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TYPICALLY UNOBSERVED VARIABLES (TUVS) AND SELECTION INTO PRENATAL INPUTS: IMPLICATIONS FOR ESTIMATING INFANT HEALTH PRODUCTION FUNCTIONS

Nancy E. Reichman
Hope Corman
Kelly Noonan
Dhaval Dave

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ABSTRACT

We examine the extent to which infant health production functions are sensitive to model specification and measurement error. We focus on the importance of typically unobserved but theoretically important variables (TUVs), other non-standard covariates (NSCs), input reporting, and characterization of infant health. The TUVs represent wantedness, taste for risky behavior, and maternal health endowment. The NSCs include father and family structure characteristics. We estimate effects of prenatal drug use, prenatal cigarette smoking, and first trimester prenatal care on birth weight, low birth weight, and a measure of abnormal infant health conditions. We compare estimates using self-reported inputs versus input measures that combine information from medical records and self-reports. We find that TUVs and NSCs are significantly associated with both inputs and outcomes, but that excluding them from infant health production functions does not appreciably affect the input estimates. However, using self-reported inputs leads to overestimated effects of inputs, particularly prenatal care, on outcomes, and using a direct measure of infant health does not always yield input estimates similar to those when using birth weight outcomes. The findings have implications for research, data collection, and public health policy.

Nancy E. Reichman
Robert Wood Johnson Medical School
University of Medicine and Dentistry of New Jersey
97 Paterson St., Room 435
New Brunswick, NJ 08903
reichmne@umdnj.edu

Hope Corman
Department of Economics
Rider University
Lawrenceville, NJ 08648-3099
and NBER
corman@rider.edu

Kelly Noonan
Department of Economics
Rider University
2083 Lawrence Road, Room SWG 306
Lawrenceville, NJ 08648
and NBER
knoonan@rider.edu

Dhaval Dave
Bentley College
Department of Economics
175 Forest Street, AAC 195
Waltham, MA 02452-4705
and NBER
ddave@bentley.edu

Introduction

Poor health at birth, typically operationalized as low birth weight, often leads to subsequent health and developmental problems, poor school performance, and adverse adult labor market outcomes (Kaestner and Corman 1995; Conley and Bennett 2000; Matte et al. 2001; Boardman et al. 2002; Conley, Strully and Bennett 2003; Case, Lubotsky and Paxson 2002; and Case, Fertig and Paxson 2005). It also generates substantial costs to health care, education, and public assistance systems (Chaikind and Corman 1991; Lewit et al. 1995).

Economists and researchers in a variety of other disciplines have long been interested in estimating the effects of prenatal inputs, such as prenatal care and cigarette smoking, on infant health outcomes (typically birth weight and infant mortality). Although correlations have been well established, it is extremely difficult to isolate causal effects because there may be unobserved "third factors" associated with both inputs and outcomes—a problem often referred to in the economics literature as endogeneity and in the medical and public health literature as confounding.[1] Another complication is that prenatal care and substance use are often misreported in birth certificates and household surveys—the two key sources of data used to analyze infant health (Penrod and Lantz 2000; Reichman and Hade 2001; Harrison, Haaga and Richards 1993). Such misreporting can result in biased estimates.

Economists have come far in understanding the causal relationships between specific inputs and birth outcomes, but much more still needs to be learned. Instrumental variables techniques, in theory, can produce unbiased estimates of the effects of prenatal inputs. In practice, however, such methods are difficult to implement empirically and often produce

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[1] Endogeneity refers to a systematic association between the error term in an equation and the independent variable of interest and is often attributed to unobserved heterogeneity in the context of health production functions. We therefore use the terms endogeneity and unobserved heterogeneity interchangeably.

implausible results. "Natural experiments," when they arise, provide a useful way of isolating causal effects, but they rarely allow for the estimation of multiple inputs and may yield estimates that are not generalizable.[2] As a result, standard regression techniques remain an important and necessary component of a multi-pronged estimation strategy of identifying effects of prenatal inputs on infant health. As such, it is imperative to understand the biases and limitations of such methods as well as how those estimates can be improved.

We use a uniquely rich dataset to conduct a comprehensive and systematic analysis of sources of bias in single-equation infant health production functions. We examine the extent to which including several theoretically important but typically unobserved variables (representing wantedness, taste for risky behavior, and maternal health endowment) change the estimated effects of prenatal inputs on birth outcomes. The economics literature on infant health suggests that such characteristics are important, but most data sets that are used to analyze the effects of prenatal inputs on infant health outcomes do not include measures of these factors or contain poorly measured proxies. We also explore the role of paternal characteristics and other non-standard covariates. Additionally, given substantial evidence of misreporting of prenatal inputs by mothers, we compare results using self-reported prenatal inputs to those using input measures that combine information from survey reports and medical records. Finally, we move beyond birth weight, which is a marker for poor infant health, by considering a direct measure of infant health—whether the infant had an abnormal health condition (defined later) at birth.

Specifically, we address the following five research questions: (1) Is a set of typically unobserved but theoretically important variables and other non-standard covariates significant in explaining the demand for prenatal inputs (illicit drug use, cigarette smoking, and prenatal care)?

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[2] See Moffitt (2005) for an excellent discussion of the pros and cons of econometric methods to address unobserved heterogeneity.

(2) Are the typically unobserved variables and other non-standard covariates significantly associated with infant health outcomes (birth weight, low birth weight, and abnormal infant conditions)? (3) What are the estimated effects of well-measured prenatal inputs on infant health outcomes in models that include the typically unobserved variables and other non-standard covariates? (4) Do the typically unobserved variables have direct effects on infant health outcomes above and beyond their indirect effects through inputs? (5) How sensitive are the estimated effects of prenatal inputs on infant health outcomes to the inclusion of the typically unobserved but theoretically important variables, the inclusion of non-standard covariates, and the use of prenatal input measures that are not strictly self-reported? The answers to these questions will help researchers assess potential sources of bias in their analyses, inform future data collection efforts, and point to where resources may be most effective in improving infant health.

Background

Empirical studies

Since early work by Rosenzweig and Schultz (1983) and Corman, Joyce and Grossman (1987), many economists have used instrumental variables techniques to estimate the effects of prenatal inputs (frequently, prenatal care) on infant health outcomes (frequently, birth weight). In theory, these models account for the selection of mothers into prenatal care and risky prenatal behaviors. By examining the differences in the estimated effects of inputs on outcomes in one- and two-stage models, inferences are made about the direction and extent of selection in input use.

It is difficult to compare estimates of the effects of prenatal care on birth weight across existing studies because they often use different measures of prenatal care, consider different birth weight outcomes (some examine birth weight in grams while others examine low birth weight), focus on specific racial groups or other sub-populations, and use different estimation techniques. Even studies that seemingly should produce similar estimates often produce widely divergent findings. For example, two of the classic studies in the field used the same measures of prenatal care (months of delay) and infant health (birth weight) but produced dramatically different estimates of the effects of prenatal care. Rosenzweig and Schultz (1983) find that each month of prenatal care delay reduces birth weight by 7 percent, or about 226 grams, while Grossman and Joyce (1990) find the effect of a one-month delay in care to be -37 grams (and significant) for blacks and -23 grams (but insignificant) for whites. That is, Rosenzweig and Schultz find effects that are six to nine times greater than those found by Grossman and Joyce.[3] Both of these studies found evidence of unobserved heterogeneity in prenatal care use.

The general lack of consistency across studies may reflect, at least in part, identification problems that a few recent studies have been able to overcome. Evans and Lien (2005) exploit a natural experiment as an alternative to estimating instrumental variables models with price/availability identifiers. They find that prenatal visits do not have a significant effect on birth weight overall, but that they have a positive effect among mothers early in their pregnancies. Conway and Deb (2005) find that prenatal care increases birth weight only among mothers who had "uncomplicated" pregnancies—by about 30-35 grams. The finding of a small or no overall effect of prenatal care is consistent with findings from a recent descriptive study with extremely rich data, including many typically unobserved but theoretically important variables (Reichman and Teitler 2005), and a recent review in the medical literature indicating

[3] It is important to note that the two studies used data from different geographical areas and years, included different sets of covariates, used different estimation techniques, and had different focuses.

that few features of prenatal care would be expected to increase birth weight at the aggregate level (Lu et al. 2003).

Relatively few economic studies have examined the effects of unhealthy prenatal behaviors, such as cigarette smoking and illicit drug use.[4] Lien and Evans (2005) and Noonan et al. (2007) find that cigarette smoking during pregnancy reduces birth weight by about 180 and 225 grams, respectively. Kaestner, Joyce and Wehbeh (1996) and Noonan et al. (2007) find that prenatal illicit drug use reduces birth weight by about 180 and 100 grams, respectively.[5] Rosenzweig and Schultz (1983) and Lien and Evans (2005) find no evidence of unobserved heterogeneity in prenatal cigarette smoking.[6] Noonan et al. (2007) find a similar result for illicit drug use.[7] Overall, estimates of the effects of smoking and drug use on birth weight are more consistent across studies than those of prenatal care, and studies using price/availability measures as identifiers have not found evidence of unobserved heterogeneity in prenatal substance use. However, the existing literature is small and the findings need to be replicated and further explored.

[4] The medical literature offers clear hypothesized mechanisms by which maternal cigarette smoking decreases birth weight. It also offers hypothesized mechanisms by which prenatal illicit drug use may reduce birth weight, although the associations do not appear to be as dose-response specific as that of smoking (Chomitz, Cheung, and Lieberman 1995). Prenatal alcohol use is generally considered a risky behavior and heavy use is associated with fetal alcohol syndrome, but the theoretical and empirical links between alcohol and birth weight are weak. For this reason, we do not include prenatal alcohol use in our analysis.

[5] For the Kaestner, Joyce and Wehbeh (1999) study, we infer the effect based on their estimate of a 5.7 percent reduction in birth weight and a mean birth weight of 3,200 grams (a figure from our own data). The authors did not report the average birth weight in their sample.

[6] Rosenzweig and Schultz (1983) use a number of identifiers to predict smoking, including cigarette prices and the prices and availability of health inputs. Lien and Evans (2005) exploit state variations in cigarette tax hikes to identify the effects of prenatal smoking. Both compare OLS estimates with two-stage estimates and find the estimated effects of smoking on birth weight to be very similar across specifications, regardless of functional form.

[7] Noonan et al. (2007) use bivariate probit models to estimate the effects of drug use on low birth weight. Using cocaine prices and future drug use as identifiers, they perform (over)identification tests and find that a single-equation a probit model is appropriate.

Typically unobserved but theoretically important variables

In the economic literature, selection into prenatal inputs has generally been attributed to three sets of factors—wantedness, tastes, and maternal health endowment—that are typically unobserved. Not including these factors in single-equation infant health production functions may bias the estimated effects of prenatal inputs. Below, we describe how these factors enter into the production of infant health.

Following Corman, Joyce, and Grossman (1987) and the theoretical literature on which they build, parents' utility can be expressed as a function of consumption goods (C), infant health (H_i), parents' health (H_p), tastes, and any other relevant arguments as follows:[8]

(1) $U=U\ (C,\ H_i,\ H_p,\ tastes)$

Infant health is a function of prenatal inputs (which can be positive, such as prenatal care, or negative, such as smoking or drug use) as well as the health endowment of the mother (which reflects H_p and may affect her reproductive efficiency), as shown in the infant health production function that follows:

(2) $H_i = f\ (input_1,\ input_2,\ \ldots.input_n,\ maternal\ health\ endowment)$

The demand for each input can be expressed as follows:

(3) $Input_i = g_i$ *(price and availability of* $input_i$*, prices and availability of substitute and complementary inputs, income, maternal health endowment, tastes, wantedness)*

Thus, infant health is an argument in the parent's utility function (Equation 1), and the parents' utility maximization is constrained by the process underlying the production of infant health (Equation 2). Wantedness reflects the relative importance of infant health versus other factors (e.g., own health) in the parent's utility function and therefore impacts prenatal input use

[8] We assume that the parents maximize one (joint) utility function. Others, including Rosenzweig and Schultz (1983), have assumed an individual (maternal) utility function.

(Equation 3) and other investments in infant health that may be unobserved. The maternal health endowment enters the infant health production directly (through biological processes) and may also affect infant health indirectly through the use of prenatal inputs (e.g., mothers with poor health endowments may attempt to offset an expected unfavorable birth outcome by utilizing more healthy inputs). Maternal risk-taking and time preference (taste for risky behaviors) affect maternal engagement in risky behaviors (such as smoking and drug use) and investments in own health, which in turn can impact infant health production directly through the maternal health endowment (Equation 2) or indirectly through the maternal health endowment or other inputs (Equation 3). While theory suggests that wantedness, taste for risky behaviors, and maternal health endowments play important roles in the infant health production process, few studies directly incorporate such factors and the literature is fragmented. Relevant empirical findings are discussed below.

Wantedness

Grossman and Joyce (1990) model the decision to continue a pregnancy (rather than abort) as an endogenous determinant of birth outcomes using data on births and abortions in New York City. First they estimate the probability of giving birth, controlling for individual characteristics and availability of family planning and abortion services. They then compute λ, the inverse of the Mills ratio, for each woman who gave birth (as a proxy for wantedness) and include λ in a birth weight production function. They find that the coefficient of λ is positive and significant for black (but not white) women and infer that black women with high levels of wantedness are more likely than those with low levels to have healthy babies.[9] The authors do

[9] λ is inversely related to the probability of giving birth (versus aborting). Joyce and Grossman (1990) interpret λ as a measure of wantedness, as women with a high λ have a low likelihood of continuing the pregnancy but decide to do so. They infer that women with high λs have a strong unmeasured desire for their babies.

not examine the mechanisms through which wantedness would translate to birth outcomes, but suggest that it likely operates through prenatal care or other inputs.

Joyce and Grossman (1990) extend the Grossman and Joyce study by assessing the effects of λ on prenatal care use. Using the same data, they find that λ is negatively and significantly related to prenatal care delay among both blacks and Hispanics. That is, higher levels of wantedness lead to less delayed care. However, as the authors point out, "(e)arly prenatal care is but one form of healthy behavior. Pregnant women who initiate care promptly may eat more nutritiously, suffer less stress, engage in the appropriate exercise, and use fewer drugs and other potentially harmful substances than women who begin late care" (Grossman and Joyce 1990, p. 985). The results of Joyce and Grossman (1990) are consistent with findings from numerous descriptive studies (Weller et al. 1987; Marsiglio and Mott 1988; Altfeld et al. 1997; Faden, Hanna and Graubard 1997; Kost, Landry and Darroch 1998; Pagnini and Reichman 2000; Coleman, Reardon and Cougle 2005), most of which use direct retrospective assessments of wantedness or intention. Collectively, these studies indicate that unwanted or unintended pregnancy is negatively associated with prenatal care use and positively associated with unhealthy prenatal behaviors.

Taste for risky behaviors

Recent studies (Bell and Zimmerman 2003; Clarke et al. 1999; Echevarria and Frisbie 2001; Pagnini and Reichman 2000) find that prenatal cigarette smoking, alcohol consumption, and illicit drug use are associated with inadequate, late, or no prenatal care. These findings are consistent with, but do not prove, a hypothesis that a taste for risky prenatal behavior leads to poor prenatal care use. Ogunyemi and Hernandez-Loera (2004) find that mothers who use cocaine during pregnancy are more likely than those who do not use cocaine to have sexually transmitted diseases (STDs), previous medical problems, obstetric complications, and previous preterm deliveries. These findings suggest that having an STD during pregnancy may serve as a proxy for taste for risky behavior.[10]

Maternal health endowment

Cardiac disease, hypertension, chronic diabetes, and other health conditions are associated with an increased likelihood of intrauterine growth retardation (Bernabe et al. 2004) and therefore may affect the mother's expected birth outcome and her use of prenatal inputs. Two recent studies examine the effects of maternal mental health on prenatal behavior and infant health outcomes. Warner (2003) and Conway and Kennedy (2004) find that maternal depression reduces the likelihood of adequate prenatal care among black, but not white, women. Conway and Kennedy posit that not only may depression affect birth weight through prenatal behaviors, but it may also have direct effects on birth weight through the mother's biochemistry. They find evidence of direct negative effects for whites, but not blacks, holding prenatal care use constant. Thus, they find some evidence of both direct and indirect effects of maternal depression on birth weight.

Input reporting

A potential source of bias in infant health production functions is that prenatal input use is often misreported. Comparing maternal self-reports, birth certificates, and medical records, Penrod and Lantz (2000) find that mothers tend to report earlier care than what appears on birth certificates and that medical records indicate the greatest delay. They also find that women with adverse birth outcomes tend to over-report early prenatal care and that this reporting bias leads to underestimates of the effects of early prenatal care on birth weight. Reichman and Hade (2001)

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[10] STDs also may affect birth outcomes directly (see Goldenberg et al. 1997 for a discussion of hypothesized medical pathways).

examine detailed data from physical examinations, medical records, and interviews and find that early prenatal care is over-reported in birth certificates. They also find that prenatal cigarette smoking is underreported in birth certificates and that mothers' pre-pregnancy health conditions, which economic theory suggests may be important sources of selection into prenatal inputs, are substantially underreported in birth certificates. A recent follow-up to the Reichman and Hade study finds that the reporting of first trimester prenatal care varies by the birth outcome (it is slightly more likely to be over-reported for low birth weight and preterm births than for normal birth weight and full-term births), but that the misreporting of prenatal smoking does not vary by those outcomes (Reichman and Schwartz-Soicher 2007). Kaestner, Joyce and Wehbeh (1996) find substantial underreporting of illicit drug use when comparing results from drug tests at the time of the birth to data from New York City birth certificates, and that using self-reported drug use rather than "actual" drug use overstates the true effect of prenatal drug use on birth weight. Noonan et al. (2007) also find substantial underreporting of prenatal drug use and that self-reported drug use leads to overestimates of the effects of prenatal drug use on birth weight.

Outcome measurement

A limitation of existing research on infant health production that has received little attention is the exclusive focus on birth weight and infant mortality. Although birth weight is a widely used and well-measured index of subsequent morbidity and a valuable outcome in its own right, it is not a direct measure of infant health. Low birth weight is a strong risk factor for infant mortality and morbidity among survivors, but many low birth weight children (even the very lightest) have no serious health problems (Reichman 2005). Thus, using birth weight or low birth weight to proxy infant health can lead to incorrect inferences about the production of infant health. As far as we know, only one study in the economics literature (Noonan et al. 2007) examines the production of infant health using direct measures of infant morbidity.

Our contribution

Overall, past research indicates that: (1) estimates of the effects of prenatal care on birth weight vary widely; (2) studies have found no evidence of unobserved heterogeneity in prenatal cigarette smoking or drug use, although the existing literature is small; (3) theory and past empirical research suggest that wantedness, tastes, and maternal health endowment may underlie selection into prenatal inputs; (4) there is evidence of misreporting of prenatal inputs—in socially desirable directions—in both birth certificates and surveys; and (5) as far as we know, only one economic study of infant health production has used a direct measure of infant health as a complement to birth weight outcomes. The literature is fragmented and no single study has accounted for the various theorized sources of selection and examined multiple well-measured inputs and outcomes. We address this gap by using uniquely rich data to explore the extent to which typically unobserved but theoretically important variables and other non-standard covariates affect the estimates of three different prenatal inputs on birth weight and a direct measure of infant health. A comprehensive and systematic analysis of this type is essential for understanding the relationships between prenatal inputs and infant health, for informing future research, and ultimately, for designing effective interventions and policies to improve infant health.

Data

We use data from a recent population-based birth cohort survey that have been linked to medical records of mother respondents and their babies and to neighborhood characteristics at the census tract level. The Fragile Families and Child Wellbeing (FFCWB) survey follows a cohort of parents and their newborn children in 20 large U.S. cities (in 15 states). The study was designed to provide information about the conditions and capabilities of new (mostly unwed) parents; the nature, determinants, and trajectories of their relationships; and the long-term consequences for parents and children of welfare reform and other policies. The survey data are rich in sociodemographic characteristics of both mothers and fathers, and include information on parents' relationships and living arrangements.

The FFCWB study consists of a stratified random sample of births in 75 hospitals between 1998 and 2000. By design, approximately three quarters of the interviewed mothers were unmarried (births were randomly sampled in each hospital, but once a marital quota was reached, married mothers were screened out). Face-to-face interviews were conducted with 4898 mothers while they were still in the hospital after giving birth.[11] Additional data have been collected from the hospital medical records (from the birth) for a sub-sample of 3,517 births in 19 cities (in 15 states).[12] The medical record data contain information on prenatal substance use from laboratory tests of the mother or baby and in notes by physicians or social workers; information on the timing of prenatal care initiation; and detailed measures of the mother's health endowment (more information is given below, under "Measures"). Measures of census tract-level poverty were linked to the data using the mothers' addresses at the time of the birth. Follow-up interviews were conducted with mothers when the child was one, three, and five years old. We use data on the 3,124 non-multiple births that have complete information on all main analysis variables from the postpartum survey, medical records, and address files. We describe our measures below and present characteristics of the full sample, the sample of low birth weight

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[11] Additional background on the research design of the FFCWB study is available in Reichman et al. (2001).

[12] The medical record data collection was ongoing and the analysis sample includes cases that were available at the time. Access to the hospital medical records generally reflects administrative decisions of the different hospitals rather than decisions on the part of individual respondents to have their records reviewed.

(< 2500 grams) births, and the sample of infants with abnormal health conditions (defined later) in Table 1.

Measures

Unhealthy Inputs: Illicit Drugs and Cigarettes

Arendt et al. (1999) find that using postpartum interviews combined with medical records was the best way to ascertain illicit substance use during pregnancy. Although the FFCWB postpartum interview was far less detailed than that used by Arendt et al., we adopt the strategy of combining responses to a postpartum survey with a review of the mothers' and infants' medical records to ascertain both drug use and cigarette smoking during pregnancy. During the mother's interview in the hospital after giving birth, she was asked whether she had used any illicit drugs and whether she had smoked cigarettes during her pregnancy. This information was combined with detailed information from medical records to create measures of prenatal substance use, as described below.

<u>Prenatal illicit drug use</u>

The medical records contain information about the mother's drug use during pregnancy from laboratory tests of the mother or baby and in notes by physicians, nurses, or social workers. For some of the births, drug tests on the mother or newborn were administered and the results recorded in the mother's or baby's chart. The drug tests could have taken place at any time during the pregnancy or post-partum hospital stay. In other cases, it was possible to make a positive assessment of illicit drug use on the basis of case notes during the course of prenatal care or ICD-9 codes for drug addiction during pregnancy. Unfortunately, we have no information on the basis for decisions about whether to test specific mothers and infants for drugs. We do know that universal screening for newborns is not recommended and that pediatricians have grappled with issues of how to ascertain prenatal drug use and when newborn testing is appropriate (American Academy of Pediatrics 1995). Pregnant mothers are generally asked about substance use, often as part of a standardized prenatal screening instrument, and drug tests can be administered to them (when warranted and with their consent) and to their infants when deemed appropriate (American College of Obstetricians and Gynecologists 2006). The bottom line is that testing is recommended (for the mother and/or infant) or ordered (for the infant) based on suspicion of prenatal drug use. Thus, it is possible that the medical records do not identify all mothers who used drugs.

Of the 3,124 mothers in our sample, 1251 (40%) had results from toxin screens in their charts. Of these, 172 of those mothers (13.7%) tested positive for cocaine, heroin, marijuana, other drugs (including amphetamines, methadone, and barbiturates/benziodiazepines) or unspecified drugs, or a combination of drugs. An additional 138 cases of prenatal drug use were picked up from notes in various places in the mothers' and babies' charts. Overall, 9.9 percent of the mothers in our sample had some indication of prenatal drug use recorded in their own or their baby's chart.

Our measure of prenatal drug use is whether there was any indication of prenatal drug use from the postpartum interview *or* medical records (11% of our sample).[13] This figure is in the range presented in a review of sixteen studies by Howell et al. (1999). Not surprisingly given the evidence of systematic underreporting of drug use in household surveys (Harrison, Haaga, and Richards 1993), it is higher than the rates found in a national survey that asked individuals whether they were pregnant, and if they were, whether they had used any illicit drugs in the past month (3.3%) and whether they had used any hard drugs in the past month (1.1%) (Substance

[13] We think it unlikely that mothers who had not used illicit drugs during pregnancy would report in their postpartum interviews that they had done so.

Abuse and Mental Health Services Administration [SAMHSA], 2000).[14] Based on our combined measure, about half of drug-using pregnant women in our sample admitted having used drugs during pregnancy (Table 1).

<u>Prenatal cigarette smoking</u>

Our measure of prenatal cigarette smoking, whether the mother smoked at all during pregnancy, also combines maternal postpartum reports with information in the medical records. The reports of smoking from the two sources differ much less than those of illicit drug use. Almost one quarter (24%) of the mothers in our sample had smoked cigarettes at some time during pregnancy according to their medical records or self-reports, while 20 percent reported that they had smoked at all. Over 80 percent of the mothers who smoked cigarettes according to our combined measure reported that they had done so (Table 1). The rates of smoking in our sample are comparable to national estimates, which indicate that 19 percent of pregnant women report smoking in the past month.[15]

Healthy Input: Prenatal care

Based on the medical records, 48 percent of the mothers in our sample initiated prenatal care in the first trimester, 39 percent began care later than the first trimester, and 13 percent had missing information on when care began. According to mothers' postpartum reports, 77 percent of the mothers received prenatal care in the first trimester. We used the medical record information on the timing of prenatal care initiation (when a date was available) to construct a

[14] The SAMHSA data are from the National Household Survey on Drug Abuse for 2000 and, when weighted, are representative of the U.S. population age 12 and over. The specific computation was for pregnant women age 15 to 44 within the overall sample. http://www.oas.samhsa.gov/nhsda/2kdetailedtabs/Vol_1_Part_4/sect6v1.htm#6.23b .

[15] Source: SAMHSA, National Household Survey on Drug Abuse, 2000. http://www.oas.samhsa.gov/nhsda/2kdetailedtabs/Vol_1_Part_4/sect6v1.htm#6.26b. While our sample is disproportionately economically disadvantaged, we do not expect the rate of prenatal smoking in our sample to be higher than that for a national sample, because according to SAMHSA: 1. White women have higher rates of smoking than black and Hispanic women (and our sample is only 18% white). 2. High school graduates who do not go on to graduate college are the educational group most likely to smoke (and this group comprises only 31% of our sample).

measure of whether the mother received first trimester care (versus later than that or not at all). For the mothers with missing information, we used self-reports. According to this measure, 57 percent of the mothers in our sample received first trimester prenatal care. Twenty nine percent of the mothers who reported that they received first trimester prenatal care were recoded based on information documented in the medical records that they initiated care later than the first trimester (not shown).

Typically Unobserved Variables (TUVs)

We include a number of measures, most of which are from the medical records, that reflect theoretically important but typically unobserved sources of potential selection in prenatal input use. Below we describe these measures, which we refer to as TUVs, and later (under "Analytical Framework and Empirical Implementation") we discuss how each fits into the economic model of infant health production.

During the postpartum interview, the mother was asked whether she had considered having an abortion rather than carrying the pregnancy to term. In our sample, almost 30 percent of the mothers reported that they had considered having an abortion when they found out that they were pregnant (we code these pregnancies as unwanted).[16] Joyce, Kaestner and Korenman (2002) find considerable disagreement between mother's prospective and retrospective reports of pregnancy intendedness, but that the two different assessments yield similar effects of pregnancy intendedness on late prenatal care, heavy smoking during pregnancy, and low birth weight.

From the mother's medical record, we used information on infections that are often transmitted sexually (STDs). Over one quarter (28%) of the mothers in our sample had at least

[16] Unfortunately, the women were not asked if the pregnancy was unintended, which would be a more direct measure of unwantedness. A disadvantage of our measure is that women who had an unintended pregnancy but would not have considered an abortion for religious or moral reasons would be miscoded. We address this issue further, to the extent possible, in supplemental analyses.

one of the following infections during the first prenatal visit or later in the pregnancy: pelvic inflammatory disease, syphilis, chlamydia, genital herpes, gonorrhea, human papilloma virus, hepatitis B, hepatitis C, or human immunodeficiency virus.

We also include information from the medical records on a variety of health conditions in the mother's medical history.[17] These measures include lung disease (acute or chronic lung disease or asthma), other pre-existing health conditions (e.g., cardiac disease, chronic diabetes, hypertension, and liver disease), pre-pregnancy underweight (Body Mass Index less than 18.5), and pre-pregnancy morbid obesity (Body Mass Index greater than or equal to 39). We also include a measure of the mother's mental health endowment. The mother was coded as having a pre-existing mental illness if there was any documentation of a diagnosed DSM-IV mental disorder (e.g., depression, anxiety, bipolar disorder, schizophrenia, anorexia, suicidality, and mental retardation) in her medical record.[18]

Standard Covariates

We include a basic set of demographic variables that are typically available in data sets that are used to estimate infant health production functions—maternal age (in years), education (which we code as high school graduate, some college but not graduate, or college graduate—compared to less than high school), race/ethnicity (non-Hispanic black, Hispanic, or other non-white non-Hispanic—compared to non Hispanic white), nativity (whether the mother was foreign-born), parity (whether it was the mother's first birth), and marital status (whether the mother was married to the baby's father at the time of the birth).

Non-Standard Covariates (NSCs)

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[17] Except for the wantedness variable, all TUVs were coded from information in the mother's medical records and indicate whether there was a history (or current diagnosis) of the given condition. Much of this information was recorded during the first prenatal visit when the health history was taken.

[18] Substance abuse disorders were not included in this measure.

We are also able to include a rich set of characteristics of the mother, father, and the parents' relationship status that may be related to both input use and infant health but not usually available in data sets used to estimate infant health production functions. We refer to this set of measures as non-standard covariates, or NSCs. In particular, recent studies have found paternal factors to be independent predictors of prenatal input use (Teitler 2001; Sangi-Haghpeykar et al. 2005; Huang and Reid 2006) and infant health (Reichman and Teitler 2006). From the survey, we include insurance information (whether the birth was covered by Medicaid or other government program—henceforth referred to as "Medicaid"). From the medical records, we include the number of previous pregnancies (whether they resulted in live births or not; including both spontaneous and induced abortions). From the survey, we include whether the mother lived with both of her parents at age 15, whether she attends religious services at least several times per month, whether she knew the father at least one year prior to conception, whether the father had fewer years of education than the mother, whether the father was a different race/ethnicity than the mother, and whether the father was at least five years older than the mother.[19] We also include the percentage of households in the mother's census tract with income under the poverty line.[20]

Infant Health Outcomes

We estimate infant health production functions for birth weight (in grams) and low birth weight (< 2500 grams, which represents the standard clinical threshold). Birth weight was obtained from the medical records. We also estimate production functions for a direct measure of infant health—whether the infant had a serious abnormal condition (i.e., one that is associated

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[19] Because of the high correlation between mother's and father's age, education, and ethnicity, we use differences for these variables.

[20] In this sample, there is an average of 1.7 births per census tract, with 63 percent of the 1851 tracts containing only one birth.

with both immediate and, quite possibly, longer-term morbidity). The coding was conducted by an outside pediatric consultant who systematically reviewed the medical record data on infant conditions, as well as data from the one-year interviews on physical disabilities of the child (identifying serious conditions that were likely present at birth), and coded all conditions based on the degree of severity and the likelihood that they were caused by maternal prenatal behavior (see coding grid and explanation in Appendix Table 1). For this analysis, we exclude abnormalities for which there is no connection to prenatal behavior or only a very weak connection. The excluded conditions (e.g., Down Syndrome, congenital heart malformations) are for the most part random, given that the pregnancy resulted in a live birth.

Empirical Implementation

We assess the sensitivity of the estimated effects of prenatal inputs in infant health production functions (Equation 3) to the inclusion of typically unobserved but theoretically important variables, the inclusion of non-standard covariates, and the use of "actual" inputs (that combine information from medical records and self-reports) rather than exclusively self-reported inputs. The breadth and scope of our analyses preclude estimating a structural system with three endogenous inputs—prenatal care, smoking, and illicit drug use. As discussed above, comparing one- and two-stage structural models, Rosenzweig and Schultz (1983) and Lien and Evans (2005) found no evidence that single-equation birth weight models produced biased estimates of the effects of prenatal smoking. Similarly, Noonan et al. (2007), using the same rich data that we use in the current study and testing the validity of one- versus two-stage structural models, found no evidence that single-equation models of low birth weight produced biased estimates of the effects of prenatal drug use.

According to Conway and Deb (2005), instrumenting maternal choice variables "strains an already weakly identified birth weight equation (p. 493)." It is even more problematic when estimating equations with multiple inputs. Natural experiments are rare, cannot be used to identify multiple inputs, and may not produce generalizable estimates. Our strategy is to use well-measured and rich data (including measures of "actual" inputs and theoretically important sources of heterogeneity) to estimate a set of "gold standard" single-equation models and assess the plausibility of our results in the light of theory and past research indicating no unobserved heterogeneity in prenatal smoking or drug use. We do explore the potential endogeneity of prenatal care, the one input for which past studies have found evidence of unobserved heterogeneity, in a supplementary two-stage analysis.

Based on the theoretical framework described earlier, we specify equations that reflect our specific research questions. We consider unwantedness as a taste or preference that should affect infant health exclusively through the inputs (i.e., it should not have a direct effect on infant health). The STD measure serves two roles: First, it may reflect a taste for risky behavior, which could affect outcomes through input demand. Second, it measures a prenatal health condition that could affect input demand and also have direct effects on infant health. The other five TUVs (pre-existing lung disease, other pre-existing physical health condition, pre-existing mental illness, pre-pregnancy underweight, and pre-pregnancy morbidly obese) all reflect the maternal health endowment and therefore may have both indirect (through inputs) and direct effects on infant health.

To address our first research question (whether TUVs and NSCs explain the demand for inputs), we estimate separate demand equations for each input (any illicit drug use, any cigarette smoking, and first trimester prenatal care) as follows:

(3a) $Input_i = g_i$ *(TUVs, standard covariates, NSCs, city indicators)*

Because the inputs (as we construct them) are dichotomous, we estimate probit models. We use the "actual" measures of inputs for this set of models. The TUVs are measures of tastes and health endowments, as discussed above. Many of our standard and non-standard covariates (e.g., education and census tract-level poverty) are proxies for income. We include city indicators to control for city or state input prices, input availability, and policies. We assess the joint significance of the TUVs and NSCs in the input demand equations.

To address our second research question (whether TUVs and NSCs are significantly associated with infant health), we estimate reduced-form production functions for each health outcome (birth weight, low birth weight, and abnormal conditions) that include the same right-hand-side variables as Equation 3a, but not the prenatal inputs:

(2a) Health Outcome = f (TUVs, standard covariates, NSCs, city indicators)

We address our third research question (the effects of prenatal inputs on infant health) by estimating equations that include "actual" inputs in addition to our rich set of covariates, as follows:

(2b) Health Outcome = f ("actual" prenatal inputs, TUVs, standard covariates, NSCs, city indicators)

To the extent that STDs represent a taste for risky behavior, that measure would not directly enter the health production function. Similarly, unwantedness represents a taste and would not directly enter the health production. However, tastes are related to input use (Equation 3). If all relevant inputs are not included in the infant health production function, then excluding tastes could lead to biased estimates of the effects of included prenatal inputs. Therefore, we include variables reflecting tastes (STDs and unwantedness) in Equation 2b in addition to the TUVs that measure the maternal health endowment.

We use the same set of production functions to address our fourth research question (whether TUVs are significantly associated with infant health, holding inputs constant). We assess both the statistical significance of the individual TUVs and their overall contribution to explanatory power.

Our fifth research question asks about the differential impacts of TUVs, NSCs, and "actual" input measures on estimates of the effects of prenatal inputs on infant health. To address this question, we estimate infant health production equations with four different specifications for each of the three outcome measures (all include standard covariates and city indicators): (A) The full model using "actual" inputs, TUVs and NSCs (Equation 2b); (B) a model with "actual" inputs and NSCs but excluding TUVs; (C) a model with "actual" inputs and TUVs but excluding NSCs; (D) a model with "actual" inputs but excluding both TUVs and NSCs (i.e., using only typically available covariates). We also estimate Models A through D using self-reported rather than "actual" inputs. Specification D, which includes employs self-reported inputs, is the most typically estimated model (except that prenatal drug use is not routinely available), since it includes covariates and measures that are available in most data sets used to study infant health. We compare the estimated effects of inputs across models. We consider Model A, which includes TUVs, NSCs and "actual" rather than self-reported inputs, our operationalized gold standard.

Results

Our sample is predominately minority and poor (Table 1). Half (49%) of the sample is black and one third (29%) is Hispanic. Over one-third of the mothers did not complete high school. Two thirds were on Medicaid at the time of the birth. Ten percent of the infants in the sample were low birth weight and 12 percent had abnormal health conditions as we have defined them. Of the infants who were low birth weight, 37% had at least one abnormal health condition; of the infants who were born with an abnormal condition, 27% were low birth weight.

Question 1: Is a set of typically unobserved but theoretically important variables (representing wantedness, taste for risky behavior, and maternal health endowment) and other non-standard covariates significant in explaining the demand for prenatal inputs (prenatal care, illicit drug use, and cigarette smoking)?

Table 2 presents probit results for any prenatal illicit drug use, any prenatal cigarette smoking, and first trimester prenatal care, respectively. In each cell, the first figure represents the probit coefficient, the figure in parentheses is the standard error of the probit coefficient, and the figure in brackets represents the marginal effect. We also report chi-square statistics and p-values from Wald tests of the joint significance of the TUVs and NSCs.

Unwantedness (as we have measured it, by whether the mother considered having an abortion), STD during pregnancy, and pre-existing mental illness have strong positive associations with prenatal drug use,[21] and the mother's education, nativity, marital status, religious attendance, and the father's characteristics all have significant associations with prenatal drug use.[22] The unwantedness measure and pre-existing mental illness have large and highly significant associations with prenatal cigarette smoking: Women who considered having an abortion were 7 percentage points more likely than those who did not consider having an abortion to smoke cigarettes during pregnancy, and mothers with pre-existing diagnosed mental illness were 19 percentage points more likely than those without pre-existing mental illness to smoke cigarettes during pregnancy. Most standard covariates and NSCs are also associated with smoking in the expected directions. Notably, Medicaid birth is positively associated with smoking and negatively associated with first trimester care all else all else (i.e., education,

[21] The magnitude of the coefficient of mental illness may seem high, but it is consistent with a "self-medication hypothesis" discussed by numerous researchers and recently tested by Harris and Edlund (2005).
[22] Interestingly, we find that mothers who partner with significantly older but less-educated men of a different race/ethnicity are the most likely to use substances during pregnancy.

marital status, and census-tract poverty) equal, religiosity is a strong negative predictor of drug use and smoking, and the father characteristics are independently associated with drug use and smoking.

Mothers who considered abortion were 13 percentage points (about 25%) less likely to receive first trimester prenatal care than those who did not consider abortion. Mental illness, which was a strong predictor of smoking and drug use, is not a significant predictor of first trimester care. However, we find strong evidence for adverse selection into early prenatal care based on the mother's physical health endowment. Mothers with pre-existing physical health conditions other than lung disease were 7 percentage points more likely than those without conditions to get first trimester care.

Using Wald tests, we assess the joint significance of both the TUVs and the NSCs in the drug use, cigarette smoking, and first trimester prenatal care models and find that both sets of factors are significant in explaining each of the three inputs. Overall, the results indicate that: (1) TUVs and NSCs are strong predictors of prenatal inputs in the expected directions, but the associations vary by TUV, NSC and input; (2) unwantedness, as characterized by retrospective reports of having considered an abortion, is a strong predictor of all three inputs; (3) the mother having a pre-existing physical health problem other than lung disease is an important predictor of first trimester prenatal care; and (4) pre-existing diagnosed mental illness is a strong predictor of both prenatal smoking and drug use but not first trimester prenatal care.

Question 2: Are TUVs and NSCs significantly associated with infant health outcomes (birth weight, low birth weight, and abnormal infant conditions)?

Table 3 shows reduced-form estimates of the effects of each of the TUVs on birth weight, low birth weight, and abnormal infant conditions. Each estimate reflects the combined indirect effect of the TUV (via input use) plus the direct effect (if any) on the health outcome. All models include the full set of covariates from Table 2 (TUVs, NSCs, standard covariates, and an indicator for the city in which the birth took place), although only the TUV estimates are presented. For birth weight, we estimate Ordinary Least Squares models and present multiple regression coefficients with robust standard errors in parentheses. For low birth weight and abnormal conditions, we estimate probit models and present marginal effects calculated at mean values, with standard errors of the marginal effects in parentheses. We find that the significance (and sometimes the sign) of the different TUVs varies by outcome.

Although Table 2 indicated that our measure of unwantedness is positively related to prenatal substance use and negatively associated with first trimester care, Table 3 indicates that the only outcome with which it is significantly associated is abnormal infant health condition. STDs are a significant risk factor for abnormal conditions, and pre-existing lung disease and other health conditions increase the likelihood of low birth weight. Pre-pregnancy morbid obesity (a relatively rare condition in our sample) is not significantly associated with infant health outcomes, all else equal, but pre-pregnancy underweight reduces birth weight and increases the probability of low birth weight. History of mental illness is strongly associated with both birth weight and low birth weight, in the expected directions.

From the tests at the bottom of Table 2, we find that both the TUVs and NSCs are significant predictors for all three outcomes.[23]

Question 3: What are the estimated effects of well-measured prenatal inputs on infant health outcomes in models with a rich set of covariates, including TUVs and NSCs?

Results from our gold standard infant health production functions are presented in Table 4. These models include the three "actual" inputs, the TUVs, standard covariates, the NSCs, and

[23] Because birthweight is a continuous variable, we use F-tests to determine whether the TUVs and NSCs are jointly significant. Because low birth weight and infant health conditions are dichotomous measures, with models estimated via probit, we use Wald tests.

the city in which the birth took place. We find that prenatal illicit drug use reduces birth weight by 139 grams, that it increases the likelihood of low birth weight by 4 percentage points, and that it increases the likelihood of an abnormal infant condition by 6 percentage points. The estimated effect on low birth weight is very similar to that found by Noonan et al. (2007) in both single equation probit and bivariate probit models that used the same data on which the current analyses are based. We find that prenatal cigarette smoking decreases birth weight by 174 grams and increases the likelihood of low birth weight by 5 percentage points, but that it is unrelated to abnormal infant conditions. The estimate for birth weight is very similar to those of Rosenzweig and Schultz (1983) and Lien and Evans (2005), who tested for endogeneity and found that single equation models produced unbiased estimates. Consistent with a growing number of studies, including a recent study by Evans and Lien (2005) that exploited a natural experiment, first trimester care is unrelated to both birth weight and low birth weight. It is also unrelated to abnormal infant conditions.

Question 4: Do the TUVs have direct effects on infant health outcomes above and beyond the indirect effects through inputs?

From Table 4, we find evidence of direct associations between TUVs and infant health outcomes. That is, not only are TUVs strongly related to prenatal input use, but some are also related to infant health outcomes when holding inputs constant. The strength of the association depends on the specific TUV and outcome. Even when controlling for the three inputs, we find that: (1) STDs are strongly related to abnormal infant conditions; (2) maternal physical health endowments are strongly related to low birth weight; and (3) maternal mental health endowment is strongly related to low birth weight. In terms of (2), pre-existing physical health conditions other than lung disease increase the probability of low birth weight, and underweight (possibly representing nutritional inadequacy) is a strong and significant predictor of birth weight (in the expected direction) but not low birth weight or abnormal infant conditions. For maternal and physical health endowments, the finding of strong effects on low birth weight but only weak effects on birth weight indicates that the effects operate at the low tail of the birth weight distribution, perhaps because of an interactive effect with other risk factors (such as prenatal inputs or other factors). In other words, if the infant is likely to be low birth weight, the maternal health conditions may compound that risk, but if the infant is not at high risk for being low birth weight those same conditions may be much less consequential.

Question 5: How sensitive are the estimated effects of prenatal inputs on infant health outcomes to the inclusion of TUVs, the inclusion of NSCs, and the use of "actual" measures of prenatal inputs?

We consider production functions with alternate specifications, allowing us to examine the extent to which the TUVs and NSCs change the estimated effects of the prenatal inputs and to compare our results from Table 4 with those from a "typical" model with self-reported inputs and a standard set of covariates. Panel 1 in Table 5 presents estimates for models that use our "actual" measures of prenatal inputs that combine information from medical records and self-reports. Panel 2 presents the estimates for a corresponding set of models that use self-reported rather than "actual" inputs. All models include standard covariates and city indicators. In Panel 1, the first figure in each cell (Model A, which includes the TUVs and NSCs) is identical to the corresponding figure in Table 4. Model B includes the NSCs but not the TUVs. Model C includes the TUVs but not the NSCs. Model D includes only the standard covariates (which are typically available in birth certificates and other data sets used to study the production of infant health) plus city indicators. Going from Model A through D, the model becomes less specified (except, perhaps, from B to C) and going from Panel 1 to Panel 2, the inputs are less accurately measured.

Several findings stand out from Table 5: (1) The self-reported input measures have stronger effects than the "actual" measures, particularly for first trimester care. (2) Both the TUVs and the NSCs are significant predictors in the health production functions. (3) Including the TUVs changes the estimated effects of substance use little. (4) Prenatal illicit drug use is significantly associated with abnormal infant conditions, regardless of specification. (5) First trimester prenatal care has no association with birth weight, low birth weight, or abnormal infant conditions, except when the self-reported measure of first trimester care is used (Panel 2). That is, prenatal care measured from different sources ("actual" versus self-reported) leads to very different inferences about the effectiveness of prenatal care.

Supplemental Analyses

We conducted a number of supplementary analyses to explore the potential endogeneity of prenatal care, assess the sensitivity of our results, investigate potential mechanisms, and explore differences by race.[24] Unless indicated otherwise, all sets of supplemental results correspond to Models A – D in Panel 1 of Table 5, for all three outcomes.

Potential endogeneity of prenatal care

As discussed earlier, previous research has not found evidence of endogeneity of prenatal cigarette smoking and illicit drug use. That is not the case, however, for prenatal care. To test for the potential endogeneity of first trimester prenatal care, we estimated a bivariate probit system, in which low birth weight and first trimester prenatal care were the dependent variables and the full set of covariates from Table 2 was included. Based on the finding by Currie and Reagan (2003) that distance to hospital is associated with well-child checkups, we used a measure of distance to the birth hospital from the mother's residence (in meters) as an identifier for first trimester prenatal care. We also used the number of family planning clinics in the mother's

[24] The results from supplementary analyses are not presented, but are available upon request.

congressional district as an identifier. Tests revealed that (1) the identifiers were jointly significant predictors of first trimester care, (2) the identifiers were excludable from the low birth weight equation[25], and (3) the error terms in the prenatal care equation and the low birth weight equation were not significantly correlated. This provides evidence that our single equation estimates of the effects of prenatal care on birth outcomes (which indicate no effect) are not biased.

Sensitivity analyses

We ran models that excluded city indicators, excluded the cases for which the start date of prenatal care was not available in the medical records, excluded drug use (to make our models more comparable to those estimated by others), and excluded our measure of unwantedness (which, as discussed earlier, is the most potentially endogenous of the TUVs). We found that the results were remarkably insensitive to these alternative specifications. The only difference was that in the models that excluded prenatal drug use, first trimester care became significant at the 10% level for birth weight; however, the effect was still small—about 35 grams.

Alternative outcome measures

To undertake a preliminary exploration into the mechanisms behind the low birth weight effects, we estimated models (1) with preterm birth (less than 37 weeks) as the outcome, using the full sample, and (2) with low birth weight as the outcome, but restricting the sample to full term births (at least 37 weeks gestation). For (1), the pattern of results was very similar to that for low birth weight. For (2), the pattern was very similar to that for low birth weight using the full

[25] To ensure that our identifiers are excludable from the outcome equation (uncorrelated with low birth weight net of first trimester care and the other variables in the low birth weight equation), we follow Rashad and Kaestner (2004) and use a just-identified bivariate probit with the other identifier as a predictor in the low birth weight equation. We perform Wald tests to determine whether the identifiers are significant in predicting low birth weight. The results indicate that regardless of which identifier we use to perform the test, the identifiers are not significant predictors of low birth weight.

sample; the only difference was that prenatal drug use was no longer significant in Model A. It thus appears that, on the whole, the inputs operate through both length of gestation and rate of fetal growth. However, these mechanisms need to be further explored. Unlike most studies that rely on self-reported gestational age, the results from this set of supplementary models were based on a measure of "actual" gestational age from the medical records.

Race-specific models

As mentioned earlier, many researchers estimate race-specific birth outcome production functions and find differential (larger) impacts of prenatal care on birth weight or low birth weight for blacks than for whites. We estimated a supplementary set of models and tested for the validity of pooling non-Hispanic blacks and non-Hispanic whites in our sample. [26] Except in one case (the model for continuous birth weight as the outcome that included self-reported inputs—Model D), the production functions of the two racial groups were not significantly different. In that case, the effect of first trimester care was strong (103 grams) and significant for blacks, whereas it was small and insignificant (2 grams) for whites. In our gold standard specification (Model A for "actual" inputs), we found that first trimester prenatal care did not significantly affect birth weight for whites or blacks and that the magnitudes were similar for the two groups (24 grams for blacks and 44 grams for whites).

Conclusion

We undertook a comprehensive analysis of sources of bias in infant health production functions using data from a national urban birth cohort study that oversampled non-marital births—the dominant clientele of programs designed to improve birth outcomes. The key

[26] In these models, we included only non-Hispanic whites and non-Hispanic blacks. Because of small cell sizes, we did not include city indicators.

findings were that: (1) Measures of wantedness, taste for risky behaviors, and maternal health endowment—which economic theory suggests are important sources of unobserved heterogeneity—are strongly associated with both prenatal inputs and infant health outcomes, but excluding them from infant health production functions generally does not bias the estimated effects of prenatal inputs. The same is true for an additional set of non-standard but potentially important covariates, including father and family structure characteristics. (2) Self-reported measures of inputs lead to overestimated effects of smoking, drug use, and prenatal care on birth weight outcomes. The difference is particularly dramatic for prenatal care; consistent with recent studies, we found no significant effects of first trimester prenatal care on any infant health outcome when using our measure of prenatal care that was based primarily on medical records. (3) Using a direct measure of infant health leads to similar inferences about the effects of smoking and drug use as when using birth weight outcomes. However, while the effect of smoking on low birth weight is large, its effect on the likelihood of an abnormal infant health condition is insignificant.

The results can be used to inform and guide future research on the production of infant health. In particular, researchers can be more confident in using single-equation models with self-reported inputs under certain circumstances and may find it compelling to move beyond birth weight when characterizing infant health. That said, the results must be considered in context. The effects of drug use may vary by type of substance, and those of both smoking and drug use are likely to depend on the duration and intensity of use. Similarly, the effects of prenatal care may vary by quality and intensity of care. Finally, the results for smoking and prenatal care should *not* be interpreted to mean that smoking does not harm infants' health or that first trimester prenatal care has no beneficial effects. The birth weight effects of smoking may lead to cognitive deficiencies or physical health problems as the child ages. Additionally, mothers who smoke cigarettes during pregnancy may be likely to smoke postnatally, exposing the child to second-hand smoke, which can have adverse health consequences. Similarly, early prenatal care could increase the use of postnatal health-promoting behaviors such as regular preventive pediatric care. The effects of prenatal behaviors on postnatal health behaviors and longer-term child health outcomes have been under-explored and represent fertile ground for future research.

An implication of this study for data collection is that surveys should make efforts to obtain high quality data on prenatal care and infant health outcomes, perhaps through improved question wording or through linkages with other sources of data. Such efforts would improve the estimation of infant health production functions. Another implication is that collecting data on the typically unobserved but theoretically important variables and non-standard covariates we examined, while not necessary for improving the precision of infant health production function estimates, would enhance studies of maternal and infant health more generally as many of these factors were strongly and independently associated with input demand and birth outcomes. Additionally, collecting rich data on the quality and intensity of prenatal inputs is a logical next step.

Finally, this study has broad implications for public health policy. First, the finding that prenatal drug use has strong deleterious effects on infant health (based on either birth weight or measured health conditions) suggests that early screening and treatment for substance use during pregnancy may improve infant health. Second, the findings of small or insignificant effects of prenatal care suggest that medical and psychosocial care that begins after conception may be too little too late to improve birth outcomes and that earlier intervention is necessary to achieve that goal. The findings that STDs during pregnancy and pre-existing mental illness are strongly and independently related to abnormal infant conditions and low birth weight, respectively, suggest that addressing sexual and mental health issues prior to conception, rather than during the confines of a pregnancy, may not only enhance the well-being of mothers, but may also improve the health of their children. More generally, the findings suggest that promoting health and healthy behaviors in women of reproductive age is needed to improve aggregate birth outcomes and that interventions to prevent (and treat) drug use and cigarette smoking among girls and young women may be wise investments.

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Table 1: Characteristics of Full Sample, Low Birth Weight sample, and Sample with Abnormal Infant Health Conditions[a]

	Full Sample (N=3124)	Low Birth Weight (N=321)	Abnormal Infant Health Condition (N=375)
Prenatal Inputs			
"Actual" [b]			
Used Illicit Drugs	.11	.24	.19
Smoked Cigarettes	.24	.43	.30
Received First Trimester Prenatal Care	.57	.53	.53
Self-Reported			
Used Illicit Drugs	.06	.15	.11
Smoked Cigarettes	.20	.37	.25
Received First Trimester Prenatal Care	.77	.53	.53
Typically Unobserved Variables (TUVs)			
Considered Abortion	.30	.37	.35
STD During Pregnancy	.28	.38	.35
Pre-Existing Lung Disease	.13	.20	.15
Other Pre-Existing Physical Health Condition	.08	.12	.07
Pre-Pregnancy Underweight	.04	.06	.03
Pre-Pregnancy Morbidly Obese	.02	.01	.01
History of Mental Illness	.11	.22	.16
Standard Covariates – Mother			
Age (years)	24.94	25.30	24.88
	(5.93)	(6.52)	(6.15)
Age Squared	657.30	682.54	656.55
	(326.74)	(362.96)	(339.15)
Less Than High School[c]	.36	.40	.40
High School Graduate	.31	.35	.31
Some College (but not graduate)	.23	.18	.21
College Graduate	.09	.07	.08
Non-Hispanic White[c]	.18	.17	.17
Non-Hispanic Black	.49	.64	.53
Hispanic	.29	.17	.26
Other Race/Ethnicity	.04	.02	.04
Immigrant	.16	.08	.10
First Birth	.37	.40	.41
Married at Time of Birth	.23	.14	.19

Continued on next page

Table 1 (cont.)

	Full Sample	Low Birth Weight	Abnormal Infant Health Condition
Non-Standard Covariates (NSCs) - Mother			
Medicaid Birth	.67	.81	.71
Number of Previous Pregnancies	.76	.76	.74
	(.43)	(.43)	(.44)
Lived With Both Parents At Age 15	.41	.36	.40
Attends Religious Services Several Times Per Month	.38	.31	.34
% Under Poverty in Census Tract	.19	.21	.20
	(.13)	(.14)	(.14)
Knew Each Other at Least 12 Months at Time of Conception	.84	.82	.83
NSCs - Father			
Less Educated Than Mother	.26	.27	.24
Different Race/Ethnicity Than Mother	.15	.14	.18
At Least 5 Years Older Than Mother	.27	.32	.27
Infant Health Outcomes			
Birth Weight (grams)	3221	1989	2923
	(610.90)	(505.57)	(884.64)
Low Birth Weight (< 2500 grams)	.10	1	.27
Abnormal Infant Health Condition	.12	.37	1

[a] For mother's age and age squared, number of previous pregnancies, % under poverty in census tract, and birth weight, means and standard deviations are presented. For all other measures, figures are proportions.
[b] "Actual" measures combine information from self-reports and medical records, as described in the text.
[c] Omitted category in regression models

Table 2: Determinants of Demand for Prenatal Inputs [a]

	Illicit Drug Use	Cigarette Smoking	First Trimester Prenatal Care
		Probit Coefficient (Standard Error) [Marginal Effect]	
Typically Unobserved Variables (TUVs)			
Mother Considered Abortion	.34*** (.11) [.04]	.26*** (.08) [.07]	-.33*** (.04) [-.13]
STD During Pregnancy	.27*** (.09) [.03]	.09 (.06) [.02]	.04 (.05) [.02]
Pre-Existing Lung Disease	.04 (.08) [.00]	.05 (.07) [.01]	-.03 (.08) [-.01]
Other Pre-Existing Physical Health Condition	-.16 (.08) [-.02]	-.07 (.09) [-.02]	.19** (.08) [.07]
Pre-Pregnancy Underweight	-.04 (.19) [-.00]	.15 (.14) [.04]	-.10 (.16) [-.04]
Pre-Pregnancy Morbidly Obese	-.41 (.29) [-.03]	-.43* (.24) [-.09]	.16 (.21) [.06]
History of Mental Illness	1.02*** (.12) [.21]	.59*** (.08) [.19]	-.10 (.07) [-.04]
Standard Covariates – Mother			
Age	.06 (.04) [.01]	.07* (.03) [.02]	.12*** (.04) [.05]
Age Squared	-.00 (.00) [-.00]	-.00 (.00) [-.00]	-.00*** (.00) [-.00]
High School Graduate	-.34*** (.07) [-.04]	-.41*** (.09) [-.10]	.14** (.06) [.06]

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Table 2 (cont'd): Determinants of Demand for Prenatal Inputs

	Illicit Drug Use	Cigarette Smoking	First Trimester Prenatal Care
		Probit Coefficient (Standard Error) [Marginal Effect]	
Standard Covariates - Mother			
Some College	-.61*** (.10) [-.06]	-.64*** (.08) [-.15]	.14** (.07) [.06]
College Graduate	-1.17*** (.23) [-.07]	-1.17*** (.10) [-.19]	.43*** (.11) [.16]
Non-Hispanic Black	.13 (.13) [.02]	-.63*** (.10) [-.17]	-.08 (.08) [-.03]
Hispanic	-.14 (.13) [-.02]	-.90*** (.13) [-.20]	-.04 (.08) [-.02]
Other Non-White Non-Hispanic	.03 (.23) [.00]	-.36 (.27) [-.08]	-.43*** (.11) [-.17]
Immigrant	-.87*** (.21) [-.07]	-.83*** (.12) [-.17]	-.03 (.07) [-.01]
First Birth	.07 (.09) [.01]	-.04 (.08) [-.01]	.42*** (.09) [.16]
Married at Time of Birth	-.46*** (.11) [-.04]	-.39*** (.10) [-.09]	.31*** (.06) [.12]
Non-Standard Covariates (NSCs) – Mother			
Medicaid Birth	.07 (.10) [.01]	.14** (.07) [.04]	-.13** (.06) [-.05]
Lived With Both Parents At Age 15	.06 (.07) [.01]	-.08 (.05) [-.02]	.02 (.06) [.01]

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Table 2 (cont'd): Determinants of Demand for Prenatal Inputs

	Illicit Drug Use	Cigarette Smoking Probit Coefficient (Standard Error) [Marginal Effect]	First Trimester Prenatal Care
Number of Previous Pregnancies	.06 (.11) [.01]	.19* (.10) [.05]	.30*** (.09) [.12]
Attends Religious Services	-.17** (.08) [-.02]	-.23*** (.07) [-.06]	.04 (.07) [.02]
% Under Poverty in Census Tract	.18 (.22) [.02]	.31 (.31) [.08]	-.04 (.15) [-.01]
Mother Knew Father at Least 12 Months	.01 (.08) [.00]	-.09 (.06) [-.03]	-.03 (.07) [-.01]
NSCs – Father			
Less Educated Than Mother	.31*** (.09) [.04]	.23*** (.06) [.06]	-.04 (.04) [-.02]
Different Race/Ethnicity Than Mother	.18** (.07) [.02]	.23** (.10) [.07]	.04 (.07) [.02]
5 Years Older Than Mother	.10*** (.08) [.01]	.25*** (.05) [.07]	-.07 (.05) [-.03]
Log-Likelihood	-830.96	-1383.39	-1957.68
Wald Test (no TUVs)	χ^2=198.46 P=.00	χ^2=142.20 P=.00	χ^2=76.71 P=.00
Wald Test (no NSCs)	χ^2=43.19 P=.00	χ^2=109.47 P=.00	χ^2=125.66 P=.00
Wald Test (no TUVs or NSCs)	χ^2=1152.90 P=.00	χ^2=3175.61 P=.00	χ^2=2898.54 P=.00
N	3124	3124	3124

*** significant at 1% level; ** significant at 5% level; * significant at 10% level
[a] "Actual" measures that combine information from self-reports and medical records, as described in the text.
All models include indicators for the city in which the birth took place.

Table 3: Reduced-Form Marginal Effects of TUVs on Infant Health Outcomes

	Birth Weight (grams)	Low Birth Weight (< 2500 grams)	Abnormal Infant Health Condition
	(1)	(2)	(3)
Considered Abortion	-.60 (24.91)	.003 (.01)	.02* (.01)
STD During Pregnancy	-13.17 (26.59)	.02 (.01)	.04** (.01)
Pre-Existing Lung Disease	-31.68 (31.51)	.03** (.02)	.01 (.02)
Other Pre-Existing Physical Health Condition	-37.32 (52.72)	.04* (.02)	-.01 (.02)
Pre-Pregnancy Underweight	-117.03*** (30.25)	.05* (.03)	-.04 (.03)
Pre-Pregnancy Morbidly Obese	91.83 (71.67)	-.02 (.03)	-.03 (.05)
History of Mental Illness	-100.82** (47.84)	.06*** (.02)	.03 (.02)
Mean	3221	.10	.12
N	3122	3124	3101
F-test or Wald Test (no TUVs)	$F_{7,18}$=8.99 P=.00	χ^2=99.26 P=.00	χ^2=55.17 P=.00
F-test or Wald Test (no NSCs)	$F_{9,18}$=7.21 P=.00	χ^2=119.89 P=.00	χ^2=63.89 P=.00
F-test or Wald Test (no TUVs or NSCs)	$F_{16,18}$=48.53 P=.00	χ^2=924.14 P=.00	χ^2=5208.46 P=.00

TUV = typically unobserved variable; NSC = non-standard covariate
*** significant at 1% level; ** significant at 5% level; * significant at 10% level
All models include TUVs, NSCs, standard covariates, and city in which the birth took place.
Birth weight is estimated using Ordinary Least Squares (standard errors in parentheses). Low birth weight and abnormal conditions are estimated using probit models; the marginal effects are presented with standard errors in parentheses.

Table 4: Infant Health Production Models: Marginal Effects of Inputs and TUVs on Infant Health Outcomes

	Birth Weight (grams)	Low Birth Weight (< 2500 grams)	Abnormal Infant Health Condition
	(1)	(2)	(3)
Prenatal Illicit Drug Use	-139.26** (49.70)	.04** (.02)	.06*** (.02)
Prenatal Cigarette Smoking	-173.56*** (27.83)	.05*** (.01)	.00 (.02)
First Trimester Prenatal Care	17.61 (18.42)	.00 (.01)	-.01 (.01)
Considered Abortion	23.35 (26.56)	-.00 (.01)	.02 (.01)
STD During Pregnancy	-2.81 (26.59)	.02 (.01)	.03*** (.01)
Pre-Existing Lung Disease	-27.31 (32.81)	.03** (.02)	.01 (.02)
Other Pre-Existing Physical Health Condition	-45.43 (52.13)	.04** (.02)	-.01 (.02)
Pre-Pregnancy Underweight	-108.67** (30.20)	.04 (.03)	-.04 (.03)
Pre-Pregnancy Morbidly Obese	64.47 (74.48)	-.01 (.03)	-.03 (.05)
History of Mental Illness	- 28.54 (39.50)	.04** (.02)	.01 (.02)
Mean	3221	.10	.12
N	3122	3124	3101

***Significant at 1% level, **5% level, *10% level
TUV = typically unobserved variable
Birth weight model is estimated using Ordinary Least Squares (standard errors in parentheses). Low birth weight and abnormal conditions are estimated using probit models; the marginal effects are presented with standard errors in parentheses. All models include variables from Table 2 plus city indicators.

Table 5: Infant Health Production Models: Effects of Prenatal Inputs on Infant Health Outcomes

			Birth Weight (grams)	Low Birth Weight (< 2500 grams)	Abnormal Infant Health Condition
Panel 1: "Actual" Inputs			(1)	(2)	(3)
	Prenatal Illicit Drug Use	A	-139.26**	.04**	.06***
		B	-144.59**	.05***	.07***
		C	-144.05***	.04**	.06***
		D	-153.67***	.06***	.07***
	Prenatal Cigarette Smoking	A	-173.56***	.05***	.00
		B	-176.35***	.06***	.01
		C	-182.07***	.06***	.00
		D	-186.06***	.07***	.01
	First Trimester Prenatal Care	A	17.61	.00	-.01
		B	15.33	.00	-.01
		C	22.23	.00	-.00
		D	19.98	.00	-.01
	No TUVs	B	$F_{7,18}$=7.04 P=.00	χ^2=51.99 P=.00	χ^2=26.72 P=.00
	No NSCs	C	$F_{9,18}$=5.26 P=.00	χ^2=93.53 P=.00	χ^2=27.96 P=.00
	No TUVs or NSCs	D	$F_{16,18}$=105.15 P=.00	χ^2=2170.72 P=.00	χ^2=1840.29 P=.00
Panel 2: Self-Reported Inputs					
	Prenatal Illicit Drug Use	A	-172.55**	.06**	.07***
		B	-175.56**	.07***	.08***
		C	-169.58**	.06**	.07***
		D	-177.06**	.07***	.07***
	Prenatal Cigarette Smoking	A	-213.19***	.05***	.01
		B	-216.47***	.06***	.01
		C	-225.29***	.06***	.01
		D	-230.29***	.07***	.01
	First Trimester Prenatal Care	A	49.78*	-.02**	-.03**
		B	47.95*	-.02**	-.03***
		C	53.85*	-.02**	-.03**
		D	52.16*	-.02**	-.03**
	No TUVs	B	$F_{7,18}$=7.53 P=.00	χ^2=41.21 P=.00	χ^2=25.32 P=.00
	No NSCs	C	$F_{9,18}$=5.24 P=.00	χ^2=97.87 P=.00	χ^2=47.62 P=.00
	No TUVs or NSCs	D	$F_{16,18}$=116.87 P=.00	χ^2=591.38 P=.00	χ^2=1734.68 P=.00
	Mean		3221	.10	.12
	N		3122	3124	3101

***Significant at 1% level, **5% level, *10% level

TUV = typically unobserved variable; NSC = non-standard covariate

Each figure represents the marginal effect of an input on an outcome (using Ordinary Least Squares for birth weight and probit for low birth weight and abnormal condition). In each cell, results are presented from four different model specifications (all models include standard covariates and city indicators):

Model A: includes TUVs and NSCs

Model B: includes NSCs but not TUVs

Model C: includes TUVs but not NSCs

Model D: includes neither TUVs nor NSCs

Appendix: Construction of Abnormal Infant Health Condition Variable

Infant health conditions were recorded in several places in the mothers' or infants' hospital medical records and were also asked about in the mothers' follow-up surveys.

Medical Records

The abstraction form that was used to collect information from the hospital medical records for each birth was designed with input from medical consultants. The sections of the form used to obtain information for the coding of the infant health conditions ("Abnormal Conditions of the Newborn," "Newborn Screen Test Results," "Other Notes Not Collected Elsewhere") are attached. Each condition, including those listed in the other (specify) fields, were recorded in a database that was provided to a pediatric consultant who was instructed to determine whether a given condition had potential long-term adverse health consequences, and if it did, to code that condition according to the relevant cell in the 16-square grid (attached). The columns in the grid pertain to severity of the condition (high, medium, low, unknown) and the rows pertain to whether the condition is associated with maternal prenatal behavior (likely, possibly, not associated, not known). For cases with multiple conditions, each potentially long-term condition was assigned a code.

Survey Question

The survey question that was used (from the mother's one year follow-up interview) was as follows:

"*Does (CHILD) have any physical disabilities*?" (underlining included on survey instrument). If the respondent answered "yes," the following was asked "*What type of physical disability does (he/she) have?"* with the following response categories (verbatim from survey instrument): C*erebral palsy, total blindness, partial blindness, total deafness, partial deafness, Down's syndrome, problem with limbs (specify), and other (specify).*

These conditions, including responses to the other (specify) categories, were coded as described above (using information from the medical records abstractions). However, only conditions that were likely present at birth (such as Cerebral Palsy or Down Syndrome) were assigned codes.

Variable construction

For this paper, we were interested in identifying coded infant conditions that were not low severity and that could potentially be related to maternal prenatal behavior. In the grid, the relevant cells are shaded in gray. We coded cases as having an abnormal infant health condition if the infant had at least one condition in any of the following cells (regardless of whether that infant also had a condition in any of the remaining cells): 5, 6, 8, 9, 10, 12, 13, 14, 16.

ABNORMAL CONDITIONS OF NEWBORN

	Respiratory System	**Yes (+)**	**No (-)**
CHI1.	Apnea Problems During Nursery Stay..	1 ☐	0 ☐
CHI2.	Assist. ventilation <30 Min...	1 ☐	0 ☐
CHI3.	Assist. ventilation >30 Min..	1 ☐	0 ☐
CHI4.	Hyaline Membrane Dis./RDS..	1 ☐	0 ☐
CHI5.	Meconium Aspiration Syndrome..	1 ☐	0 ☐
CHI6.	Other respiratory condition	1 ☐	0 ☐
CHI6O.	Specify other respiratory condition ________________________________		
	Central Nervous System		
CHI9.	Hydrocephalus..	1 ☐	0 ☐
CHI10.	Microcephalus...	1 ☐	0 ☐
CHI11.	Seizures..	1 ☐	0 ☐
CHI12.	Spina bifida/Meningocele	1 ☐	0 ☐
CHI13.	Other Central Nervous System	1 ☐	0 ☐
CHI13O.	Specify other _________________________________		
	Gastrointestinal System		
CHI14.	Hyperbilirubinemia During Nursery Stay (Jaundice)	1 ☐	0 ☐
CHI15.	Hernia (Hiatal, Abdominal, Inguinal)...	1 ☐	0 ☐
CHI20.	Other gastrointestinal	1 ☐	0 ☐
CHI20O.	Specify other _________________________________		
	Circulatory System		
CHI21.	Cardiac Problems	1 ☐	0 ☐
CHI22.	Heart malformations	1 ☐	0 ☐
CHI23.	Other circulatory	1 ☐	0 ☐
CHI23O.	Specify other_________________________________		
	Renal/Genital/Urinary System		
CHI24.	Malformed genitalia	1 ☐	0 ☐
CHI25.	Renal agenesis..	1 ☐	0 ☐
CHI26.	Other genital urinary tract	1 ☐	0 ☐
CHI26O.	Specify other _________________________________		
	Musculoskeletal/Integumental		
CHI27.	Cleft lip/palate	1 ☐	0 ☐
CHI28.	Hip Dysplasia...	1 ☐	0 ☐
CHI30.	Club foot	1 ☐	0 ☐
CHI31.	Other musculoskeletal/integumental	1 ☐	0 ☐
CHI31O.	Specify other _________________________________		
	Chromosomal		
CHI32.	Down syndrome (TRI SOMY 21)...	1 ☐	0 ☐
CHI33.	Other	1 ☐	0 ☐
CHI33O.	Specify other _______________________________		
CHI34.	**No Abnormal Conditions**...	1 ☐	0 ☐

NEWBORN MISCELLANEOUS

		Yes(+)	No (-)
CHJ9.	Newborn Screen Test(s) Abnormal	1 ☐	0 ☐
CHJ10.	If Newborn Screen Test Abnormal, is abnormality specified?	1 ☐	0 ☐
CHJ10O.	Specify ____		

CHNOTES2: Other notes not collected elsewhere:

____

____

Coding Grid for Infant Health Conditions

	Severity			
	High	Medium	Low	Unknown
Not Behavior Related	1	2	3	4
Possibly Behavior Related	5	6	7	8
Likely Behavior Related	9	10	11	12
Not Enough Information To Determine if Behavior Related	13	14	15	16

Cell	**Examples of conditions**
1	Microcephalus, renal agenesis, total blindness, Down Syndrome
2	Malformed genitalia, hydrocephalus, cleft palate
3	Assisted ventilation < 30 minutes, jaundice during nursery stay
4	Thick meconium present in amniotic fluid, ear malformation
5	Cerebral palsy
6	Uterine growth restriction
7	Trouble feeding
8	Circulatory anomaly
9	Fetal alcohol syndrome
10	HCV (Hepatitis C)
11	Candidiasis of skin and nails
12	NONE
13	Seizures
14	Infection/e-coli
15	Oral thrash
16	Facial frontal bruising