WORKING PAPER # 388
INDUSTRIAL RELATIONS SECTION
PRINCETON UNIVERSITY
REVISED JANUARY, 1998

Further Estimates of the Economic Return to Schooling from a New Sample of Twins

Cecilia Elena Rouse

July, 1997
Revised: January, 1998

I thank Michael Boozer, Alan Krueger, and Douglas Staiger for useful conversations, Lisa Barrow, Casundra Anne Cliatt, Lasagne Anne Cliatt, Eugena Estes, Kevin Hallock, Dean Hyslop, Jon Orszag, Michael Quinn, Lara Shore-Sheppard, and Cedric Tille for excellent assistance with the survey, John Abowd for access to LISREL, and three anonymous referees for helpful comments. This paper has been supported by the Mellon Foundation and The National Academy of Education and the NAE Spencer Postdoctoral Fellowship Program.

Abstract

In a recent, and widely cited, paper, Ashenfelter and Krueger (1994) use a new sample of identical twins to investigate the contribution of genetic ability to the observed cross-sectional return to schooling. This paper re-examines Ashenfelter and Krueger's estimates using three additional years of the same twins survey. I find that the return to schooling among identical twins is about 10 percent per year of schooling completed. Most importantly, unlike the results reported in Ashenfelter and Krueger, I find that the within-twin regression estimate of the effect of schooling on the log wage is smaller than the cross-sectional estimate, implying a small upward bias in the cross-sectional estimate. Ashenfelter and Krueger's measurement error corrected estimates are insignificantly different from those presented here, however. Finally, there is evidence of an important individual-specific component to the measurement error in schooling reports.

Cecilia Elena Rouse
Industrial Relations Section
Firestone Library
Princeton University
Princeton, NJ 08544
rouse@princeton.edu
[JEL: J24, I21]

In a recent, and widely cited, paper, Ashenfelter and Krueger (1994) use a new sample of identical twins to investigate the contribution of genetic ability to the observed cross-sectional return to schooling. An innovation in their paper is the use of multiple measurements of schooling to address the potentially severe attenuation bias in within-twin estimates of the return to schooling that arise from measurement error. Surprisingly, Ashenfelter and Krueger's within-twin estimate of the return to schooling is larger than the comparable ordinary least squares (OLS) estimate. And, their measurement error corrected estimates of the return to schooling range from 12 to 16 percent, with their most efficient estimate being approximately 13 percent. Although Ashenfelter and Krueger emphasize that these unusually large estimates result from the measurement error corrections, Neumark (1994) hypothesizes that the large estimates result from upward omitted ability bias in the within-twin analysis that is exacerbated with the instrumental variables (IV) measurement error correction.

This paper re-examines Ashenfelter and Krueger's estimates using three additional years of the same twins survey. Using the larger sample, I estimate that the return to schooling among identical twins is about 10 percent per year of schooling completed. Most importantly, unlike the results reported in Ashenfelter and Krueger, and consistent with earlier twins studies (such as Behrman, Hrubec, Taubman, and Wales (1980)), I find that the within-twin regression estimate of the effect of schooling on the log wage is smaller than the cross-sectional estimate, implying a small upward bias in the cross-sectional estimate. The within-twin measurement error corrected estimates are also smaller than the cross-sectional estimates. Combined, these results suggest that the within-twin analyses of the return to schooling are less upward biased than the cross-sectional estimates. In addition, Ashenfelter and Krueger's measurement error corrected estimates are not significantly different from those presented here. Given that the survey instrument, population, and interviewers were generally the same, their unusual results are likely due to sampling error. Finally, there is evidence of an important individual-specific component to the measurement error in schooling reports.

II. Ashenfelter and Krueger's Empirical Framework

The analysis of the effect of schooling on wage rates is based on a standard log wage equation,

$$y_{1i} = A_i + bS_{1i} + gZ_{1i} + dX_i + \varepsilon_{1i} \quad (1)$$

and

$$y_{2i} = A_i + bS_{2i} + gZ_{2i} + dX_i + \varepsilon_{2i} , \quad (2)$$

where y_{1i} and y_{2i} are the logarithms of the wage rates of the first and second twins in a pair, S_{1i} and S_{2i} are the schooling levels of the twins, Z_{1i} and Z_{2i} are other attributes that vary within families, X_i are other observable determinants of wages that vary across families, but not within twins (such as race and age), and ε_{1i} and ε_{2i} are unobservable individual components. The return to schooling is b .

In order to estimate the return to schooling (and to other twin-specific characteristics) I difference equations (1) and (2) to eliminate the ability effect, obtaining the first-differenced, or fixed-effects, estimator,

$$y_{2i} - y_{1i} = b(S_{2i} - S_{1i}) + g(Z_{2i} - Z_{1i}) + \varepsilon_{2i} - \varepsilon_{1i} . \quad (3)$$

One of Ashenfelter and Krueger's important innovations is to use multiple measures of schooling to address the problem of measurement error, which is well-known to be exacerbated in first-differenced equations (Griliches 1977). As part of the survey, each twin was asked to report on her own schooling level and on her sibling's. Writing S_k^j for twin j 's report on twin k 's schooling implies there are two ways to use the auxiliary schooling information. The clearest way to see this is to consider estimating the wage equation in first-differenced form. There are four estimates of the schooling difference ΔS_i :

$$\Delta S'_i = S_{2,i}^2 - S_{1,i}^1 = \Delta S_i + \Delta v'_i \quad (4)$$

$$\Delta S''_i = S_{2,i}^1 - S_{1,i}^2 = \Delta S_i + \Delta v''_i \quad (5)$$

$$\Delta S_i^* = S_{2,i}^1 - S_{1,i}^1 = \Delta S_i + \Delta v_i^* \quad (6)$$

$$\Delta S_i^{**} = S_{2,i}^2 - S_{1,i}^2 = \Delta S_i + \Delta v_i^{**} , \quad (7)$$

where ΔS_i indicates the true schooling difference and the Δv_i terms represent measurement error.

First, one can use $\Delta S'$, the difference in the self-reported education levels, as the independent variable, and $\Delta S''$, the difference in the sibling-reported estimates of the schooling levels, as an instrumental variable for $\Delta S'$. The IV estimates assume that the measurement error in the independent variable is classical (i.e., uncorrelated with the measurement error in the instrument and uncorrelated with the true level of schooling.) The IV estimate using $\Delta S''$ as an instrument for $\Delta S'$ will generate consistent estimates of the return to schooling even if there is a family effect in the measurement error because the family effect is subtracted from both $\Delta S'$ and $\Delta S''$. However, $\Delta S'$ and $\Delta S''$ will be correlated if there is a person-specific component of the measurement error (generating “correlated measurement error”). To eliminate the person-specific component of the measurement error it is sufficient to estimate the schooling differences using the definitions in equations (6) and (7), which amounts to calculating the schooling difference reported by each sibling and using one as an instrument for the other.

III. The Data and Sample

The data on twin pairs were obtained from interviews conducted at the Twinsburg Twins Festival, which is held annually in Twinsburg, Ohio. Ashenfelter and Krueger's analysis is based on interviews conducted during the summer of 1991. In this paper, I augment their sample with additional data gathered during 1992, 1993, and 1995 thereby increasing the sample size from 149 to 453 twin pairs.¹

My sample consists of identical twins both of whom have held a job at some point in the previous two years and are not currently living outside of the United States. For the 19 percent of the twins in the sample who were interviewed more than once, I average their responses to most questions across the years.² I consider a set of twins "identical" if both twins responded that they were identical. In the few cases where a respondent was interviewed more than once and gave conflicting answers to whether she and her twin are identical, I average the responses and consider the pair identical if the average over the years and over the twins is more than 0.5 (i.e., that the twins answered that they were identical more often than not).³

Table 1 provides a comparison of some of the characteristics of my sample of twins with Ashenfelter and Krueger's sample, and data from the Current Population Survey (CPS) for the period 1991-1993. The characteristics of the twins samples may differ from the CPS because the twins survey does not represent a random sample of twins or because twins do not share identical characteristics with the general population. It is apparent from Table 1 that the respondents in the twins samples are better educated and have a higher hourly wage than the general population. And, the twins samples contain relatively more white workers than the general population. All of these differences may arise from the way twins select themselves into the pool of Twins Festival attendees. The twins samples also contain relatively fewer married people than the general

¹ See Ashenfelter and Krueger for a complete description of the festival and the data collection effort. Copies of all four interview schedules are available from the author on request.

² I have also tried keeping only the first observation, and keeping all observations, for those interviewed more than once with similar results.

³ Ashenfelter and Rouse (forthcoming) find that the results are not sensitive to alternative methods for classifying the twins as identical, such as whether the twins were alike as "two peas in a pod" while they were young, whether both agree they are identical, and whether they have been given a genetic test.

population. It is unclear what effect, if any, these differences would have on inferences one might draw from the samples of twins.⁴

Further, the addition of three more years of surveys has changed the mean sample characteristics very little. The survey participants using the larger sample are little older than Ashenfelter and Krueger's sample, earn slightly more, and are more likely to be married and female. Appendix Table 1a shows the correlation matrix which allows for direct estimates of the extent of measurement error in (the cross-sectional) reported schooling in these data. Ashenfelter and Krueger estimate a reliability ratio⁵ for the schooling levels of between 0.92 and 0.88, implying that 8-12 percent of the measured variance in schooling is due to measurement error. The error in reported schooling in the larger sample is somewhat lower with a reliability ratio of 0.93-0.91.

IV. Empirical Results

A. The Basic Results

Ashenfelter and Krueger's basic OLS, generalized least squares (GLS)⁶, first-differenced, and IV estimates are reproduced in columns (1)-(4) of Table 2 along with similar regressions using the larger sample.⁷ Both the OLS and GLS cross-sectional estimates of the return to schooling (in columns (5) and (6)) using the larger sample are about 10 percent, slightly higher than those estimated by Ashenfelter and

⁴ However, OLS estimates of log wage equations using the twins sample and the CPS suggest only small differences between the primary characteristics of the two samples. In addition, the educational distribution in these data is extremely close to that reported in Lykken, Bouchard, McGue, and Tellegen (1990) from the Minnesota Twins Registry.

⁵ The reliability ratio is the ratio of the variance in the true level of schooling to the variance in the reported measure of schooling.

⁶ The GLS estimates are the seemingly unrelated regression method (Zellner 1962). I use GLS to increase efficiency by exploiting cross-equation restrictions and to ensure correct computation of sampling errors.

⁷ These estimates are from Ashenfelter and Krueger's Table 3.

Krueger.

One can estimate the extent to which omitted ability is biasing the OLS estimate by comparing the schooling coefficient in column (3) to that in column (1) (for the bias before correcting for measurement error) or by comparing the coefficients in columns (4) and (2) (for the bias after correcting for measurement error). Ashenfelter and Krueger's within-twin (or first-differenced) estimate of the return to schooling was higher than the comparable cross-sectional estimate. This pattern is consistent with a downward bias in the OLS estimate due to an omitted family or ability effect (although the within-twin estimate is within a standard error of the cross-sectional estimate). In other words, they estimate that the correlation between omitted ability and schooling may be slightly negative in cross-sectional analyses. An alternative explanation is offered by Griliches (1979) (and more recently Neumark (1994)) who shows that such a result is theoretically possible in the presence of upward ability bias in the OLS estimate if the upward ability bias is exacerbated in within-twin estimates. This would occur if the correlation between schooling and ability is larger within twins than across twins. This theoretical possibility is applicable to all twin and sibling studies, and a point to which I return in Section IV C.

Analysis using the larger sample, however, suggests that Ashenfelter and Krueger's result is an anomaly. Using all four years I estimate an upward bias in the OLS estimate of about 29 percent, before I correct for measurement error.⁸ Further, when Ashenfelter and Krueger account for measurement error in this specification, their estimate of the return to schooling rises to a surprising 16.7 percent. Once measurement error is addressed using the larger sample, however, the estimated return to schooling rises to about 9.5 percent, and the estimated upward bias in the OLS estimate falls to 6 percent.⁹

⁸ This result is consistent with most other within-twin (or within-family) estimates of the return to schooling that also find an upward bias in the OLS estimate (see Altonji and Dunn (1996), Ashenfelter and Zimmerman (1997), and Behrman, Rosenzweig, and Taubman (1994) for recent examples.)

⁹ Given that the reliability ratio for the difference in twins' schooling levels (assuming independent measurement errors) is about 0.62, as reported in Appendix Table 1b, the expected IV estimate is a return to schooling of 12.1 percent which is larger than the actual estimate of 9.5 percent. Note, however, that the

Table 3 replicates the specifications in Table 2 adding an interaction between whether the twins were interviewed in 1991 (and therefore in Ashenfelter and Krueger's sample) in order to test for whether the discrepancies in the coefficients are statistically significant.¹⁰ While the first-differenced estimate that is uncorrected for measurement error indicates that the difference in the coefficients generated by the two samples is statistically significant at the 5 percent level, the preferred IV estimate of the difference has a p-value of 0.13. Given that similar survey instruments were employed on the same population using similar interview teams, the unexpected sign of the ability bias and the large magnitudes in the return to schooling in Ashenfelter and Krueger are likely due to sampling variability.¹¹

B. Independent and Correlated Measurement Errors

The second innovation in Ashenfelter and Krueger's paper is their ability to test for the presence of an individual-specific component to the measurement error in schooling. If the individual-specific component of the measurement error is important, IV estimates assuming independent measurement errors will be inconsistent. Table 4 contains estimates that control for observable differences between twins while

actual estimate is within a standard error of the predicted estimate. The interested reader will also notice that in Appendix Table 1b the covariance between ΔS^* and $\Delta \text{Log Wage}$ does not equal the covariance between ΔS^{**} and $\Delta \text{Log Wage}$ (although they should since the twins are sorted randomly.) This apparent discrepancy is entirely due to sampling variability. I estimated these two covariances 2000 times randomly sorting the twins differently each time. The means of the two covariances are equal; the mean covariance is 0.192. In addition, the mean reliability ratio (for Appendix Table 1b) assuming independent measurement error is 0.613 and that allowing for correlated measurement error is 0.748; these are very close to the reported values.

¹⁰ I employ slightly different sample selection criteria than Ashenfelter and Krueger which results in slightly different samples for 1991. However, if I restrict my sample to those interviewed in 1991, I get qualitatively results similar to those reported by Ashenfelter and Krueger.

¹¹ If I fully interact the model in column (1) with having been interviewed in 1991, the p-value of the test of the joint significance of the interactions is 0.065. Much of the significance is driven by the interaction with whether the respondent is white, however, as the p-value rises to 0.14 when the interaction with race is excluded from the F-test. I have also interacted the difference in education in columns (7) and (8) with dummy variables indicating the year of the interview. The OLS estimates (that correspond to column (7)) indicate significant differences between the years although the IV estimates do not. These results are available from the author on request.

assuming both independent and correlated measurement errors.¹² The GLS estimate that ignores the family effect is contained in the first column of Table 4. The cross-sectional estimate of the economic return to schooling, conditional on other covariates, is 11.1 percent. The fixed-effects estimate provided in column (2) of the table falls to 8.9 percent. Column (3) in Table 4 uses $\Delta S'$, the difference in the self-reported education levels, as the independent variable, and $\Delta S''$, the difference in the sibling-reported estimates of the schooling levels, as an instrumental variable for $\Delta S'$. As the table indicates, the IV estimate is about the same magnitude as the cross-sectional estimate in column (1).

The last two columns in Table 4 report the results of fitting equation (3) to the data using one twin's report of the within-twin schooling difference as an instrument for the other twin's report of the same difference. This strategy generates an estimate that is consistent in the presence of a person-specific component to the measurement error. Similar to the results in columns (2) and (3), the IV estimates that allow for correlated measurement errors are also close to the conventional cross-sectional estimates of the economic return to schooling. Although the individual-specific component to the error term should make the estimate assuming independent measurement errors larger than the estimate that relaxes this assumption, the results in column (5) suggest a return to schooling of 12 percent compared to an estimate of 11 percent in column (3). This difference again highlights the importance of sampling error as the two estimates are well within a standard error of one another.¹³

Although the IV estimates suggest that the assumption of independence in the measurement errors

¹² In Table 4 I include other covariates to follow Ashenfelter and Krueger. In addition, I use all waves of the survey. I present separate estimates excluding the initial, 1991, survey in Appendix Table 2.

¹³ This interpretation of the difference is reinforced by a second (and underappreciated) source of variability in twin studies: the order of the twins is random. As a result, the first-differenced ("fixed-effects") estimates can vary depending on the order in which the data have been sorted. I have re-estimated the first-differenced estimates in Tables 2-4 2000 times randomly changing the order of the data each time. The estimates presented here are essentially at the mean of the estimates generated; the only exceptions are that the mean estimates allowing for correlated measurement errors in Table 4 are 0.083 for column (4) and 0.109 for column (5). It is also worth noting that when I performed this same exercise using only the 1991 data, about 30 percent of the OLS within-twin estimates were lower than the cross-sectional estimate.

is not economically important, one can test the assumption more formally using a method of moments framework. The theoretical covariance matrix for Δy , $\Delta S'$, $\Delta S''$, ΔS^* , and ΔS^{**} implied by equations (3)-(7) is reproduced in Table 5a under the assumption that there is a person-specific component to the measurement error which is the fraction " ρ_v " of the total measurement error variance. (Thus, ρ_v is the correlation between the measurement errors in the reports of schooling by one sibling.) Note that the restriction $\rho_v=0$ results in the theoretical covariance matrix assuming independent measurement errors, i.e., the first three columns and rows of Table 5a. Thus, the independent measurement error model is nested within the correlated measurement error model, and it is possible to test the restriction. The empirical covariance matrix (that does not partial out the effects of other twin-specific characteristics) is presented in Table 5b.

Table 6 contains generalized method of moments estimates (implemented using a maximum likelihood strategy with the statistical package LISREL) of the basic parameters set out in Tables 5a and 5b. The estimates in columns (1)-(3) assume independent measurement errors. Because of the two measures of the difference in schooling levels, the parameters are over-identified. Separate estimates using each measure of the difference are in columns (1) and (2); estimates restricting these coefficients to be equal are in column (3). Again, the estimates of the return to schooling are smaller than those reported in Ashenfelter and Krueger. The restricted model (column (3)) suggests a return to schooling of 0.107 compared to an estimate of 0.162 reported in Ashenfelter and Krueger. The χ^2 statistic of over-identifying restrictions, presented at the bottom of the table, indicates that the restrictions are not rejected.¹⁴ I present the correlated measurement error model that restricts ρ_v to zero in column (4) and that allows ρ_v to vary in column (5). The economic return to schooling assuming no correlation between the errors is 0.105 and falls to 0.099 when the errors are allowed to be correlated. The estimate of ρ_v suggests a fair degree of positive correlation between the

¹⁴ These estimates are not fully efficient because not all of the restrictions have been imposed. This was done for comparison with Ashenfelter and Krueger and computational ease. Given the similarity of the point estimates it is unlikely that imposing the extra restrictions would result in any qualitative changes.

two error terms that is statistically significant¹⁵, although the correlation is smaller in magnitude than that reported by Ashenfelter and Krueger. The results in Table 6 provide clear evidence of an important person-specific component to the measurement error in schooling levels.

C. Within-Twin vs. Cross-Sectional Estimates of the Return to Schooling

As originally highlighted by Griliches (1979), a potentially important issue with within-twin (and within-sibling) estimates of the return to schooling is whether the resulting estimates are actually less (upward) biased than cross-sectional estimates. If the ratio of the within-twin variance in ability to the within-twin variance in schooling is greater than the ratio of the cross-sectional variance in ability to the cross-sectional variance in schooling, then within-twin estimates of the return to schooling may actually be more upward biased than cross-sectional estimates.

While more severe upward ability bias in within-twin estimates is theoretically possible, Ashenfelter and Rouse (forthcoming) provide (indirect) evidence that cross-sectional estimates of the return to schooling likely contain more upward ability bias than within-twin estimates. For example, approximately 60 percent of the cross-sectional variance in schooling is between families (once corrected for measurement error), and between family measures of schooling are highly correlated with observables such as marital status, union status, job tenure, and spouse's education, whereas the within-twin measures of schooling are not.

In addition, in all cases presented here, the cross-sectional estimates are greater than the within-twin estimates, whether or not the within-twin estimates are corrected for measurement error. Therefore, to the extent that omitted ability is upward biasing the within-twin estimates, it is more severe in the cross-sectional estimates.

A final point made by Neumark (1994) is that because the OLS within-twin estimates of the return

¹⁵ In addition, a likelihood ratio test between the two models rejects the model that restricts the correlation to be zero.

to schooling suffer from both downward and upward biases (due to measurement error and ability biases), whereas the IV within-twin estimates only suffer from upward biases (due to ability bias), the OLS within-twin estimate of the return to schooling may most accurately reflect the “true” return to schooling. This situation would exist if the within-twin ability bias were large enough to off-set the (relatively large) measurement error bias. This is a theoretical possibility that requires an estimate of the magnitude of the potential ability bias in twins analyses. While the magnitude of this bias is currently unknown, the upward ability bias in cross-sectional estimates likely provides an upper-bound. Given that recent IV estimates of the return to schooling employing other identifying strategies suggest little ability bias in cross-sectional estimates (e.g., Angrist and Krueger (1991), Card (1993), and Kane and Rouse (1993)), the overall evidence likely favors the measurement error corrected within-twin estimates.

V. Conclusion

The results in this paper using additional data on twins indicate that each year of schooling increases earnings by about 10 percent, smaller than Ashenfelter and Krueger’s final estimate of 13 percent. More importantly, unlike the results reported by Ashenfelter and Krueger, the larger sample of identical twins indicates that schooling levels are positively correlated with ability in cross-sectional analyses. Finally, a model assuming no individual-specific component to the measurement error in schooling levels is rejected by the data.

References

- Altonji, J. and Dunn, T. (1996) The Effects of Family Characteristics on the Return to Education. Review of Economics and Statistics 78, 692-704.
- Angrist, J. D. and Krueger, A. (1991) Does Compulsory School Affect Schooling and Earnings?. Quarterly Journal of Economics 106, 979-1014.
- Ashenfelter, O. and Krueger, A. (1994) Estimating the Returns to Schooling Using a New Sample of Twins. American Economic Review 84, 1157-1173.
- Ashenfelter, O. and Rouse, C. (forthcoming) Income, Schooling, and Ability: Evidence from a New Sample of Identical Twins. Quarterly Journal of Economics.
- Ashenfelter, O. and Zimmerman, D. J. (1997) Estimates of the Return to Schooling from Sibling Data: Fathers, Sons, and Brothers. Review of Economics and Statistics 79, 1-9.
- Behrman, J. R., Hrubec, Z., Taubman, P., and Wales, T. J. (1980) Socioeconomic Success: A Study of the Effects of Genetic Endowments, Family Environment, and Schooling. Amsterdam: North-Holland.
- Behrman, J. R., Rosenzweig, M. R., and Taubman, P. (1994) Endowments and the Allocation of Schooling in the Family and in the Marriage Market: The Twins Experiment. Journal of Political Economy 102, 1131-1174.
- Card, D. (1993) Using Geographic Variation in College Proximity to Estimate the Return to Schooling. National Bureau of Economic Research Working Paper No. 4482, October.
- Griliches, Z. (1977) Estimating the Returns to Schooling: Some Econometric Problems. Econometrica 45, 1-22.
- Griliches, Z. (1979) Sibling Models and Data in Economics: Beginnings of a Survey. Journal of Political Economy 87, S37-S64.
- Kane, T. J. and Rouse C. E. (1993) Labor Market Returns to Two- and Four-year College: Is a Credit a Credit and Do Degrees Matter?. Princeton University Industrial Relations Section Working Paper No. 311.
- Lykken, D.T., Bouchard Jr., T.J., McGue, M. and Tellegan, A. (1990) The Minnesota Twin Family Registry: Some Initial Findings. Acta Genet Med Gemelloi 39, 35-70.
- Neumark, D. (1994) Biases in Twin Estimates of the Return to Schooling: A Note on Recent Research. National Bureau of Economics Research Technical Working Paper No. 158.
- Zellner, A. (1962) An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias. Journal of the American Statistical Association 57, 348-368.

Table 1
Descriptive Statistics: Means and Standard Deviations

	Identical Twins		CPS***
	1991*	1991-1993, 1995**	
Self-reported Education	14.11 [2.16]	14.08 [2.06]	13.16 [2.59]
Sibling-reported Education	14.02 [2.14]	13.99 [2.07]	
Hourly Wage	\$13.31 [11.19]	\$14.56 [12.54]	\$12.04 [7.61]
Age	36.56 [10.36]	37.88 [11.50]	37.61 [11.40]
White	0.94 [0.24]	0.92 [0.27]	0.77 [0.42]
Female	0.54 [0.50]	0.59 [0.49]	0.47 [0.50]
Covered by union	0.24 [0.43]	0.22 [0.41]	0.19 [0.39]
Married	0.45 [0.50]	0.48 [0.49]	0.61 [0.49]
Interviewed More than Once		0.19 [0.39]	
Sample Size	298	906	476,851

* Source: Twinsburg Twins Survey, August 1991 (Ashenfelter and Krueger 1994).

** Source: Twinsburg Twins Survey, 1991-1993, 1995

*** Source: The Current Population Survey (CPS) sample is drawn from the 1991-1993 Outgoing Rotation Group files; the sample includes workers age 18-65 with an hourly wage greater than \$1.00 per hour in 1993 dollars and the means are weighted using the earnings weight.

Table 2

Ordinary Least-Squares (OLS), Generalized Least-Squares (GLS), First-Differenced, and Instrumental Variables (IV) Estimates of Log Wage Equations for Identical Twins: Ashenfelter and Krueger's Results and Those Obtained with the Larger Sample

	1991*				1991-1993, 1995**			
	OLS (1)	GLS (2)	First-Differenced (3)	First-Differenced by IV (4)	OLS (5)	GLS (6)	First-Differenced (7)	First-Differenced by IV (8)
Own Education	0.084 (0.014)	0.087 (0.015)	0.092 (0.024)	0.167 (0.043)	0.105 (0.008)	0.101 (0.009)	0.075 (0.017)	0.095 (0.027)
Age	0.088 (0.019)	0.090 (0.023)			0.097 (0.009)	0.098 (0.011)		
Age ² ($\div 100$)	-0.087 (0.023)	-0.090 (0.023)			-0.099 (0.011)	-0.099 (0.013)		
Female	-0.204 (0.063)	-0.206 (0.064)			-0.325 (0.034)	-0.326 (0.041)		
White	-0.410 (0.127)	-0.428 (0.128)			-0.082 (0.060)	-0.071 (0.072)		
Sample Size	298	298	149	149	906	906	453	453
R ²	0.260	0.219	0.092		0.336	0.268	0.043	

Notes: Standard errors are in parentheses. All regressions include a constant. These regressions assume independent measurement errors.

* Source: Ashenfelter and Krueger (1994).

** Source: Twinsburg Twins Survey, 1991-1993, 1995.

Table 3

**OLS, GLS, First-Differenced, and IV Estimates of the
Log Wage Equations for Identical Twins: A Direct Comparison of Ashenfelter and Krueger's
Results and Those Obtained Using the Larger Samples**

	OLS (1)	GLS (2)	First- Differenced (3)	First-Differenced by IV (4)
Own Education	0.112 (0.010)	0.104 (0.011)	0.047 (0.022)	0.055 (0.039)
Own Education × Interviewed in 1991	-0.024 (0.017)	-0.010 (0.019)	0.066 (0.033)	0.083 (0.054)
Interviewed in 1991	0.306 (0.245)	0.098 (0.265)		
Age	0.098 (0.009)	0.098 (0.011)		
Age ² (÷100)	-0.099 (0.011)	-0.099 (0.013)		
Female	-0.326 (0.034)	-0.329 (0.041)		
White	-0.081 (0.061)	-0.068 (0.072)		
Sample Size	906	906	453	453
R ²	0.338	0.269	0.051	

Notes: Standard errors are in parentheses. All regressions include a constant. These regressions assume independent measurement errors.

Source: Twinsburg Twins Survey, 1991-1993, 1995.

Table 4

**GLS, First-Differenced, and IV Estimates of the Return to Schooling
for Identical Twins**

	GLS (1)	Assuming Independent Measurement Errors [†]		Assuming Correlated Measurement Errors ^{††}	
		First- Differenced (2)	First-Diff. by IV (3)	First- Differenced (4)	First-Diff. by IV (5)
Own Education	0.111 (0.009)	0.089 (0.016)	0.110 (0.027)	0.071 (0.016)	0.119 (0.021)
Age	0.091 (0.011)				
Age ² ($\div 100$)	-0.104 (0.013)				
Female	-0.261 (0.041)				
White	-0.076 (0.069)				
Covered by a Union	0.104 (0.039)	0.087 (0.050)	0.089 (0.051)	0.085 (0.051)	0.090 (0.051)
Married	0.039 (0.035)	0.017 (0.046)	0.017 (0.046)	0.017 (0.046)	0.015 (0.047)
Tenure (Years)	0.020 (0.002)	0.020 (0.003)	0.020 (0.003)	0.020 (0.003)	0.021 (0.003)
Sample Size	890	445	445	445	445
R ²	0.341	0.144		0.124	

Notes: Standard errors are in parentheses. All regressions include a constant.

[†] The difference in education is the difference between twin 1's report of twin 1's own education and twin 2's report of twin 2's own education. The instrument used is the difference between twin 2's report of twin 1's education and twin 1's report of twin 2's education.

^{††} The difference in education is the difference between twin 1's report of twin 1's own education and twin 1's report of twin 2's education; the instrument used is the difference between twin 2's report of twin 1's education and twin 2's report of twin 2's own education.

Table 5a
Theoretical Covariance Matrix

	Δy	$\Delta S'$	$\Delta S''$	ΔS^*	ΔS^{**}
Δy	$\beta^2 \sigma_{\Delta S}^2 + \sigma_{\Delta \varepsilon}^2$	$\beta \sigma_{\Delta S}^2$	$\beta \sigma_{\Delta S}^2$	$\beta \sigma_{\Delta S}^2$	$\beta \sigma_{\Delta S}^2$
$\Delta S'$		$\sigma_{\Delta S}^2 + 2\sigma_{v'}^2$	$\sigma_{\Delta S}^2 - 2\rho_v \sigma_{v'} \sigma_{v''}$	$\sigma_{\Delta S}^2 + \sigma_{v'}^2$ $- \rho_v \sigma_{v'} \sigma_{v''}$	$\sigma_{\Delta S}^2 + \sigma_{v'}^2$ $- \rho_v \sigma_{v'} \sigma_{v''}$
$\Delta S''$			$\sigma_{\Delta S}^2 + 2\sigma_{v''}^2$	$\sigma_{\Delta S}^2 + \sigma_{v''}^2$ $- \rho_v \sigma_{v'} \sigma_{v''}$	$\sigma_{\Delta S}^2 + \sigma_{v''}^2$ $- \rho_v \sigma_{v'} \sigma_{v''}$
ΔS^*				$\sigma_{\Delta S}^2 + \sigma_{v'}^2 + \sigma_{v''}^2$ $- \rho_v \sigma_{v'} \sigma_{v''}$	$\sigma_{\Delta S}^2$
ΔS^{**}					$\sigma_{\Delta S}^2 + \sigma_{v'}^2 + \sigma_{v''}^2$ $- \rho_v \sigma_{v'} \sigma_{v''}$

Table 5b
Empirical Covariance Matrix

	Δy	$\Delta S'$	$\Delta S''$	ΔS^*	ΔS^{**}
Δy	0.279	0.167	0.129	0.129	0.167
$\Delta S'$		2.060	1.339	1.723	1.676
$\Delta S''$			2.286	1.894	1.731
ΔS^*				2.095	1.521
ΔS^{**}					1.886

Note: There are 445 observations.

Table 6
Generalized Method of Moments Estimates

Z	Independent Errors			Correlated Errors	
	Unrestricted Estimates		Restricted Estimates	Restricted Estimates	
Parameter	(1)	(2)	(3)	(4)	(5)
β	0.096 (0.028)	0.125 (0.027)	0.113 (0.024)	0.105 (0.023)	0.099 (0.021)
$\sigma^2_{\Delta S}$	1.339 (0.121)	1.339 (0.121)	1.342 (0.121)	1.441 (0.119)	1.524 (0.119)
$\sigma^2_{\Delta e}$	0.267 (0.018)	0.258 (0.018)	0.262 (0.018)	0.264 (0.018)	0.265 (0.018)
$\sigma^2_{\Delta v'}$	0.721 (0.094)	0.721 (0.094)	0.700 (0.092)		
$\sigma^2_{\Delta v''}$	0.947 (0.103)	0.947 (0.103)	0.967 (0.102)		
$\sigma^2_{v'}$				0.275 (0.037)	0.260 (0.042)
$\sigma^2_{v''}$				0.381 (0.040)	0.394 (0.045)
ρ_v					0.289 (0.047)
χ^2 (dof)	NA	NA	1.359 (1)	45.781 (7)	11.158 (6)
[p-value]			[0.244]	[0.000]	[0.084]

Note: Estimated asymptotic standard errors are in parentheses. In column (4) ρ_v is constrained to equal zero. “dof” are the degrees of freedom. These are generalized method of moments estimates assuming that the errors are normally distributed.

Appendix Table 1a
Cross-Sectional Correlation Matrix for Identical Twins

	Log Wage ₁	Log Wage ₂	Educ ₁ ¹	Educ ₁ ²	Educ ₂ ²	Educ ₂ ¹
Log Wage ₁	1.000					
Log Wage ₂	0.635	1.000				
Education ₁ ¹	0.301	0.317	1.000			
Education ₁ ²	0.279	0.292	0.931	1.000		
Education ₂ ²	0.216	0.361	0.757	0.780	1.000	
Education ₂ ¹	0.219	0.340	0.757	0.740	0.906	1.000

Notes: “Log Wage_k” is twin “k”’s report of his/her own wage, “Education_k^j” is twin “j”’s report of twin “k”’s education.

Appendix Table 1b
Within-Twin Correlation Matrix for Identical Twins

	$\Delta \text{Log Wage}$	$\Delta S'$	$\Delta S''$	ΔS^*	ΔS^{**}
$\Delta \text{Log Wage}$	1.000				
$\Delta S'$	0.220	1.000			
$\Delta S''$	0.162	0.617	1.000		
ΔS^*	0.169	0.829	0.865	1.000	
ΔS^{**}	0.230	0.850	0.834	0.765	1.000

Notes: $\Delta S'$ is the own-twin report of the schooling difference; $\Delta S''$ is the twin-report of the schooling difference; ΔS^* is one twin’s report of the schooling difference; and ΔS^{**} is the other twin’s report of the schooling difference. See equations (4)-(7).

Appendix Table 2

**GLS, First-Differenced, and IV Estimates of the Return to Schooling for Identical Twins
Excluding the 1991 Survey**

	GLS (1)	Assuming Independent Measurement Errors [†]		Assuming Correlated Measurement Errors ^{††}	
		First- Differenced (2)	First-Diff. by IV (3)	First- Differenced (4)	First-Diff. by IV (5)
Own Education	0.115 (0.010)	0.069 (0.022)	0.076 (0.039)	0.040 (0.021)	0.104 (0.030)
Age	0.089 (0.013)				
Age ² ($\div 100$)	-0.098 (0.016)				
Female	-0.319 (0.049)				
White	-0.001 (0.075)				
Covered by a Union	0.080 (0.047)	0.062 (0.061)	0.061 (0.061)	0.065 (0.062)	0.066 (0.063)
Married	0.027 (0.041)	-0.029 (0.055)	-0.029 (0.055)	-0.029 (0.056)	-0.032 (0.057)
Tenure (Years)	0.019 (0.003)	0.015 (0.003)	0.015 (0.004)	0.015 (0.004)	0.016 (0.004)
Sample Size	588	294	294	294	294
R ²	0.375	0.085		0.065	

Notes: Standard errors are in parentheses. All regressions include a constant.

[†] The difference in education is the difference between twin 1's report of twin 1's own education and twin 2's report of twin 2's own education. The instrument used is the difference between twin 2's report of twin 1's education and twin 1's report of twin 2's education.

^{††} The difference in education is the difference between twin 1's report of twin 1's own education and twin 1's report of twin 2's education; the instrument used is the difference between twin 2's report of twin 1's education and twin 2's report of twin 2's own education.