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ABSTRACT

This paper develops a method to correct for non-random measurement error in a binary indicator of illicit drugs. Our results suggest that estimates of the effect of self reported prenatal drug use on birth weight are biased upwards by measurement error -- a finding contrary to predictions of a model of random measurement error. We show that more accurate estimates of the true effect of drug use on birth weight can be obtained by using the predicted probability of falsely reporting drug use. This suggests that out-of-sample information on drug use may improve estimates of the effect of reported drug use in other settings.

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I. INTRODUCTION

The adverse consequences of maternal drug use on birth outcomes is a serious public health issue. Clinical data have clearly established that use of illicit drugs during pregnancy is significantly correlated with the incidence of low birth weight and a variety of other neonatal health ailments.[1] Indeed, Joyce [1990] and Joyce, Racine and Mocan [1992] show that the dramatic rise in the aggregate rate of low birth weight among blacks in New York City between 1984 and 1988 is directly associated with the rise in illicit drug use. Moreover, as Hay [1991] and Phibbs et al. [1993] document, the economic consequences of prenatal illicit drug use are potentially enormous. Although well-controlled investigations have estimated the consequences and costs of prenatal illicit drug use in a clinical setting, the extent of the problem in the general population is not well known. National surveys such as National Maternal and Infant Health Survey and vital statistics are a potential source of data on prenatal illicit drug use in the general population, but experience from clinical studies suggests that self-reported drug use seriously under-estimates not only the prevalence, but also the potential magnitude of the consequences of prenatal illicit drug use.

The primary purpose of this paper is to investigate the potential ways that measurement error may bias estimates of the effect of prenatal illicit drug use on infant health.
We confront two issues which are frequently skirted in the economics literature. First, we relax the standard assumption that measurement error is random. Second, we discuss measurement error in the context of binary variables. In addition, we suggest a method to correct for non-random measurement error with a binary indicator of illicit drugs which uses out-of-sample information to predict the probability of falsely reporting nonuse.

Our empirical results suggest that the estimates of the impact of self reported prenatal illicit drug use on birth weight are biased upwards by measurement error -- a finding in direct contrast to predictions from a standard model of random measurement error. The upshot is that the costs and consequences of prenatal illicit drug use based on hospital discharge data and vital records probably have been overstated. We also show that more accurate estimates of the true effect of illicit drug use on birth weight can be obtained by using the predicted probability of falsely reporting illicit drug use. This suggests that out-of-sample information on illicit drug use may improve estimates of the effect of reported drug use in other settings.

II. BACKGROUND

<u>Continuous Measure of Illicit Drug Use</u>

The empirical model is based on the household production theory of Becker [1965] and consists of a structural production function of infant health. We use birth weight as our measure of infant health. The empirical specification is similar to that found in previous studies examining the determinants of birth weight.[2] The production function is assumed to have the following linear form,

$$(1) \qquad BW_i = \beta_0 + \beta_1 M_i + \beta_2 D_i + \Sigma \beta_k Z_{ik} + e,$$

where M is prenatal care received by the mother, D is illicit drug use during pregnancy, Z is a vector of demographic variables related to both the child and mother, the β_i are parameters to be estimated and e is an error term.

The parameter of interest is β_2, which measures the effect of maternal drug use on birth weight. Since women have powerful incentives to underreport illicit drug use, actual drug use is almost certainly measured with error. If only D_i were measured with error, and the error were random, then the estimate of β_2 is biased towards zero. In the case of illicit drug use, however, random error would appear improbable since reported use is likely to be correlated with actual use. Moreover, the likelihood of a false positive appears remote given the stigma and potential consequences associated with drug use. Thus, in the discussion which follows, our maintained hypothesis is that illicit drug use is under-reported and never over-reported.[3] This relationship can be written as

(2) $$d_i = D_i - u_i ,$$

where d_i is observed drug use, D_i is actual drug use, and u_i is measurement error. Given the absence of over-reporting, u_i is non-negative, and less than or equal to D_i. Thus, when observed drug use is substituted for actual drug use, equation (1) becomes

(3) $$BW_i = \beta_0 + \beta_1 M_i + \beta_2 d_i + \beta_2 u_i + \Sigma \beta_k Z_{ik} + e.$$

With only observed drug use included in equation (3), Maddala [1977] shows that not only β_2 is biased, but all parameter estimates are biased. Specifically, the estimate of β_2 can be expressed as follows:

(4) $$b_2 = \beta_2 (1 + \delta).$$

Equation (4) reflects the omitted variable bias associated with the exclusion of u_i from equation (3). In the simple case of a single regressor, δ equals the following,

$$(5) \quad \delta = C(d,u) / V(d) = [C(D,u) - V(u)] / [V(D) + V(u) - 2\ C(D,u)]$$

where C( ) and V( ) denote the covariance and variance respectively. Note that in equation (4), δ can be expressed in terms of the observed (d) or actual (D) drug use. In the more general case of multiple regressors, δ is equal to the partial correlation between observed drug use and the measurement error holding constant all of the other variables in equation (1).[4]

With a continuous measure of illicit drug use the direction of the bias in b_2 depends on the sign of C(D,u) and relative magnitudes of C(D,u) and V(u). In the standard treatment of random measurement error, C(D,u) is zero and b_2 is an underestimate of the true parameter. If C(D,u) is not zero, however, the direction of the bias is indeterminate. For instance, under-reporting by heavy drug users implies that C(D,u) is greater than 0, but the direction of the bias is ambiguous because the sign of the term, C(D,u) - V(u), is unknown. Under-reporting by marginal users implies that C(D,u) is less than 0, in which case b_2 is always an underestimate of the true parameter.[5]

<u>Binary Measure of Drug Use</u>

Frequently, the only measure of drug use available to the researcher is a binary indicator of use. Aigner [1973] derives results for the case of a single binary variable measured with error. He demonstrates that unlike the case of a single continuous variable measured with error, both the expected value of the error and its covariance with the actual measure are always nonzero. Aigner [1973] shows that δ in equation (4), reduces to -n, the proportion of users who falsely report nonuse. Thus, C(d,u) in equation (4) is negative and it is straightforward to show that C(D,u) is positive but less than V(u). A positive covariance between the actual variable and the measurement error [C(D,u) >0] is in direct contrast to random measurement error in the case of a single continuous variable in which C(D,u) is zero. Yet despite this difference, a single binary variable measured with error still yields a downward biased estimate of the true parameter.

Aigner [1973] uses individuals diagnosed with and without a disease as an example of a binary variable. Classification errors occur when individuals who have the disease are misdiagnosed as not having the disease (false negatives). Implicit in his discussion of measurement error is the assumption that individuals correctly classified with the disease are at the same stage of the disease as those who are misdiagnosed. Put differently, the extent of one's illness has no effect on the likelihood of misclassification. When applied to illicit drug use, this is a strong and overly restrictive assumption, since the intensity of use should affect the probability of detection. Even with a random screen of urine samples, for instance, frequent users are more likely to test positive for illicit drug use than infrequent users given the limited window for capturing exposure. With self reports, however, it is unclear whether intense users are more likely to admit to use than less intense users. It would depend in part on the sanctions or support that admitted users receive.

If the likelihood of reporting drug use is correlated with the frequency or quantity of drug consumption, then equation (3) should be modified to allow the effect of illicit drug use to vary between observed (d_i) and unobserved (u_i) users as follows:

$$(6) \qquad BW_i = \beta_0 + \beta_1 M_i + \beta_2 d_i + \beta_3 u_i + \Sigma \beta_k Z_{ik} + e.$$

In equation (6), the coefficients on observed use (d_i) and the measurement error (u_i) are no longer equal. In effect, d_i and u_i measure different levels of illicit drug use. This change alters Aigner's result. It is not the case that the estimate of the effect of actual drug use will be biased towards zero. The direction of the bias is indeterminate.[6]

Differences in the intensity of illicit drug use between those who report use and those who do not, has important implications for empirical estimates of the consequences and costs of illicit drug use. For example, in a widely cited government report, Kusserow [1990] estimated the marginal costs for delivery, perinatal care and foster care for an infant exposed to cocaine at over $30,000. The report acknowledged that many cases of cocaine exposed newborns were missed. If under-reporting leads to downward biased estimates of costs as assumed in the standard model, then readers may conclude that true costs have been underestimated.

This discussion is not intended to downplay the social and economic impact that cocaine and crack have had over the past 10 years. However, estimates of the costs of prenatal illicit drug use extrapolated from surveys and clinical studies may be misleading if 1) true prevalence of illicit drugs is under-reported, and 2) given under-reporting, the estimated impact of illicit drug use is biased. There is little doubt that studies of infant health based on self-reported use have under-estimated true prevalence, as the studies by Zukerman et al. [1989] and Ostrea et al. [1992] demonstrate. The question that we seek to address is whether under-reporting leads to downward or upward biased estimates of the impact of illicit drug use on infant health. In addition, if the bias can be in either direction, are there empirical strategies which will yield consistent estimates of observed and actual use?

III. AN EMPIRICAL STRATEGY

The assumption that actual use is uncorrelated with measurement error in the case of a continuous variable, or that true positives are no different from false positives in the binary case, has important empirical implications. If we relax these assumptions, then standard approaches to measurement error, such as instrumental variables, become extremely difficult to implement. More specifically, we are skeptical that one could find a variable that was correlated with actual use, in our case illicit drug use, and uncorrelated with the error given an association between actual use and the error.

Our solution is to seek more information regarding the nature of under-reporting. In brief, we use data from a well controlled clinical study of prenatal drug use in which we have information on self reported drug use as well as results from a toxicology analysis of women's urine. We consider self reported use as a measure of observed use (d_i) and positive results from the urinalysis as actual use (D_i). Comparison of the two enables us to identify which women falsely reported nonuse. We are also able to compare the effect of actual prenatal illicit drug use on birth weight with the effect when only observed use is included in the model. We then test whether a predicted measure of falsely reported nonuse [u_i in equation (6)], lessens the bias associated with observed use, and whether a combination of d_i and predicted u_i yields estimates that are close to the estimate of the effect of actual use (D_i).

To make these ideas more precise, rewrite equation (2) as follows:

(2a) $u_i = D_i - d_i$,

where D_i, our measure of true use, which equals one if a woman self reports illicit drug use, or if her urine tests positive for illicit substances; d_i equals one only when a woman self reports use. Consequently, u_i is one if a woman falsely reported nonuse and zero otherwise.

With a measure of u_i we estimate the following,

$$(7) \qquad u_i = \alpha_0 + \alpha_1 M_i + \alpha_2 d_i + \Sigma \alpha_k Z_{ik} + e .$$

In equation (7), α_2 is an estimate of δ in equation (4). As suggested by Aigner, an estimate of δ allows us to correct for the bias in the coefficients obtained from a model which uses only the self reported measure of drug use. In addition, this estimate of δ could be applied to coefficients from other samples in which urine toxicology tests are not available. As we noted, we find this overly restrictive because it assumes that reported illicit drug use (d_i) has the same effect on infant health as does unreported use (u_i).

An alternative and more flexible procedure is to obtain a predicted value of u_i and estimate equations (1) and (6) directly. This will yield estimates of the effect of actual, reported and unreported drug use on birth weight. Our predicted u_i is obtained by assuming that there is an underlying latent variable, u^*_i, that measures the tendency to underreport drug use, and that it is a linear function of several exogenous variables. This equation may be written as

$$(8) \qquad u^*_i = \alpha_0 + \Sigma\, \alpha_n X_{in} + v_i \,,$$

and,

$$u_i = 1 \text{ if } u^*_i > 0$$

$$u_i = 0 \text{ if } u^*_i < 0 \,.$$

We assume that v_i is a normally distributed random variable, and estimate a probit regression model in order to obtain a predicted value of u^*_i. Next, we transform our predicted u^*_i into a probability using the standard normal distribution, and calculate a predicted u_i by assigning a value of 1 or 0 depending on whether the predicted probability for that person is greater than the mean probability observed for the sample.[7] We combine the predicted dichotomous version of u_i with d_i to create an estimate of actual use which we refer to as D^*_i. We estimate equation (1) with D^*_i substituted for D_i.

With actual measures of D_i, d_i and u_i for each woman we have a straightforward way of testing the robustness of our procedure by comparing the coefficients on the predicted u_i to the coefficient on actual u_i, when each is used in equation (6). We can make a similar comparison between D_i and D^*_i when each is used in equation (1). This will provide evidence as to the utility of the procedure when applied to the much larger sample of birth certificates for the entire municipal hospital system.

Another advantage of using a predicted u_i, as opposed to the actual u_i is that the predicted index measures the likelihood of under-reporting, not actual under-reporting. The inclusion of this variable in the model helps to overcome the problem associated with the fact that the urine test may not identify all under-reporting. If the women who underreport and test positively are similar to the women who underreport, but are not subsequently identified, then our predicted u_i will reflect total under-reporting in the sample. The use of predicted u_i may do a better job of accounting for measurement error than use of the urine results, since it accounts for those individuals who underreported but were not identified as such by the urine tests.

IV. DATA

We have two sources of data. The first is from a clinical study of prenatal illicit drug use at a large municipal hospital in New York City. We include all women who delivered at the facility between 18 November 1991 and 11 April 1992 (N=1,323). After exclusions due to death and missing data, the actual sample is 1,279 mother/infant pairs. Exposure to illicit drugs was assessed at or around delivery and was measured in two ways. First, all women were asked by a physician or resident whether they had used any illicit substances within the past week. Urine samples collected routinely at delivery were then anonymously tested for exposure to one of four substances, marijuana, cocaine, heroin and methadone. Neither the woman nor her physician knew that the woman's urine, which is routinely collected around delivery, would be tested for illicit drug use.[8] Nor were the results from the screen made known to either the physician or the woman. Of the 132 women exposed to any illicit drug, 96 were detected based solely on urine tests, 16 by self reports exclusively, and 20 by urine tests and self reports. Thus, only 17 percent (20/116) of the women whose urine samples were positive for illicit drugs admitted to use.

We divide illicit drug use into two groups: those who used marijuana, heroin, methadone or cocaine (N=132) in the week prior to delivery and those who used cocaine (N=78). Among the cocaine users, 69 were exposed to only cocaine, and 9 were exposed to cocaine and some other drug. We estimate the model separately for each group.[9]

The second data set is a sample of birth certificates from New York City. Since 1988, New York City birth certificates have included a separate indicator for prenatal use of cocaine, marijuana, heroin and methadone. The indications are a combination of maternal self reports and physician diagnoses. We use the birth certificates from all births delivered at the 11 municipal hospitals in New York City between 18 November 1991 and 11 April 1992, the same dates over which data for the clinical study were collected. Approximately 35 percent of all births to New York City residents are delivered within the municipal hospitals. For a more detailed description of New York City birth certificate data see Joyce [1994].

V. RESULTS

The empirical strategy is as follows. First, we estimate the effect of actual drug (D_i) use and reported drug (d_i) use on birth weight based on the clinical data only. A comparison of the two estimates reveals the direction and size of the bias due to measurement error. Next, we correct for the bias using the procedures outlined in the text. Finally, we apply the results from the clinical data to the total sample of births delivered at all 11 eleven municipal hospitals in New York City.

Table I contains the results of the regression analyses. The top panel contains estimates on total drug use; the bottom panel is limited to cocaine use only. Column 1, contains the estimate of the effect of actual drug use (D_i) on the natural logarithm of birth weight. Here we show that exposure to any illicit drug in the days preceding delivery is associated with a 5.7

percent decrease in birth weight. In column 2 we show the effect of observed drug use (d_i) on birth weight. We find that observed drug use is associated with an 8.0 percent decrease in birth weight. Thus, observed drug use **overestimates** the impact of illicit drug use on birth weight by 40 percent. The results for cocaine are qualitatively similar (lower panel). Reported use of cocaine overestimates the impact of actual cocaine use on birth weight by 51 percent (8.9 percent versus 13.4 percent).

To address the measurement error issue, researchers frequently use an instrumental variables (IV) procedure. Although we are skeptical that the necessary conditions underlying the proof of consistency for the IV estimator can be met, we use an IV procedure so that we can contrast the results from such a procedure with our solution. In the case of a binary endogenous variable, Heckman and Robb (1985) review feasible two stage IV estimators. We chose the following procedure because it requires relatively few statistical assumptions and is similar to the procedure we use later in the paper. In the first stage we predict observed drug use using a probit regression. The second stage consists of regressing birth weight on predicted observed drug use and the other right hand side variables. Predicted drug use is measured as the predicted probability.[10] The results of this procedure are listed in column 3 of Table I. As can be observed, the IV procedure yields estimates that are much different from those found in column 1, which they are intended to replicate. For example, the IV estimate of the effect for any (observed) drug use is -.310, which is dramatically different from the -.057 estimate found in column 1. Similar results are obtained for cocaine. In summary, the results presented thus far, suggest that the IV procedure does not appear to be a very good solution to the measurement error problem.

The finding that the coefficient on observed illicit drug use is an upward biased estimate of the actual impact of illicit drug use on birth weight suggests two possibilities. First, δ in equation (4) is positive. In other words, the partial correlation between unobserved (u_i) and observed (d_i) drug use holding constant other characteristics of the mother is greater than zero.[11] Or second, the level of involvement with illicit drugs, and thus its impact on birth weight, differs importantly between women who self report drug use (d_i), and users who deny use (u_i).

To test the first proposition we estimated equation (7). The coefficient on d_i, our estimate of δ, is reported in the fourth column of Table I. We also report an estimate of the effect of actual drug use using equation (4) and our estimate of δ (also in column 4). The results in column (4) illustrate that our estimate of δ is negative for both any illicit drug use and cocaine use. Consequently, the estimate β_2 from equation (4) overestimates the impact of actual drug use on birth weight by 82 percent for any drug (-.104 versus -.057) and by 92 percent for cocaine (-.089 versus -.172). To test the second proposition we estimate equation (6). The specification of equation (6) allows the impact of illicit drug use on birth weight to differ by users who self report and those who deny use. The results are presented in column (5). For both any drug use and cocaine use the impact of reported use on birth weight is twice as large as the effect of unreported use. Women who report using any drug in the week prior to giving birth have babies that weigh 8.9 percent less than the infants of non-users, but women who did not report their drug use have babies that weigh only 4.2 percent less than the infants of non-users. For cocaine use, those women who report their use have infants that weigh 14.8 percent less than infants of non-users, whereas those women who do not report their cocaine use have infants that weigh 6.6 percent less than the infants of non-users.

The conclusion that we draw from the results in columns (1) - (5) of Table I is that measurement error in a single binary variable will yield classically downward biased estimates only under highly restrictive assumptions. In the case of prenatal illicit drug use, one must assume that women who report use are similar to users who deny use with respect to the intensity of drug use and its impact on the fetus. Furthermore, we found that an IV procedure does not adequately address the problem, as estimates obtained from such a procedure were implausibly larger than the estimates of the effect of actual drug use. A less restrictive approach is to treat unreported use as an omitted variable and estimate equation (6). This specification yields estimates of the effect of reported and unreported drug use on birth weight.[12]

Treating measurement error as an omitted variable problem is more general, but the empirical usefulness of such a procedure depends on having a realistic estimate or proxy for unreported use. What we have proposed above is that with illicit drug use, information from small, well-controlled studies may allow us to generate an estimate of unreported drug use that can be used in larger surveys that are limited to only self reported or nonrandomly detected use. As an initial test, we estimated equation (8) using a predicted value of u_i derived from equation (6). The results are shown in column (5) of Table I. A complete set of estimates for equation (8) are in an appendix. Comparison of columns 5 and 4 are quite encouraging. For example, the estimate of reported drug use holding predicted u_i constant is -.079 (top panel, column 5) and -.089 with actual u_i (top panel, column 4). The estimates for reported cocaine compare similarly (-.148 versus -.129).[13]

Finally we combine the predicted dichotomous value of u_i with reported illicit drug use to create an estimate of actual use [D_i^* in equation (1)]. If we have measured unreported use effectively, then the coefficients on D_i^* should compare favorably with those on D_i in column (1). The results from this exercise are displayed in column (6). The estimate of our predicted actual drug use [-.072 in column (6)] overestimates the decrease in birth weight as measured by actual drug use slightly [-.057 in column (1)]. For cocaine, the estimate of the effect of predicted actual cocaine use [-.090 in column (6)] on birth weight is almost identical to that obtained using actual cocaine use (-.090 versus -.089).

To summarize, we have found that measurement error in prenatal illicit drug use leads to overestimates of the true effects of drug use on birth weight. The estimates of the effect of drug use on birth weight associated with reported drug use are between 40 percent and 50 percent larger than the estimate of actual drug use. These findings are opposite of what would be expected in the case of a single binary variable measured with error as presented by Aigner [1973]. The findings, however, are consistent with other clinical studies in which the impact of exposure to cocaine on infant health is substantially less among women who deny prenatal use of cocaine, but whose urine or the infant's meconium reflects exposure (Bateman et al. [1993]; Ostrea et al. [1992]).

We also have found that the probability of reporting drug use is significantly related to the underlying level of drug use, and the results imply that relatively heavy drug users are more likely to report their use. More importantly, the results from our analysis suggest that reasonably good estimates of the effect of illicit drug use can be obtained by using characteristics of the mother to predict the probability of not reporting drug use. The predicted value from this regression, a proxy for unobserved use, performed well in empirical tests. Combining the predicted value of unreported use with reported use also yielded estimates of the effects of illicit drug use on birth weight that closely approximated the actual effect.

VI. APPLICATION TO MUNICIPAL HOSPITAL DATA

In this section we apply our correction procedure to a larger data set of births in which the only information on prenatal illicit drug use comes from indications reported on the confidential portion of the New York City birth certificate. These indications are based on maternal self reports and physician diagnoses. The sample consists of all births at 11 New York City municipal hospitals during the same period which data for the clinical study were collected. The objective is to examine whether our correction procedure performs reasonably when applied out-of-sample.

The current application is not ideal because women from the clinical study were not a random sample of the larger population of municipal hospital deliveries. As can be seen from Table II, women from all 11 municipal hospitals are less likely to be African-American, less likely to smoke, are more likely to deliver a first birth, and have higher levels of reported cocaine use than the sample of women from the clinical study.

Another important difference is that reported use of illicit drugs in the clinical data was limited to maternal self reports. In birth certificate data, exposure to illicit drugs could have come from a urine screen ordered by a physician because use was suspected. Since urinalysis is generally prescribed in obvious instances of drug use, reported drug use from the birth certificates may capture a more homogenous group of heavy users. Despite these differences, we have obtained relatively similar populations in terms of income since over 83 percent of women in each sample are on Medicaid. Moreover, the correction procedure that we propose controls for observed characteristics, and thus the differences just noted between the two samples may not be problematic. A potentially more important problem is whether the two samples differ by unobserved characteristics. We present the results with this caveat in mind.

To implement the correction procedure, we first calculate a predicted u_i for each woman from the 11 municipal hospitals with the estimated parameters from equation (8). Note the parameters from equation (8) were obtained with clinical data only. Next, we calculate a predicted measure of actual drug use (i.e., D^*_i), and use these two variables to estimate equations (1) and (6) for births from all 11 municipal hospitals.

Column 1 of Table III lists the estimates of observed drug use on birth weight. Infants born to women reported to have used any illicit drug prior to delivery weigh 13.4 percent less than infants whose mother had no indication of illicit drug use. Reported cocaine use is associated with a birth weight deficit of 15.7 percent. These estimates of the effect of observed drug use are slightly larger than those in Table I, and probably reflect the different screening methods between the two samples. Including the predicted value of unobserved use (u_i) in the model results in estimates that have the same pattern as those observed in Table I. As can be seen in column 2 of Table III, reported maternal use of illicit drugs has a larger impact on birth weight than does unreported use. For instance, reported cocaine use is associated with a birth weight deficit of 15.4 percent whereas unreported cocaine use is associated with a birth weight deficit of 4.2 percent.

Finally, we construct a measure of actual drug use (D^*_i) by combining reported use and our predicted unobserved use, and estimate equation (1). The results compare favorably to those from the clinical data only. Specifically, our proxy for actual use of any drug is associated with a 7 percent decline in birth weight; the same measure limited to cocaine is associated with a decrease in birth weight of 8.8 percent. Note that reported illicit drug use on the birth certificates is associated with a larger birth weight deficit than reported drug use in the clinical study. Nevertheless, the constructed measures of actual use (D_i^*) yield practically identical estimates to those in column (6) of Table I. Furthermore, the estimates in column (3) of Table III are much closer to the estimates of actual use in column (1) of Table I than are the measures of reported use when entered alone in the regressions.

VII. CONCLUSIONS

In this paper, we have proposed and tested a method for correcting the bias due to a badly measured binary variable for which the measurement error is non-random. In particular, we have examined the effects of maternal drug use on birth weight, when drug use is self reported. There were several significant findings. First, it was found that under-reporting of maternal drug use results in an overestimate of the actual effect of drug use on birth weight. This result is somewhat surprising and contrasts with standard arguments relating to measurement error. It also has important implications regarding previously estimated consequences of maternal drug use on birth weight that use self reported drug use. Second, the results from our analysis suggest that our proposed method for correcting problems associated with measurement error has wider applicability. Using a predicted measure of the extent and nature of under-reporting of drug use, we were able to closely approximate the true effects of drug use on birth weight. In addition, when applied to a larger sample, our methodology appears to have performed reasonably well, although there is no definitive way to accurately assess the performance of the procedure in this case. In summary, our findings suggest that the proposed methodology is an appropriate and relatively inexpensive way to address a serious empirical problem.

Appendix Table I

Partial Correlations Between Measurement Error and Explanatory Variables

Variable	Cocaine Coeff.	Cocaine Std. Err.	Any Drug Coeff.	Any Drug Std. Err.
Constant	-0.264	0.073	-0.415	0.091
Log Mother's Age	0.101	0.022	0.150	0.028
Mother Smokes	0.150	0.016	0.176	0.020
First Birth	-0.016	0.012	-0.032	0.015
Early Prenatal Care	-0.070	0.013	-0.049	0.016
American Black	0.060	0.012	0.075	0.015
Twins	0.033	0.036	0.024	0.045
Observed Cocaine	-0.212	0.042		
Observed Any Drug			-0.233	0.038
Adj. R Square	0.1595		0.1374	
Observations	1279		1279	

Appendix Table II

Estimates from Probit Regressions Predicting Unreported Drug Use

	Cocaine		Any Drug	
Variable	Coeff.	Std. Err.	Coeff.	Std. Err.
Constant	-6.464	1.237	-5.687	0.918
Log Mother's Age	1.370	0.369	1.202	0.276
Mother Smokes	0.950	0.167	0.796	0.137
Early Prenatal Care	-0.563	0.162	-0.243	0.137
American Black	0.665	0.172	0.501	0.133
Less Than HS	-0.229	0.207	-0.152	0.160
College	-0.421	0.264	-0.244	0.184
Missing Education	0.112	0.452	0.180	0.383
Self Payer	-0.590	0.402	-0.142	0.261
Other Payer	0.255	0.295	0.457	0.209
Syphilis	0.515	0.276	0.275	0.250
Observations	1279		1279	

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1. See the papers by Cherukuri et al. [1988], Zuckerman et al. [1989], McCalla et al. [1992] and Bateman et al. [1993] for evidence regarding the correlation between maternal drug use and neonatal health ailments.

2. Papers by Rosenzweig and Schultz [1983] and Grossman and Joyce [1990] have extensive discussions of the empirical issues associated with estimating a structural production function of infant health.

3. With a continuous measure of illicit drug use, the absence of over-reporting may appear extreme. Attempts by users to report exposure may over estimate actual use. We present the continuous model as a point of comparison to a binary measure of illicit drug exposure which is presented below. In the binary case over-reporting is a false positive, that is, users answer yes to illicit drug use when in fact they have not been exposed. Finally, we ignore the type of measurement error that arises from poor data collection such as coding errors.

4. Even in the more general case of several explanatory variables, if the measurement error is assumed to be random, b_2 will be an underestimate of the true effect (Levi 1973)

5. Note that given the absence of over-reported use, b_2 and β_2 will always have the same sign even when C(D,u) is less than 0, since $(1 + \delta)$ will always be positive.

6. The bias formula would also be changed, and equation (4) would now become,

$$\text{(4a)}\quad b_2 = \beta_2 + \beta_3\,\delta.$$

Here b_2 estimates the effect of **observed** use (d_i). The effect of actual use (D_i) cannot be recovered from equation (6).

7. The results presented later in the text are not sensitive to the use of a different threshold

to classify users. The use of a threshold equal to twice the mean yielded qualitatively similar results as those presented.

8. For a detailed description of the data and collection methods see Joyce et al. (1994).

9. We estimate the models separately by drug user group because the focus of the paper is measurement error. Including more than one drug measure in the model would necessitate predicting false negatives for multiple substances, including some that have relatively few users. In addition, multicollinearity would be a problem because all of the predicted values would be derived from the same set of explanatory variables.

10. The variables used to predict drug use are listed in appendix table I. We also experimented with an alternative measure of predicted drug use similar to one we use later in the paper. In this case we assign a value of 0 or 1 to predicted drug use depending on whether predicted drug use was greater than the mean drug use observed in the sample.

11. In terms of Aigner's model, a positive δ implies that the measurement error is correlated with other right hand side variables. In the absence of any such correlation (or variables), Aigner proves that δ is negative.

12. See equation (4a) in footnote 4.

13. The standard errors associated with the coefficients on our predicted measures of drug use (u_i) are not adjusted for the fact that these variables have been constructed from estimates that are subject to variation. Thus the estimated standard errors are smaller than the true standard errors. Obtaining consistent estimates of the true standard errors requires a complex bootstrapping procedure that is beyond the scope of this paper (Schenker and Welsh 1988; Brownstone 1991).

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Table I

Estimates of the Effect of Illicit Drug Use on Birth Weight
Clinical Study Sample (N=1279)

Any Drug Use	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Actual Use	-.057 (.024)			-.104			-.072 (.021)
Reported Use		-.080 (.037)	-.310 (.123)		-.089 (.037)	-.079 (.037)	
Unreported Use (Error u_i)					-.042 (.027)	-.068 (.025)	
Delta (δ)				-.233 (.037)			

Cocaine Use	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Actual Use	-.089 (.030)			-.172			-.090 (.024)
Reported Use		-.134 (.051)	-.395 (.174)		-.148 (.051)	-.129 (.051)	
Unreported Use (Error u_i)					-.066 (.034)	-.078 (.028)	
Delta (δ)				-.212 (.042)			

Note: In column 3, the estimate is obtained using an IV procedure. In column 4, the estimate of the effect of actual use is constructed using the estimate of δ in that column. In columns 6 and 7, the estimates are obtained from a model that uses predicted measures of unreported drug use. See text for details on these variables were constructed. Standard errors are in parentheses.

Table II

Simple Descriptive Statistics

for Clinical and Municipal Hospital Samples

Variables Used in Birth Weight Model

	Clinical Sample		Municipal Hospital	
	Mean	Std. Dev.	Mean	Std. Dev.
Logarithm of Mother's Age	3.227	0.240	3.220	0.237
Mother Smokes	0.166	0.372	0.100	0.300
First Birth	0.268	0.443	0.350	0.477
Received Early Prenatal Care	0.779	0.415	0.768	0.422
American Black	0.303	0.460	0.232	0.422
Twins	0.022	0.146	0.021	0.144
Reported Cocaine Use	0.017	0.130	0.034	0.180
Unreported Cocaine Use	0.044	0.205	NA	NA
Reported Any Drug Use	0.035	0.184	0.043	0.203
Unreported Any Drug Use	0.068	0.252	NA	NA
Observations	1279		12032	

Variables Used Only in Measurement Error Model

	Clinical Sample		Municipal Hospital	
	Mean	Std. Dev.	Mean	Std. Dev.
Less Than High School	0.199	0.400	0.470	0.499
College	0.172	0.378	0.135	0.342
Missing Education	0.017	0.130	0.023	0.149
Self Payer	0.066	0.248	0.124	0.330
Other Payer	0.026	0.242	0.038	0.191
Syphilis	0.037	0.188	0.005	0.073
Observations	1279		12032	

Table III

Estimates of the Effect of Illicit Drug Use on Birth Weight
Municipal Hospital Sample (N=12034)

Any Drug Use	(1)	(2)	(3)
Actual Use (D^*_i)			-.070 (.007)
Reported Use	-.134 (.012)	-.134 (.012)	
Unreported Use (Error u_i)		-.030 (.009)	

Cocaine Use	(1)	(2)	(3)
Actual Use (D^*_i)			-.089 (.008)
Reported Use	-.157 (.013)	-.154 (.013)	
Unreported Use (Error u_i)		-.042 (.011)	

Note: In columns 2 and 3 the estimates are obtained from a model that uses predicted measures of unobserved drug use. See text for details on how these variables were constructed. Standard errors are in parentheses.