though it is much smaller. It is conceivable that these raw differences reflect other characteristics that are correlated with both race/ethnicity and residential location. For example, it is not uncommon for studies of Environmental Justice to find that counties with manufacturing plants emitting toxic releases are both more heavily African American and higher income, a finding that may just reflect the fact that these counties also tend to be more urban.

Table 3 shows estimates from linear probability models of the form

$$(1)\quad \Pr(\text{live} < 2{,}000\text{m facility}) = \beta_0 + \beta_1 X + \beta_2 Zip + \beta_3 Year + \varepsilon,$$

where the dependent variable is whether an individual mother lives within 2,000 meters of a facility. The vector X includes controls for the mother's race/ethnicity, mother's education (less than high school, high school, some college, college, or more), mother's age (less than 20, 20 to 24, 25 to 29, 30 to 34, 35 to 39, and 40 or over), parity (first, second, third, fourth, or higher order birth), and child gender. When control variables are missing, the regressions include indicators for missing values. The models include zip code fixed effects to control for other characteristics of the location as well as indicators for each year

[13] Plants are required to file a separate form for each substance and must identify whether the release was to ground, water, or air. Like Currie and Schmeider (2009), I focus on airborne releases because people living close to a plant may be more likely to be exposed to them than to water or ground releases. The previous calendar year's toxic releases are required to be reported by July 1. Several studies have examined compliance to the reporting regulations and data quality (see Gerald V. Poje and Daniel M. Horowitz 1990; John Brehm and Hamilton 1996; Thomas E. Natan and Catherine G. Miller 1998; Scott de Marchi and Hamilton 2006; Dinah A. Koehler and John D. Spengler 2007). While these papers point to some underreporting, overall compliance was high and changes in reported releases correspond to changes in plant operations and production levels.

Table 3—Within Zip Code Differences in Maternal Characteristics between Those within 2,000 Meters and Those farther from a Superfund or Toxic Release Inventory Site

Characteristics	Superfund	Toxic releases
High school graduate	−0.0006	−0.0115
	[0.0005]	[0.0006]**
Some college	−0.0015	−0.0214
	[0.0004]**	[0.0008]**
College graduate	−0.0032	−0.0375
	[0.0005]**	[0.0011]**
Black	0.0074	0.0532
	[0.0019]**	[0.0019]**
Hispanic	0.0003	0.0398
	[0.0012]	[0.0011]**
Smoker	0.0012	0.0117
	[0.0003]**	[0.0006]**
Age 20–24	0.0006	0.0021
	[0.0003]*	[0.0005]**
Age 25–29	0.0006	0.007
	[0.0004]	[0.0006]
Age 30–34	−0.0004	−0.0193
	[0.0005]	[0.0008]**
Age 35–39	−0.0006	−0.0256
	[0.0010]	[0.0009]**
Age 40+	−0.001	−0.0282
	[0.0009]	[0.0011]**
Constant	0.0323	0.4815
	[0.0062]**	[0.0014]**
R^2	0.307	0.507
Observations	9,169,128	11,410,768

Notes: All regressions include zip code fixed effects and year fixed effects (as well as indicators for whether the child is male), parity, and indicators for missing values of the controls. All samples include only singleton births between 1989 and 2003 in Florida, Michigan, New Jersey, Pennsylvania and Texas. For Superfund, births conceived after the initiation of a cleanup are omitted.

***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

of birth: hence, these models ask whether within zip codes, minority mothers and/or less educated mothers are more likely to live near TRI or Superfund sites. Standard errors are clustered at the county-year level to allow for correlations within those cells.

The first column of Table 3 shows the probability of living near a site falls with education but is roughly 40 percent higher for African American women than for others. It is interesting that, conditional on the other factors, smokers are more likely to live near a Superfund site, perhaps indicating a role for tastes.

Column 2 shows that the same patterns hold but are stronger for residence near a TRI site. Overall, almost half the sample lives within 2,000 meters of a TRI site. Even within zip code, the college educated are 3.8 percentage points less likely to live close to a site, while African American and Hispanic women are 5.3 and 4.0 percentage points more likely to live close to a site, respectively. Smokers are also more likely to live close to TRI sites. It is striking that older mothers are much less likely to live close to a TRI site.[14]

These estimates strongly support the claims of the environmental justice literature that minorities and people of lower socioeconomic status are more likely to be exposed to potentially harmful pollutants for reasons that cannot be explained by their broad geographical distribution, education, or other observable characteristics. They suggest that data collected at a fine enough level of disaggregation can deliver a clear answer to this question.

B. *Voting with the Feet*

A second question that can be addressed with these data is whether mothers move when there are changes in environmental conditions. A large number of studies have investigated this question using hedonic models of housing prices.[15] For example, Chay and Greenstone (2005) use a discontinuity created by the implementation of the Clean Air Act as an instrument for reductions in air pollution between 1970 and 1980. They find that the large reductions in pollution that were mandated in counties that were out of compliance with pollution standards were capitalized into housing prices.

However, the estimated effects of amenities on housing prices often vary considerably from study to study (V. Kerry Smith and Ju-Chin Huang 1995). For example, Linda T. M.

[14] This could be partially an effect of income given that income is not available in the data and hence not included in the regressions. But since the models do control for zip code, the difference between a high income and a low income zip code is controlled. It may also be a function of tastes: it is possible that women who give birth at older ages are more cautious about environmental hazards.

[15] See Smith and Huang (1995) and Nicolai V. Kuminoff, Smith, and Christopher Timmins (2010) for surveys of this literature.

Bui and Christopher J. Mayer (2003) found no effect of toxic releases on housing prices at the zip code level. But Felix Oberholzer-Gee and Miki Mitsunari (2006) find that average housing prices fell after the TRI data were first released in June 1989, and that they fell most in houses less than a half mile from an emitting plant.

Limitations of housing price data and hedonic models of housing prices make it useful to look more directly at whether residents "vote with the feet" following changes in neighborhood amenities (Charles M. Tiebout 1956). One obvious limitation is that housing prices are observed only when houses are sold. Hence, if a disamenity is such that it results in unsold or even abandoned housing, it may be difficult to see this in the housing price data. Second, data on housing sales often have only limited information about the characteristics of the structures, making it difficult to ascertain that "treatment" housing units are similar to "controls." Third, the people most affected by environmental disamenities may be renters rather than owners, so their transactions are not observed.

A more subtle point given the literature on "tipping" (see David Card, Alexandre Mas, and Jesse Rothstein 2008) and on the way that people of different racial or ethnic groups sort across neighborhoods (Patrick Bayer, Fernando Ferreira, and Robert McMillan 2007) is that it is possible for the character of a neighborhood to change considerably even without a change in housing prices. For example, Bayer, Ferreira, and McMillan (2007) conclude that consumer preferences for racial segregation can generally be accommodated without the need for price differences to clear markets.

A handful of previous studies have conducted direct investigations of the relationship between environmental amenities and mobility using decennial census data. Trudy Ann Cameron and Ian T. McConnaha (2006) examine changes in demographic characteristics around four Superfund sites at various stages of cleanup. Using data on the census tract level, they do not find consistent patterns across sites, however. Greenstone and Gallagher (2008) also use data at the census tract level and find little change in the demographic composition of tracts in census years before and after Superfund cleanups.

H. Spencer Banzhaf and Randall P. Walsh (2008) overlay California with half-mile diameter circles. Focusing on circles that had a TRI facility, they then show that areas in which releases increased (or decreased) experience losses (or gains) in population between 1990 and 2000. The main potential difficulty is that other things might have changed in these neighborhoods between 1990 and 2000—for example, plant shutdowns would reduce pollution, but might also reduce employment opportunities.

In this section I first ask whether there is any evidence of maternal sorting in response to Superfund cleanups. The Vital Statistics Natality Data offer a complete census of births, which is the relevant population for examining infant health, and the fact that it is continuous is a great advantage over decennial census data. As discussed above, I can also look at individual mothers in a given radius of a Superfund site, rather than using means taken over an arbitrary geographic unit.

In order to examine the effects of cleanups, I estimate difference-in-differences models of the form

$$
\begin{aligned}
(2)\quad & \Pr(\textit{Maternal Characteristic}) \\
& = \beta_0 + \beta_1 \textit{Close} + \beta_2 \textit{After Cleanup} \\
& \quad + \beta_3 \textit{During Cleanup} + \beta_4 \textit{Close} \\
& \quad \times (\textit{During Cleanup}) + \beta_5 \textit{Close} \\
& \quad \times (\textit{After Cleanup}) + \beta_6 \textit{Zip} \\
& \quad + \beta_7 \textit{Year} + \varepsilon,
\end{aligned}
$$

where the dependent variable is the probability that a mother belongs to a particular demographic group (such as "white college educated"), the sample is restricted to people within 5,000 meters of a Superfund site, and "*Close*" is defined as being within 2,000 meters of a Superfund site. "*During Cleanup*" means that a cleanup was initiated but was not yet complete, and "*After Cleanup*" indicates that the cleanup was complete.[16] *Zip* and *Year* are defined as in model (1). Here timing refers to the date of conception, and children conceived more than four years prior to the start of a cleanup, or more than four years after the completion of a cleanup, are excluded in

[16] The average Superfund site in our sample is 495 acres, or about 2 square kilometers.

order to focus on children in a relatively narrow window around Superfund cleanups. Standard errors are clustered at the county-year level to allow for correlation in the errors at that level.

The key coefficient of interest is β_5, which can be interpreted as measuring the extent to which the area surrounding a Superfund site became "whiter" (for example) after a cleanup.[17] An area could become whiter due to an appreciation in housing values following a site cleanup (Shanti Gamper-Rabindran and Timmins 2011). But this is not the only possible mechanism. It is possible that different groups place different values on environmental amenities, on average. Finally, it is possible that the removal of one disamenity makes other characteristics of the neighborhood more salient and that these characteristics are valued differently by different groups (as in Banzhaf and Walsh 2010).

The difference-in-differences formulation controls for other things that might be expected to occur, both in the immediate vicinity of a site and a little farther away. For example, if white college educated women have lower fertility on average than other groups, this should be true both within 2,000 meters of a Superfund site and between 2,000 and 5,000 meters of a site. A potential objection to the model is that the probability of cleanup may be related to characteristics of mothers near the site. However, consistent with the previous literature on the subject cited above, I find little evidence that this is the case.

Estimates from equation (2) are shown in Table 4. Here, each column includes estimates from a separate regression. The first panel shows estimates for all cleanups, while the second panel considers only cleanups of sites in the top third of the distribution of hazardous risk assessment scores (HRS). The estimates of β_5 show that Superfund cleanups have a significant effect in the equation for "white college educated" mothers: mothers in the immediate vicinity of a Superfund site are more likely to be white and college educated following cleanups. This effect is larger for the most dangerous sites, and the estimated effect of cleanup also becomes statistically significant at the 90 percent level of confidence in the equation for all white mothers, indicating that areas surrounding the most dangerous Superfund sites do become whiter following site cleanup. The coefficients on cleanup in the equations for black mothers are negative yet not statistically significant, suggesting that there may be an offsetting loss of black residents following cleanup, although I do not have the power to detect it. Overall, the results suggest educated, white mothers are more likely than other groups to respond to Superfund cleanups.

It is possible that education matters because it helps people to process information. The pure effect of information can be assessed by exploiting changes in the TRI program's reporting requirements. In 1999 reporting thresholds were dramatically lowered for persistent bioaccumulative toxins (PBTs). The amounts triggering reporting requirements fell from 10,000 pounds to 100 or 10 pounds (or to 0.1 gram in the case of dioxin) depending on the toxin. These new reports were due in 2001 and first became available in June 2002. This change in reporting requirements led 609 factories to begin to report that they emitted PBTs. In most cases, these factories were already reporting that they emitted other chemicals. Hence, mobility responses to the new PBT reporting requirements shed light on the extent to which people who presumably already know that they live close to a plant emitting toxic chemicals respond to the announcement that the plant emits a particularly dangerous chemical, such as arsenic or mercury.[18]

[17] The expected sign of β_2 is ambiguous. On the one hand, during the cleanup people might look forward to living in a cleaner neighborhood or foresee rising property values as a result of the cleanup that is in process. On the other hand, the active cleanup may itself entail inconveniences for residents, and is an active reminder of the presence of the Superfund site.

[18] The interpretation of other changes in reporting requirements is less clear. For example, in 1998, seven new SIC categories were added to the list of facilities required to report (metal mining, coal mining, electric utilities, petroleum bulk terminals, chemicals wholesalers, RCRA commercial hazardous waste treatment, and solvent recovery). People living near these facilities did not previously have any way of knowing what they emitted and could conceivably have been reassured by the reports. Newly included companies filed their first reports in 1999, and the data were released to the public in 2000. I do not find a significant effect of this change on the composition of mothers in the neighborhood of the new reporters. If the PBT plants and the new SIC plants are combined, the results are similar to those reported here for the PBT plants. Thresholds for reporting lead were lowered to 100 pounds in 2001, with the first new reports becoming available to the public in June 2003. Since the dataset currently ends in 2003, there is not enough of an "after" period to examine this change.

TABLE 4—EFFECTS OF SUPERFUND CLEANUPS ON CHARACTERISTICS OF MOTHERS WITHIN 2,000 METERS OF A SITE

Characteristic:	White (1)	White college (2)	Black (3)	Black < HS (4)	Hispanic (5)
Full sample					
Close	−0.0136	−0.0466	0.0238	0.0053	0.0078
	[0.0136]	[0.0066]**	[0.0128]	[0.0059]	[0.0127]
During × close	0.0125	0.0102	−0.0143	−0.0042	−0.0009
	[0.0103]	[0.0060]	[0.0102]	[0.0046]	[0.0096]
After cleanup × close	0.0034	0.0147	−0.0148	−0.0016	0.0060
	[0.0148]	[0.0069]**	[0.0134]	[0.0060]	[0.0119]
Mean dependent variable	0.7688	0.1454	0.2168	0.0639	0.1535
R^2	0.4149	0.1768	0.4346	0.1375	0.3665
Top HRS sites					
Close	−0.0214	−0.0455	0.0348	0.0136	0.0044
	[0.0249]	[0.0085]**	[0.0287]	[0.0126]	[0.0297]
During × close	0.0320	−0.0001	−0.0191	−0.0107	0.0073
	[0.0171]	[0.0096]	[0.0210]	[0.0082]	[0.0214]
After cleanup × close	0.0395	0.0232	−0.0370	−0.0089	0.0145
	[0.0235]*	[0.0112]**	[0.0283]	[0.0116]	[0.0283]
Mean dependent variable	0.7486	0.1350	0.1850	0.0490	0.2218
R^2	0.4248	0.1538	0.3818	0.1172	0.3829

Notes: Standard errors are clustered at the county-year level and appear in brackets. Only singleton births conceived between four years prior to the initiation of a cleanup and four years after completion are included. Only births within 5,000 meters of a site are included. "Close" is defined as within 2,000 meters of the site. Regressions control only for year of birth and zip code. There are 618,726 observations in the first panel and 267,852 observations in the second panel.

***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

Table 5 reports estimates from differences-in-differences-in-differences models that exploit comparisons between those who are closer or farther from a TRI plant; between TRI plants that were affected by the new PBT regulations and those that were not; and between births before and after the first announcements were made. These models take the following form:

$$(3)\quad \Pr(Maternal\ Race/Ethnicity) = \beta_0 + \beta_1 Close + \beta_2 PBT + \beta_3 After + \beta_4 Close \times PBT + \beta_5 Close \times After + \beta_6 PBT \times After + \beta_7 PBT \times Close \times After + \beta_8 Zip + -\beta_9 Year + \varepsilon,$$

where *PBT* indicates that the TRI site was affected by the new regulations, and *After* denotes a time after the first announcement has been made (since the announcements were made in the middle of the year, "after" is not entirely collinear with the year dummies). The sample is restricted to those within 4,000 meters of a TRI site. The other variables are defined as in model (2). The model is estimated using data from 1995 to 2003.

Table 5 confirms that white mothers, and especially white college educated mothers, are less likely to live near a TRI plant than other mothers, while black and Hispanic mothers are more likely to live near these plants. Prior to the new announcement about PBTs, white women were more likely than other women to live near plants that would be affected by the requirement. One way to interpret this result is that, conditional on living within 4,000 meters of a TRI plant, white women were more likely to live near a plant that was emitting PBTs at levels less

Table 5: Effects of New Report That the Closest TRI Site Emits PBTs on Characteristics of Mothers within 2,000 Meters of a Site

Characteristic	White (1)	White college (2)	Black (3)	Black < HS (4)	Hispanic (5)
Close to any TRI	−0.0490	−0.0395	0.0227	0.0110	0.0271
	[0.0026]**	[0.0019]**	[0.0027]**	[0.0010]**	[0.0025]**
Any new PBT reporter within 4,000 meters	0.0125	0.0064	−0.0113	−0.0011	0.0014
	[0.0061]**	[0.0049]	[0.0043]**	[0.0018]	[0.0037]
Close × new PBT reporter	−0.0026	−0.0026	0.0013	−0.0024	0.0032
	[0.0059]	[0.0038]	[0.0060]	[0.0019]	[0.0036]
After × close	0.0087	0.0053	−0.0091	−0.0048	0.0006
	[0.0032]**	[0.0024]**	[0.0029]**	[0.0012]**	[0.0026]
After × new PBT reporter	0.0051	0.0111	−0.0009	−0.0016	−0.0024
	[0.0092]	[0.0051]**	[0.0058]	[0.0022]	[0.0085]
After × close × new PBT reporter	−0.0064	−0.0113	0.0013	0.0036	0.0028
	[0.0100]	[0.0056]**	[0.0079]	[0.0031]	[0.0080]
Mean dependent variable	0.4900	0.1570	0.1960	0.0530	0.2720
R^2	0.4132	0.1893	0.3893	0.1308	0.4053
Observations	5.06 million				

Notes: Standard errors are clustered at the county-year level and appear in brackets. Only singleton births between 1995 and 2003 are included. Only births within 4,000 meters of a site are included. "Close" is defined as within 2,000 meters of the site. Regressions control for year of birth, zip code, and a dummy for "after" the announcement since the announcement occurs in the middle of the year.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

than the old 10,000 pound threshold, but higher than the new threshold. The coefficient β_5 on "*Close* × *After*" is positive for white women and negative for black women, suggesting that, over time, white women were more likely to live near TRI plants, while black women were less likely to live nearby. This pattern may be explained by the reduction in TRI emissions that has occurred over time, which has made such areas more attractive places to live (see Banzhaf and Walsh 2008; Currie and Schmeider 2009).

Estimates of the key coefficient β_7 on the triple interaction (*PBT* × *Close* × *After*) are statistically significant only for white college educated women and suggest that there was a large reduction in the probability that mothers in this category lived near the PBT emitters following disclosure of this information. The coefficient estimate suggests an 8.7 percent reduction in the fraction of mothers near such plants relative to the population of white college educated mothers living within 4,000 meters of a TRI plant.

Is such a large effect of information credible?[19] The EPA posts information from the TRI on its website, but it can be difficult to use and to interpret. However, many organizations synthesize and publicize data from the TRI. For example, organizations such as Scorecard: The Pollution Information Site (http://www.scorecard.org/env-releases/community.tcl 2005) and the Public Interest Research Group (see Abigail Caplovitz Field 2007) process and disseminate information from the TRI widely. And many state governments also disseminate information from the TRI (Hyunhoe Bae, Peter Wilcoxen, and David Popp 2008). Moreover, it is plausible that the largest effects of information (and indeed the

[19] Experiments aimed at evaluating the impact of giving consumers financial information typically have shown small effects on things like decisions about retirement plans (see Esther Duflo and Emmanuel Saez 2003; John Beshears et al. 2009; Marianne Bertrand and Adair Morse 2009). But mothers may feel more strongly about fetal health than about their retirement plans.

only statistically significant effects) should be on those with more education (Jay P. Shimshack, Michael B. Ward, and Timothy K. M. Beatty 2007). Finally, the results are consistent with those for the Superfund cleanups, where I also found larger effects for white college educated women than for others. These results suggest yet another channel through which maternal college education can affect infant health.

The preceding discussion raises some important questions. First, how much of the persistent gap in health at birth is likely to be explained by exposure to environmental toxicants? Answering this question is difficult given the rudimentary state of knowledge regarding the health effects of toxicants. For example, there are many chemicals included in the TRI for which the EPA has no risk score, and/or for which no information exists about whether the chemical is harmful to the human fetus. Even for criterion air pollutants such as CO, until recently little attention had been paid to the possible fetal health effects of ambient levels below the current EPA thresholds for concern.

Currie, Lucas Davis, and Walker (2011) use TRI plant closures as an instrument for releases and find that among mothers within 2,000 meters of a plant, a two-standard-deviation reduction in pollution reduces the incidence of low birth weight by approximately 0.02. Given the ten percentage point gap in the incidence of low birth weight between white college educated mothers and black high school dropout mothers, if all of the latter and none of the former lived near a plant, and if we assume that toxic releases increase LBW by 0.02 for those near the plant and have no impact on those more than 2,000 meters from the plant, then exposure to toxic releases could potentially explain a fifth of the gap between the two groups.

Of course, actual sorting is less extreme. If we maintain the assumptions about the relative magnitudes of the effects of toxic releases on those closer and farther from a plant, and use the actual distributions of locations shown in Table 2, then the estimates suggest that 6 percent of the gap in low birth weight between white college educated mothers and black high school dropout mothers could be attributed to differences in exposures from TRI plants.[20] This is a large enough share to suggest that while releases from TRI plants are not a "smoking gun" that explains the differential, they could be an important factor. Moreover, airborne emissions from TRI plants are not the only source of toxic exposures for the fetus and may not be the most important. For example, there are many potential sources of toxicants within the household such as tobacco smoke (as discussed above), plasticizers, and pesticides (see Virginia A. Rauh et al. 2006).

A second question concerns the incidence of environmental policies. If educated white mothers respond to environmental remediation policies and others do not, then place-based policies may exacerbate inequalities. If an area "gentrifies" in response to environmental policies, then this will tend to benefit property owners but may harm renters. Clearly, as Ian W. H. Parry et al. (2006) and Don Fullerton (2008) emphasize, it is important to understand the incidence and distributive effects of environmental policies and there is relatively little known about these issues. It may be that person-based policies such as the WIC are more equitable and effective remediation tools than place-based policies.

III. Conclusions and Directions for Future Research

This essay shows that inequality begins well before school age and, indeed, before birth, and that large differences in health at birth have important consequences for future outcomes. What is just as important, however, is to understand the malleability of health at birth. Many interventions have been demonstrated to either help or harm children while they are still in the womb. Hence, we cannot assume that differences that are present at birth reflect unchangeable, genetic factors. The new science of epigenetics makes it clear that they are much more likely to reflect interactions between "nature" and "nurture."

The fact that interventions can change health at birth does not mean that it will be easy to address sources of inequality at birth. As this

[20] For white college educated mothers, $0.3725x + 0.6275(x - 0.02) = 0.038$, where x is the incidence of LBW in the absence of toxic releases. For black mothers with less than high school education, $0.6701x + 0.3299(x - 0.02) = 0.138$. Hence, in the absence of toxic releases the rates of LBW would be 0.0306 and 0.1246, respectively, and the gap would be 0.0940 rather than 0.1.

essay has shown with an extended example, economic factors may tend to undo the effects of policy. This may be particularly likely when more advantaged people grasp the benefits of the policy more readily than those who are less advantaged.

Future research should be aimed at identifying the most important sources of inequalities at birth. This essay suggests that differential exposure to environmental toxicants is an important factor, but only one among many. Research must also evaluate the effectiveness and distributional consequences of policies intended to address inequalities at birth. For example, higher education for mothers appears to have beneficial effects on infant health through multiple pathways, but there is great controversy about the best ways to improve educational attainment. Moreover, policies designed to encourage education may reach a different part of the distribution of potential mothers than policies aimed at improving nutrition or health care among pregnant women.

Clearly, much work remains to be done documenting the consequences of inequality at birth and improving our understanding of its consequences over the life cycle; investigating the effects of policy, including the possible countervailing actions of economic agents; and, in the spirit of Richard Ely, asking: what types of interventions are most likely to give children "a fair start in life?" This is an exciting research agenda, and one that is still in its infancy!

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