Articles

Do Longer Postpartum Stays Reduce Newborn Readmissions? Analysis Using Instrumental Variables

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Objective. To determine the effect of postpartum length of stay on newborn readmission.
Data Sources. Secondary data set consisting of newborns born in Washington state in 1989 and 1990. The data set contains information about the characteristics of the newborn and its parents, physician, hospital, and insurance status.
Study Design. Analysis of the effect of length of stay on the probability of newborn readmission using hour of birth and method of delivery as instrumental variables (IVs) to account for unobserved heterogeneity. Of approximately 150,000 newborns born in Washington in 1989 and 1990, 108,551 (72 percent) were included in our analysis.
Principal Findings. Newborns with different lengths of stay differ in unmeasured characteristics, biasing estimates based on standard statistical methods. The results of our analyses show that a 12-hour increase in length of stay is associated with a reduction in the newborn readmission rate of 0.6 percentage points. This is twice as large as the estimate obtained using standard statistical (non-IV) methods.
Conclusion. An increase in the length of postpartum hospital stays may result in a decline in newborn readmissions. The magnitude of this decline in readmissions may be larger than previously thought.
Key Words. Postpartum length of stay, newborn readmission, instrumental variables

Concerns about potential adverse effects of early discharge of newborns have led the federal government and most state legislatures to pass laws mandating minimum 48-hour hospital stays following vaginal deliveries and 96-hour stays following cesarean sections. These laws were enacted without clear evidence of the dangers of early discharge. Two recent literature reviews concluded that published research neither proves nor disproves the safety of early discharge (Braveman, Egerter, Pearl, et al. 1995; Grullon and Grimes 1997).

Determining whether an increase in postpartum length of stay confers a health benefit, and how large that benefit is likely to be, would be useful to policymakers. The evidence on this question has often consisted of comparisons of health outcomes (usually newborn readmissions) between newborns with short stays and newborns with longer stays. However, these comparisons are misleading since newborns with relatively short stays differ from newborns with relatively long stays in ways other than length of stay, and these differences may influence the probability of readmission. For example, if newborns with longer stays are sicker, on average, than newborns with short stays, simple comparisons of newborn readmission rates in these two groups will understate the benefit of an increased length of stay. The purpose of this article is to obtain an estimate of the effect of longer postpartum stays on newborn readmission rates that is not contaminated by such biases.

Conclusive evidence about the causal effects of medical interventions typically comes only from randomized controlled clinical trials. In a trial of varying lengths of stay, the impact on a particular adverse outcome can be estimated using bivariate or multivariate regression. However, data from large numbers of infants would be needed to detect differences in rare outcomes between early and late discharge groups of newborns. For example, if the rate of newborn readmission is 2 percent for the group with the best outcome, at least 14,000 newborns would be needed in each of two groups to detect a 25 percent increase in the readmission rate to 2.5 percent (Braveman, Egerter, Pearl, et al. 1995). Since few hospitals have more than several thousand births a year, a trial that large would have to be conducted at more than one hospital, or over a long period of time. Either way, confounding factors—hospital characteristics, time—would be introduced, complicating efforts to isolate a cause-effect relationship. In addition, such a large trial would be costly.

The practical difficulties associated with randomized controlled trials have led most health services researchers to base their analyses of postpartum length of stay on observational studies. Many of these studies use newborn readmission as an indicator of adverse health outcome (Fox and Kanarek 1995; Gazmararian and Koplan 1996; Liu, Clemens, Shay, et al. 1997; Fos-

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ter and Schneider 1995). While more refined measures of health outcome are desirable, newborn readmission is used because it reflects morbidity, is costly, and can be identified accurately at low cost by an analyst conducting retrospective research. In addition, newborn readmission is correlated with health problems that critics of early discharge believe may be caused by short postpartum stays (e.g., brain damage due to untreated pathologic jaundice or dehydration caused by inadequate instruction in proper newborn feeding techniques).

In observational studies, unmeasured differences between newborns may lead to biased and inconsistent estimates of the effect of length of stay on readmission. Even the best-designed studies of postpartum length of stay have not controlled for some variables related to both length of stay and readmission, such as home nursing visits and breast-feeding (see, e.g., Liu, Clemens, Shay, et al. 1997). Nor have they tried to control for health problems that can be observed by the physicians treating the newborn and mother but not by the analyst conducting retrospective research.

The direction of the bias caused by omitted variables depends on their partial correlation with length of stay and newborn readmission. In the case of unobserved health problems, both correlations are probably positive (sicker newborns stay longer and are more likely to be readmitted). Under these conditions, the coefficient estimate on length of stay is upwardly biased (Pindyck and Rubinfeld 1991), meaning that early discharge appears safer than it actually is.

In the case of home nursing visits, both correlations are probably negative. That is, newborns who receive home visits tend to have shorter stays (Gazmararian, Koplan, Cogswell, et al. 1997) and are less likely to be readmitted, since visiting nurses can detect and treat minor problems before they develop into serious conditions requiring readmission. Under these conditions, the coefficient estimate on length of stay is, again, upwardly biased.

In the case of breast-feeding, the first correlation is probably negative; newborns who are breast-fed have shorter stays (Margolis, Kotelchuck, and Chang 1997). The second correlation is negative over a period of six months (Kanaaneh 1972) but may be positive over a shorter period since breast-feeding is associated with the progression of jaundice (Schneider 1986). Under these conditions, the coefficient estimate on length of stay may be either upwardly or downwardly biased.

Because the direction of bias caused by the failure to control for breast-feeding may be the opposite of the direction of bias caused by the failure to control for unobserved health characteristics and home visits, we have no way to be sure whether the overall bias in studies that have not controlled for these variables is positive or negative.[1]

In this study, we apply an econometric technique, instrumental variables (IVs), that allows consistent estimation of the effect of length of stay on newborn readmission.[2] The IV method is common in the economics literature but has not been widely used in the analysis of health outcomes (McClellan, McNeil, and Newhouse 1994) and has not previously been applied to the study of postpartum length of stay. The IV method may be inferior to randomized controlled trials, but in a nonexperimental setting, valid IV estimation is superior to standard statistical methods that do not address omitted variables bias.

The IV method requires a variable or set of variables that is highly correlated with the endogenous variable (in this case length of stay) but is not correlated with unobserved determinants of the outcome of interest (newborn readmission). When both of these assumptions are satisfied, the IV method produces consistent estimates—a major advantage over conventional statistical methods.

THE CONCEPTUAL MODEL

The decision about when to discharge a newborn is made by the newborn's and mother's physician in consultation with the newborn's parents. Physicians reimbursed on a capitated basis have a financial incentive to decrease the newborn's and mother's length of stay, since longer stays require more work (e.g., an increased number of physician visits) but do not result in increased reimbursement. Even physicians who are not reimbursed on a capitated basis may be given incentives to reduce the amount of care they provide, and these incentives may result in a decreased length of stay (Hillman, Pauly, and Kerstein 1989). However, a strong code of professional ethics and legal liability give physicians reasons to act on behalf of their patients. Therefore, physicians make discharge decisions based in part on what they believe will maximize the newborn's and mother's well-being.

The physicians observe a number of factors about the newborn's health and mother's health that affect the choice of length of stay but cannot be identified by an analyst conducting retrospective research with administrative data. These factors are correlated with the probability of newborn readmission following discharge—that is, a newborn who is ill is more likely than a newborn who is healthy to be readmitted, all other things being equal.

Estimation of the Model

We developed an empirical model that takes into account both the endogeneity of length of stay and the effect it may have on readmission. We are interested in estimating

$$LOS = b_0 + b_1X + b_2Z + \varepsilon \qquad (1)$$

$$R = a_0 + a_1LOS + a_2X + \mu, \qquad (2)$$

where LOS is the newborn's length of stay in hours; X is a vector of newborn characteristics that directly influence both length of stay and newborn readmission; Z is a vector of instruments that influence length of stay but are uncorrelated with μ; R is a dichotomous variable indicating newborn readmission within some specified period of time (e.g., 28 days); and ε and μ are random disturbance terms. If the instruments are valid, a negative sign on a_1 will provide empirical evidence that newborns receiving longer stays are also experiencing fewer readmissions.

The following variables are hypothesized to have a direct impact on both length of stay and readmission:

- *Newborn clinical characteristics.* These characteristics include congenital anomalies, newborn abnormalities,[3] gestational age, birth weight, race,[4] and gender. We do not control for jaundice because doing so would remove a major advantage of increased length of stay.
- *The mother's marital status.* This variable may influence readmissions if the presence of a husband at home makes care for an ill newborn at home easier. Evidence of the effect of marital status on length of stay is ambiguous. Some prior studies found that unmarried women stay longer (Rosenthal 1968; Huang 1975), perhaps because of the absence of a husband for support, and others found no association (Lemmer 1987; James, Hudson, Genski, et al. 1987; Patterson 1987).
- *Maternal parity.* Numerous studies have found that multiparous women tend to have shorter stays than primaparous women (Patterson 1987; James, Hudson, Genski, et al. 1987), but the effects of parity on newborn readmission are unclear. On one hand, women who have experience in child rearing may tend to handle problems at home rather than resolving them by bringing their newborns into the hospital. On the other hand, because of their child-rearing responsibilities, multiparous women may have fewer resources with which to deal with a newborn's health problems at home.
- *Insurance characteristics.* Economic theory suggests that insurance should increase both length of stay and readmission by reducing out-

of-pocket costs of hospital use to the patient (i.e., the lower the price to the patient, the more likely the patient will prefer a longer stay to a shorter one, or will prefer hospitalization to less expensive outpatient care). We include dummy variables for newborns without insurance and for those covered by Medicaid. Newborns with other, mostly private coverage are the omitted group.

Where possible, the functional form in which the independent variables enter the equations was chosen according to clinical considerations. Where these did not provide clear guidance, decisions were based on univariate analyses of a 25 percent random subsample.[5]

Choice of Instruments

For the IV method to give consistent estimates, we must select instruments that influence length of stay but are not correlated with μ. These criteria are often satisfied by variables that are correlated with the endogenous variable (in this case, length of stay) but have no direct effect on the outcome (in this case, newborn readmission).

Two variables that plausibly meet these criteria are hour of birth and method of delivery. Both variables are strong predictors of length of stay. Hour of birth, specified as a series of dummy variables, each corresponding to a four-hour block of time, influences length of stay because it affects whether a newborn will spend an extra night in the hospital. For example, in our data, newborns born between midnight and 8 a.m. are seven times more likely to be discharged the same day they were born as newborns born between 8 a.m. and 4 p.m. Method of delivery influences length of stay because mothers need more time to recuperate after a cesarean section (c-section) than they need following a vaginal delivery, and newborns are rarely discharged before their mothers.

The choice of hour of birth and method of delivery as instruments rests on the assumption that after controlling for other covariates in the equation, these variables are not correlated with unobserved determinants of newborn readmission.

Neither instrument is ideal in this respect. A high percentage of elective cesareans are scheduled from 7 to 9 a.m., and newborns delivered via elective c-section tend to have better immediate outcomes than those delivered via emergency cesareans. Newborns with certain neurologic abnormalities are more likely than other newborns to have abnormal presentations that require c-sections. Newborns with certain physical deformities such as hydrocephalus are typically delivered via c-section, in some cases because they cannot pass through the birth canal. Newborns with cesareans have significantly more respiratory problems and significantly less severe trauma than those with vaginal deliveries (Keeler, Gambone, and Kahn 1997). Maternal herpes has long been considered an absolute contraindication to vaginal delivery and could influence the probability of readmission if herpes is contracted by the newborn despite the precaution of cesarean delivery.

On the other hand, approximately 85 percent of newborn readmissions in the first week of life are due to jaundice (Catz et al. 1995). The progression of jaundice is unrelated to method of delivery and hour of birth, except insofar as these variables influence length of stay. If method of delivery or hour of birth is correlated with unobserved determinants of newborn readmission, we believe this correlation is likely to be very weak.

We estimated the model twice: once using both hour of birth and method of delivery as instruments, and once using hour of birth as the only instrument. In the latter case, method of delivery was included as an explanatory variable in the newborn readmission equation. If method of delivery does not correlate with unobserved determinants of newborn readmission, it should not be a significant predictor of newborn readmission when included as an explanatory variable. We test this null hypothesis below.

Technical Considerations

IV estimation is often performed using the two-stage least squares (2SLS) technique. Usually, the second-stage regression is linear. Since the outcome of interest in this study—newborn readmission—is dichotomous, a logistic or probit regression for the readmission equation is more appropriate than a linear regression.

A variety of estimation methods for this situation have been discussed (see, e.g., Amemiya 1978; Maddala 1983; Achen 1986; Bollen, Guilkey, and Mroz 1995). The method we used, proposed by Achen (1986) and referred to as the "two-step probit regression" by Bollen, Guilkey, and Mroz (1995), parallels 2SLS closely. First, we estimated Equation 1 by ordinary least squares and used the estimated coefficients to predict length of stay for each newborn in the sample. This predicted value is used in place of actual length of stay in Equation 2, which we estimated using probit analysis. After a rescaling step, the resulting parameter estimates are consistent (Achen 1986).[6]

Strictly speaking, the standard error estimates obtained by this procedure are not consistent (Amemiya 1978). However, Monte Carlo evidence indicates that the two-step probit regression produces standard error estimates that are typically very similar to those that would be obtained using a consistent estimation technique (Guilkey, Mroz, and Taylor 1992). In the analyses that follow, we use the "incorrect" standard error estimates to carry out tests of statistical significance.

DATA

The analysis was performed on a secondary data set developed by the RAND Management and Outcomes of Childbirth (MOC) Patient Outcomes Research Team (PORT) consisting of newborns born in Washington in 1989 and 1990. This database consists of several linked components: (1) the Washington State Birth Event Records Data (BERD) database;[7] (2) a longitudinal file of hospital discharge data for newborns and mothers during the six months following the birth hospitalization; (3) characteristics of hospitals from the 1989 American Hospital Association survey; and (4) characteristics of physicians from the 1989 and 1990 American Medical Association surveys. A list of descriptive statistics for independent variables in the length of stay and newborn readmission equations is provided in Table 1.

Of 157,311 total BERD records representing approximately 150,000 births in Washington in 1989 and 1990, 126,370 newborns were included in the data set developed by the MOC PORT. Approximately two-thirds of the omitted newborns were births that occurred at military hospitals or homes. The hospital records for such births were not reported to Washington's Department of Health as part of the BERD system. Other exclusions included 1,067 multiple births, 6,120 newborns under 2,500 grams birth weight, and 32 cases with extensive missing data (Keeler, Park, Bell, et al. 1997).

We excluded two additional groups who are not likely to be affected by postpartum length of stay legislation: newborns who died before they were discharged or were transferred to another facility upon discharge ($N = 1,204$) and newborns with stays of four or more nights ($N = 16,289$). We also excluded newborns with estimated stays of less than five hours ($N = 610$), since stays this short may reflect coding error. This left a final sample size of 108,551. (Because of overlap among the excluded groups, the sum of the number of newborns in each group does not equal the total number of newborns excluded.)

Calculation of length of stay was difficult because the time of discharge was not available in our data set. We estimated length of stay using the hour of birth, the number of nights hospitalized, and assumptions about the time of

Table 1: Independent Variables in Length of Stay and Newborn Readmission Equations

Length of stay in hours (mean)	42.68
Diagnosed with anemia†	0.05%
Diagnosed with drug withdrawal†	0.03%
Some other newborn abnormality†	4.69%
Any congenital anomaly†	1.61%
5-minute Apgar score of less than 7†	0.57%
Mild or moderate trauma†	7.97%
Diagnosed with infections†	0.26%
Severe respiratory problems†	1.85%
Severe trauma†	2.37%
Seizures†	0.27%
Assisted ventilation†	1.17%
Gestational age in weeks (mean)†	39.60
Estimated gestational age less than 37 weeks†	3.04%
Weight at birth in kg (mean)†	3.52
Weighs less than 2700 grams†	3.02%
Newborn is male†	50.79%
Newborn or mother or father is African American†	4.09%
Newborn or mother or father is Hispanic†	9.86%
Mother is married†	76.18%
Mother has had at least one previous live birth†	59.40%
Number of previous live births (mean)†	1.00
Primary payer is Medicaid†	29.76%
Primary payer is charity or self-pay†	5.80%
Information on any congenital anomaly is missing†	17.88%
Information on any newborn abnormality is missing†	17.08%
Delivered via cesarean section‡	11.21%
Delivered before 4:00 a.m.§	15.03%
Delivered between 4:01 a.m. and 8:00 a.m.§	15.17%
Delivered between 8:01 a.m. and noon§	17.04%
Delivered between 12:01 p.m. and 4:00 p.m.§	20.77%
Delivered between 4:01 p.m. and 8:00 p.m.§	16.92%
Delivered after 8:00 p.m.§	15.07%

Note: All variables are dichotomous unless otherwise noted. Percentages are reported for dichotomous variables; means are reported for continuous variables.

†Variable is used in both equations.

‡Because we were concerned that method of delivery may not be a valid instrument, we estimated the model both ways (e.g., once excluding a cesarean section dummy variable from the readmission equation and once including it).

§Instrumental variable.

discharge. Newborns discharged the same day they were born were assumed to have had a stay of (17 minus *TOB*), where *TOB* is the hour of birth in military time divided by 100. This formulation was chosen because 5 p.m., 1700 in military time, was the median time of discharge of newborns with no overnight stay in a RAND survey of 2,447 newborns born in Los Angeles and Iowa (Gifford, Morton, Fiske, et al. 2000). We assumed all other newborns (i.e., those who stayed at least one night) were discharged at 1 p.m., which was the median for newborns with stays of at least one night in the RAND survey. In the RAND survey, this definition of length of stay is within three hours of true *LOS* for 71.1 percent of newborns. The mean length of stay in our sample is 39 hours for newborns delivered vaginally and 70 hours for newborns delivered by c-section.

In this study, a newborn is defined as having been readmitted if he or she was hospitalized in the state of Washington within four weeks of discharge.[8] The choice of four weeks is arbitrary since there is no consensus in the literature as to the appropriate time window in analyzing post-discharge outcomes. Some studies have used a 60-day time period; others have used a 30-day time period; still others have analyzed periods as short as seven days (Liu, Clemens, Shay, et al. 1997; Foster and Schneider 1995). Longer time periods obscure the effect of length of stay on readmissions, since medical problems arising later are usually unrelated to the immediate postpartum period. Shorter time periods may also be misleading if they miss some readmissions related to the initial postpartum stay. We chose four weeks because other researchers have done so, and because it seems long enough to capture most readmissions resulting from premature discharge but short enough not to be unduly influenced by events later in life. Sensitivity analysis is conducted to see how using a 14- or 60-day time period affects the results.

Many previous studies evaluating the link between early discharge and readmissions have excluded newborns with medical conditions from the analytic sample (Gazmararian and Koplan 1996; Edmonson, Stoddard, and Owens 1997; Liu, Clemens, Shay, et al. 1997; Foster and Schneider 1995), thereby reducing the extent to which newborns differ in health status at birth. Edmonson, Stoddard, and Owens (1997) justify the exclusion of such cases as creating a level playing field in which selection bias can be more easily controlled. Whether this is appropriate depends on how many of these newborns have medical conditions serious enough to render them ineligible for early discharge.[9] Previous research suggests that newborns with serious medical conditions stand to benefit most from longer stays (Fox and Kanarek 1995). Omitting such newborns may introduce more selection bias than it alleviates, making early discharge appear safer than it actually is. We estimate models including: (1) all newborns, (2) only healthy newborns (term newborns with no congenital anomalies or newborn abnormalities), and (3) only sick newborns (those who are pre-term or have congenital anomalies or newborn abnormalities).

A comparison among newborns with relatively short, medium, and long lengths of stay is provided in Table 2. As expected, newborns with longer stays were sicker, on average, than their earlier discharge counterparts. The three groups presumably differed in unmeasured dimensions as well.

A comparison between newborns born at or before 12 noon and and those born after noon is provided in Table 3. Newborns in the two groups were similar in terms of most health characteristics, but newborns born after noon had shorter stays and higher readmissions, on average, than newborns born in the morning. A crude IV estimate shows that a one-hour increase in length of stay reduces the 28-day readmission rate by 0.05 percentage points (between-group difference in mean 28-day readmission rate of 0.24 percentage points divided by between-group difference in mean LOS of 4.75 hours). Thus, a crude IV estimate shows that a 12-hour increase in length of stay reduces the readmission rate by 0.6 percentage points (0.05 percentage points $\times 12 = 0.6$ percentage points).

Table 2: Selected Descriptive Characteristics of Newborns Born in Washington State in 1989–1990, by Length of Stay (Proportions)*

	< 24 Hours (n = *16,979*)	*24–48 Hours* (n = *53,795*)	*> 48 Hours* (n = *37,777*)
Newborn is male	48.16%	50.60%	52.25%
Newborn or mother or father is African American	2.59%	4.16%	4.66%
Newborn or mother or father is Hispanic	14.61%	9.90%	7.67%
Estimated gestational age less than 37 weeks	2.37%	3.01%	3.38%
Severe respiratory problems	1.08%	1.50%	2.71%
Seizures	0.12%	0.24%	0.38%
Any congenital anomaly	1.35%	1.56%	1.79%
5-minute Apgar score of less than 7	0.34%	0.50%	0.78%
Mild or moderate trauma	5.98%	8.36%	8.30%
Diagnosed with infections	0.12%	0.13%	0.50%
Assisted ventilation	0.96%	1.14%	1.31%
Severe trauma	1.94%	2.49%	2.39%
Readmitted within 14 days	3.13%	2.83%	2.14%
Readmitted within 28 days	3.95%	3.56%	2.95%
Readmitted within 60 days	5.32%	4.93%	4.31%

*$p < 0.01$ for overall χ^2 test between length-of-stay categories for each characteristic listed.

Table 3: Selected Descriptive Characteristics of Newborns Born in Washington State in 1989–1990, by Hour of Birth (Percentages for All Variables Except Length of Stay)

	A.M. Birth[†] (n = *51,283*)	*P.M. Birth*[‡] (n = *57,268*)
Length of stay in hours (mean)**	45.19	40.44
Newborn is male	50.68%	50.89%
Newborn or mother or father is African American	4.11%	4.06%
Newborn or mother or father is Hispanic*	10.36%	9.41%
Estimated gestational age less than 37 weeks	3.06%	3.02%
Severe respiratory problems	1.88%	1.84%
Seizures	0.28%	0.26%
Any congenital anomaly	1.68%	1.55%
5-minute Apgar score of less than 7	0.57%	0.58%
Mild or moderate trauma*	7.32%	8.54%
Diagnosed with infections*	0.30%	0.22%
Assisted ventilation	1.16%	1.18%
Severe trauma*	2.14%	2.58%
Readmitted within 14 days*	2.50%	2.76%
Readmitted within 28 days*	3.28%	3.52%
Readmitted within 60 days*	4.64%	4.90%

*$p < 0.01$ for overall χ^2 test between a.m. and p.m. births; **$p < 0.01$ for t-test between hour-of-birth categories.

†Newborn was born between 12:00 a.m. and 11:59 a.m.

‡Newborn was born between 12:00 p.m. and 11:59 p.m.

RESULTS

Table 4 presents coefficient estimates and p-values for the two IV models. The first IV model uses both hour of birth and method of delivery as instruments; the second IV model uses only hour of birth as an instrument.

The length of stay equation has an R^2 of 0.37. The two newborn readmission equations produce results that are similar, indicating that the model is not highly sensitive to the inclusion of method of delivery as an instrument. In both the length of stay and newborn readmission equations, the signs of the estimated coefficients are generally consistent with expectations.

The coefficient on predicted length of stay in the newborn readmission equation is −0.006 in the first model and −0.005 in the second. It is statistically significant at $\alpha = .05$ in the former but not the latter. By comparison, the length-of-stay coefficient in a single-equation probit model (i.e., a model with no instrumental variables) is −0.002.

To aid interpretation of these coefficients, we calculated the predicted probability of readmission for newborns with 39-hour stays (the mean among vaginally delivered newborns in our sample) and compared this to the predicted probability of readmission for newborns with 51-hour stays (i.e., a 12-hour increase).[10] The results of both IV models indicate that a 12-hour increase in mean postpartum length of stay would reduce the readmission rate by 0.6 percentage points (Table 5), identical to the crude IV estimate described above and twice as large as the estimate obtained through conventional statistical methods.

As discussed above, IV estimation produces reliable, consistent estimates only if two criteria are satisfied. First, the instruments must be correlated with the endogenous variable (in this case, length of stay). Second, the instruments must not have a direct effect on the outcome in the second equation (in this case, newborn readmission). Both of these criteria were discussed conceptually, but empirical examination is possible as well.

To test the null hypothesis that the instruments are not correlated with length of stay, F statistics for the length-of-stay equation were obtained for the instruments used in the two models: (1) hour of birth and method of delivery and (2) hour of birth. The F statistics for these variables are 9561.06 and 540.73, respectively. The null hypothesis of no correlation is rejected ($p = 0.000$ in both cases). Weak correlation is almost certainly not a source of bias (Staiger and Stock 1997).

To test the null hypothesis that method of delivery has no direct effect on newborn readmission, we ascertained whether this variable enters the newborn readmission equation. According to the readmission equation, Equation 2, method of delivery is not statistically significant ($p = 0.949$). This increases our confidence that method of delivery is not correlated with unobserved determinants of newborn readmission and, therefore, is a valid instrument.

To test the null hypothesis that hour of birth has no direct effect on newborn readmission, we estimated the model using method of delivery as the sole instrument and performed a chi-square test on the hour of birth dummy variables. They are not jointly statistically significant ($\chi^2_5 = 7.84$; $p = 0.165$). Again, this increases our confidence in the validity of our instruments.

We checked the robustness of our findings four ways. First, we excluded 20,893 sick or preterm newborns from the sample. Second, we excluded 87,658 healthy newborns from the sample. Third, we added additional explanatory variables, including maternal risk factors, labor and delivery

Table 4: The Effect of Length of Stay on Newborn Readmission: Model Results

	Length-of-Stay Equation		*Readmission Equation 1*†		*Readmission Equation 2*‡	
	Coef.	P > |z|	*Coef.*	P > |z|	*Coef.*	P > |z|
Predicted length of stay, in hours	—	—	−0.006	0.000	−0.005	0.117
Newborn anemia	4.539	0.010	0.340	0.160	0.339	0.161
Newborn drug withdrawal	11.346	0.000	0.025	0.956	0.022	0.961
Other newborn abnormality	4.742	0.000	0.127	0.000	0.126	0.001
Any congenital anomaly	0.566	0.086	0.278	0.000	0.278	0.000
5-minute Apgar score of less than 7	2.643	0.000	0.195	0.021	0.194	0.022
Mild or moderate trauma	2.298	0.000	0.089	0.001	0.088	0.002
Infections	10.003	0.000	0.500	0.000	0.498	0.000
Severe respiratory problems	4.711	0.000	0.248	0.000	0.247	0.000
Severe trauma	0.275	0.323	−0.099	0.058	−0.099	0.058
Seizures	4.747	0.000	0.289	0.013	0.288	0.014
Assisted ventilation	1.907	0.000	0.012	0.850	0.012	0.855
Gestational age in weeks (continuous)	−0.167	0.000	−0.101	0.000	−0.101	0.000
Estimated gestational age less than 37 weeks	1.513	0.000	0.157	0.000	0.156	0.000
Weight at birth in kg (continuous)	1.460	0.000	−0.023	0.236	−0.023	0.242
Weight less than 2700 grams	1.759	0.000	0.053	0.184	0.053	0.192
Newborn is male	0.488	0.000	0.106	0.000	0.106	0.000
Newborn or mother or father is African American	3.577	0.000	−0.178	0.000	−0.179	0.000
Newborn or mother or father is Hispanic	−2.670	0.000	−0.022	0.376	−0.022	0.415
Mother is married	0.438	0.000	0.046	0.023	0.046	0.023
Mother has had at least one previous live birth	−2.338	0.000	−0.079	0.000	−0.079	0.001
Number of previous live births (continuous)	0.264	0.000	0.011	0.201	0.011	0.206
Primary payer is Medicaid	−4.001	0.000	0.133	0.000	0.134	0.000
Primary payer is charity or self-pay	−6.077	0.000	−0.017	0.618	−0.015	0.694

continued

Table 4: Continued

	Length-of-Stay Equation		*Readmission Equation 1*†		*Readmission Equation 2*‡	
	Coef.	P > |z|	*Coef.*	P > |z|	*Coef.*	P > |z|
Information on any congenital anomaly is missing	−0.426	0.186	−0.011	0.847	−0.011	0.849
Information on any newborn abnormality is missing	1.634	0.000	0.040	0.490	0.040	0.496
Cesarean section delivery	30.297	0.000	—	—	−0.007	0.949
Delivered before 4:00 a.m.	2.737	0.000	—	—	—	—
Delivered between 4:01 a.m. and 8:00 a.m.	2.906	0.000	—	—	—	—
Delivered between 8:01 a.m. and noon	1.623	0.000	—	—	—	—
Delivered between 4:01 p.m. and 8:00 p.m.	−1.623	0.000	—	—	—	—
Delivered after 8:00 p.m.	−3.126	0.000	—	—	—	—

Note: Sample size = 108,551. The dependent variable in both readmission equations is newborn readmission or death within 28 days of discharge; the length-of-stay equation has an R^2 of 0.37.

†Excludes both method of delivery and time of birth.

‡Excludes time of birth but includes method of delivery.

Table 5: Effect of a 12-Hour Increase in Length of Stay on Newborn Readmissions

Model 1 (Both Time of Birth and Method of Delivery Are Instruments)	*Model 2 (Only Time of Birth Is an Instrument)*	*Single-Equation Probit Regression (No Instruments)*
Newborn readmission rate declines by 0.6 percentage points; 23,400 readmissions averted nationally per year.	Newborn readmission rate declines by 0.6 percentage points; 23,400 readmissions averted nationally per year.	Newborn readmission rate declines by 0.3 percentage points; 11,700 readmissions averted nationally per year.

Note: Using the coefficients from the various models, we estimated Pr(readmission) = $\Phi(\mathbf{x}_j\mathbf{b})$, where Φ is the standard cumulative normal with mean 0 and variance 1 and $\mathbf{x}_j\mathbf{b}$ is the probit score. We then checked to see how Pr(readmission) changed when LOS′ was increased by 12 hours.

To emphasize the uncertainty of the estimates, the newborn readmission rate is rounded to the nearest tenth. Estimates of the association between length of stay and newborn readmissions are based on the assumption of 3.9 million births per year. All references to "probability of newborn readmission" refer to the probability of newborn readmission or death within 28 days of discharge.

complications, month of discharge, physician characteristics, and hospital fixed effects. Fourth, we ran the models with different readmission windows (14 days and 60 days). Consistent with Fox and Kanarek (1995), the effect of length of stay on newborn readmissions was largest when the sample was limited to sick newborns.[11] Otherwise, the modifications had little effect on the predicted length-of-stay coefficient estimate in the newborn readmission equation.

DISCUSSION

This article uses the IV method to obtain consistent estimates of the effect of length of stay on newborn readmission. Conventional statistical estimates of that effect can be confounded by failure to control for variables such as unmeasured health, home nursing visits, and breast-feeding that are associated with both length of stay and readmissions. Intuitively, we think of hour of delivery as a variable that randomizes infants to differing length of stay, in the same way a coin toss might randomize assignment in a clinical trial. Assuming that hour of delivery only affects readmissions through its impact on length of stay, we can rescale the association between hour of delivery and readmissions to estimate the effect of length of stay on readmissions that would lead to that association. At the same time, we use our rich set of covariates to control for measurable differences between infants with shorter and longer lengths of stay. Our results suggest that conventional statistical methods underestimate the effect of length of stay on readmission, thereby understating the benefit of increasing length of stay.

The study has several strengths. First, we attempted to control for omitted variables bias through the use of IVs. If IV estimation in this study is valid, the estimates are consistent—a major advantage over conventional statistical methods. Second, the large size of this study provides statistical power lacking in a number of other studies of this issue. Third, unlike many previous reports that focused on a specific hospital or subpopulation, this study includes more than two-thirds of births from an entire state for two years. Fourth, the use of the BERD database allows us to control for a greater number of observable patient characteristics than most previous studies.

A limitation of this study is our inability to measure length of stay accurately.[12] Because time of discharge is not included in the data set, length of stay in hours could not be calculated with precision. This problem is common in all large retrospective studies of postpartum length of stay (see, e.g., Liu, Clemens, Shay, et al. 1997; Edmonson, Stoddard, and Owens 1997; Foster and Schneider 1995). We used hour of birth, number of nights hospitalized, and assumptions about time of discharge to estimate length of stay. A second limitation is our focus on readmissions, as opposed to more specific health outcomes that are not available in our data set, such as unscheduled emergency readmissions or readmissions related to jaundice. This shortcoming also is shared by other large retrospective analyses of postpartum length of stay (Liu, Clemens, Shay, et al. 1997; Edmonson, Stoddard, and Owens 1997; Foster and Schneider 1995).

Policy Implications

Birth is the single most common reason for hospitalization in the United States (Centers for Disease Control and Prevention 1995). As a result, even a small reduction in readmission rates can yield meaningful benefits. For example, since approximately 3.9 million births occur each year in the United States, each 0.1 percent reduction in the readmission rate implies 3,900 fewer newborn readmissions. Although not all of these readmissions are associated with specific adverse newborn health outcomes, readmissions are costly, may reduce mother-infant bonding, and may increase parents' anxiety.

Of course, the finding that an intervention yields a health benefit does not necessarily mean that the intervention should be mandated. If the cost of an intervention (in this case, longer postpartum stays) is high, the benefits of the intervention may not justify the cost. And if an alternative treatment (e.g., home nursing visits) confers the same benefit at a lower cost, reallocation of health resources toward the more cost-effective treatment will yield greater health benefits overall.

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NOTES

1. We speculate that the effect of unobserved health characteristics and home nursing visits overwhelms the effect of breast-feeding. If so, conventional statistical methods produce a coefficient estimate on length of stay that is upwardly biased (i.e., early discharge appears safer than it actually is).
2. A biased yet consistent estimator approximates the true parameter as the sample size grows. In studies with large sample sizes, more concern with consistency than with lack of bias makes sense.
3. Eighteen percent of the observations in the sample are missing data on congenital anomalies, newborn abnormalities, or both. We assigned a value of 0 to missing observations and included a missing data flag in the regressions. The missing data flags were set to 1 for those observations where the variable in question was missing data and 0 for all other observations.
4. Race is specified as two dummy variables—black and Hispanic—with all other newborns (whites, Asians, others) in the reference group. Unfortunately, we cannot incorporate Asian race into our models because this variable is not available in our data set. Asian newborns metabolize bilirubin less rapidly than other newborns and therefore are more susceptible to jaundice.
5. For example, to help determine the functional form of the low-birthweight variable, we computed the readmission rate for newborns in various birth weight categories (2,500 to 2,699 grams, 2,700 to 2,899 grams, 2,900 to 3,099 grams, and so on) . This revealed a sharp rise in the readmission rate for newborns below 2,700 grams. Based on this analysis, we decided to include two birth weight variables: a continuous variable (birth weight in kilograms) and a dichotomous variable that equals 1 if the newborn was less than 2,700 grams and equals 0 otherwise.
6. To obtain consistent estimates, each probit coefficient must be divided by s, where $s^2 = 1 + \mathrm{var}(y') - \mathrm{var}(y'')$ (Achen 1986). Here, y' is the probit forecast from the first step, and y'' is the probit forecast using the coefficients from the second-stage probit regression but with the original values of length of stay used instead of the predicted values. In all of our models, s was .999 or higher, so the rescaling step was unnecessary.

7. The BERD database links hospital discharge records for mothers and newborns to birth certificates and death certificates. The databases used to construct BERD are the Comprehensive Hospital Abstract Reporting System (CHARS) from the Washington State Office of Hospital and Patient Data and birth certificate and infant death files maintained by the Center for Health Statistics. Of approximately 150,000 newborns born in Washington in 1989 and 1990, the MOC PORT identified 133,589 three-way matches among the birth certificate, the newborn's hospital record, and the mother's hospital record, plus 23,733 two-way matches or unmatched records—a birth certificate alone or a hospital record for which an acceptable birth certificate match could not be identified. Systematic reasons for failure to match included multiple births (matching the birth record to the correct twin's or triplet's birth record was difficult) and home births. Information on many of the variables was present in both the hospital discharge record and birth certificate. The MOC PORT cross-checked and combined information from the two sources to create the analysis variables.
8. Fifty-one newborns who died within four weeks but were not readmitted are counted as readmissions. For both deaths and readmissions, the "clock" starts once the newborn is discharged, not at birth.
9. A significant proportion of newborns discharged within 24 hours have health problems. For example, in our data set, 6.0 percent of newborns discharged within 24 hours had mild or moderate trauma, 1.9 percent had severe trauma, and 1.0 percent received assisted ventilation (see Table 2).
10. For these calculations, we assume the newborns are vaginally delivered white males with no health problems, a birth weight of 3,500 grams, a gestational age of 40 weeks, who are born to married, primaparous mothers.
11. For our two IV models, the predicted length of stay coefficient estimates are between −.004 and −.005 when the sample is restricted to healthy newborns, as compared to −.009 when the sample is restricted to sick newborns.
12. In the RAND survey sample, restricted to vaginally delivered newborns with less than three nights in the hospital, actual length of stay (in hours) = 1.47 + 0.99 (our estimated length of stay), $R^2 = 0.94$. If the errors in prediction are random, using estimated length of stay rather than actual length of stay will understate the strength of the relationship between length of stay and readmissions.

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