

Under the Weather: Health, Schooling, and Economic Consequences of Early-Life Rainfall

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Life in rural areas of developing countries is prone to many kinds of risk, such as illness or mortality of household members, crop or other income loss due to natural phenomena (weather, insect infestations, or fire, for example), and civil conflict. In addition to their contemporaneous effects, the effects of certain types of shocks may still be felt many years or even decades later. From a public policy standpoint, it is particularly important to identify shocks that have large long-run effects. Moreover, the mechanics underlying the persistence of shocks may be of considerable interest. For example, a health shock may have a long-run effect simply because the health shock itself persists over time. Alternately, the health shock may not directly affect long-run outcomes, but it could affect some other outcome—such as educational attainment—that helps determine long-run well-being.

In this paper, we focus on shocks that occur at the very beginning of life. We ask how sensitive long-run individual well-being is to environmental conditions around the time of birth. In particular, we examine the effect of weather shocks around the time of birth on the adult health, education, and socioeconomic outcomes of Indonesian women and men born between 1953 and 1974. In addition, we attempt to shed light on the intervening pathways connecting early-life rainfall to adult outcomes, illuminating the roles of health and educational attainment in determining adult socioeconomic status.

This investigation has considerable data requirements. It necessitates information on weather shocks experienced by individuals several decades earlier, as well as detailed current information on adult outcomes. We use information in the Indonesian Family Life Surveys (IFLS) on an individual's year and location of birth, and link each individual in that survey to locality-specific rainfall data for their birth year. For individuals born in rural areas (on whom we focus), rainfall variation across space and time should generate corresponding variation in agricultural output and thus household income. To deal with measurement error in the rainfall data, we run instrumental variables regressions where variables for rainfall measured at slightly more distant rainfall stations serve as instruments for rainfall in the individual's birthplace and birth year.

We examine the impact of early-life rainfall on a range of adult outcomes observed in 2000. We find that higher early-life rainfall leads to improved health, schooling, and socioeconomic status for women. Women with 20 percent higher rainfall (relative to normal local rainfall) in their year and location of birth are 3.8 percentage points less likely to self-report poor or very poor health. They attain 0.57 centimeters greater height, attain 0.22 more completed grades of

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schooling, and live in households that score 0.12 standard deviations higher on an asset index. By contrast, we do not find relationships between early-life rainfall and adult men's outcomes.

We provide suggestive evidence on the intermediate pathways connecting early-life rainfall to adult socioeconomic status. Compared with rainfall in the birth year itself, rainfall in the years after the birth year has no statistically significant relationship with adult outcomes. So it is most plausible that the initial, direct effect of rainfall is on girls' health in the very earliest years after birth (rather than a lagged effect on, say, school entry). The strong relationship we find between birth year rainfall and adult height also suggests that nutrition in infancy varies with early-life rainfall. Our results suggest that rainfall's effects on crop output—and thus household income and food availability—lead to variations in parents' abilities to provide nutrition, medical inputs, and generally more nurturing environments for infant girls.

We find no effect of rainfall in the years prior to the birth year, so there is no indication that shocks in utero are important in influencing our results, in comparison to shocks experienced in infancy. While these results confirm that a rainfall shock during the first year of life has the most important influence on women's long-run outcomes, it may be that the nutritional deprivation that follows may be in the period after weaning from breast milk. So our results could well be consistent with the importance placed on the postweaning period in the existing literature (e.g., Paul Glewwe and Elizabeth King 2001), if drought-associated malnutrition in Indonesia occurs with some lag.

We also provide other regression-based evidence that helps compare the importance of various subsequent pathways (health and education) leading to adult socioeconomic status. Our evidence suggests a chain of causation that runs from early-life rainfall to infant health, to educational attainment, and finally to adult socioeconomic status. We do not find evidence that adult women's health status is an important mediator between early-life rainfall shocks and adult socioeconomic status.

This paper is broadly related to a body of research in economics on the relationship between conditions in early life and outcomes in later life.¹ In particular, this paper shares with a smaller set of other papers a strong concern with establishing causality, by focusing on the impact of exogenous conditions or "shocks" in early life on adult outcomes. These related papers examine more extreme or unusual early-life conditions, such as pandemics (Douglas Almond 2006), twin births (Jere Behrman and Mark R. Rosenzweig 2004; Heather Royer 2009), or extreme drought and civil war (Harold Alderman, John Hoddinott, and Bill H. Kinsey 2006) and therefore raise concerns about generalizability.² In comparison with this research, our paper examines a category of early-life shocks (rainfall shocks) that is highly relevant to the lives of rural populations in developing countries. It is important to establish (as we do), across a large number of cohorts and in a (relatively) representative sample of a national population, that more "typical" variation in early-life environmental conditions can also have substantial long-run effects on individuals. Among other things, these findings help justify public policies that help households cope with more typical year-to-year variation in their economic conditions, as opposed to policies that respond only to extreme events.

¹ Irma T. Elo and Samuel H. Preston (1992) review the epidemiological and demographic evidence on potential mechanisms linking childhood health to adult health (mortality) worldwide. More recent research using data from developing countries includes Alderman et al. (2001), Glewwe and King (2001), Glewwe, Hanan Jacoby, and King (2001), Behrman (2006), and John A. Maluccio et al. (2006). Research on developed countries includes Janet Currie and Rosemary Hyson (1999), Anne Case, Darren H. Lubotsky, and Christina H. Paxson (2002), Case, Angela R. Fertig, and Paxson (2005), Abhijit Banerjee et al. (2007), Currie and Enrico Moretti (2007), and Rucker C. Johnson and Robert F. Schoeni (2007).

² Another related paper is Gerard van den Berg, Maarten Lindeboom, and France Portrait (2006), who examine the impact of early-life macroeconomic conditions on longevity in the Netherlands.

Several additional features help distinguish this paper from existing research. First, the paper examines exogenous shocks in several periods before and after birth to help pinpoint the most sensitive or critical periods. Among previous papers mentioned, only Almond (2006) conducts such an examination. Second, we focus on outcomes in individuals' adult prime-age years (as opposed to the teenage years as in Alderman et al. 2006). Finally, we are able to examine a wide range of diverse outcomes in a high-quality general-purpose household survey dataset, the IFLS. By contrast, existing work must make the best of datasets that have a much more restricted set of outcome variables available, such as census data (Almond 2006), vital statistics records (Royer 2009), or smaller-scale special-purpose datasets (Behrman and Rosenzweig 2004; Alderman et al. 2006).

This paper also speaks to the literature on gender bias. Our finding of significant impacts for women and not for men is consistent with gender bias in the allocation of nutrition and other resources, particularly in times of unusual hardship. The gender bias interpretation is supported by the finding that only in the first year of life are the rainfall shocks associated with long-run outcomes, as opposed to shocks experienced in utero (before the gender of the child is known). Our paper adds to the existing literature by documenting that the impact of gender bias in early life has a very long temporal reach, and continues to be felt decades later.

The related literature on gender bias in developing countries for the most part examines gender imbalance in the short-term impact of negative shocks, rather than the long-term impacts on which we focus. While the evidence is somewhat mixed, other studies in Indonesia and elsewhere have found that the short-term negative impacts of shocks are greater for girls than for boys. Jean Dreze and Amartya Sen (1989) cite several studies that find that households often prioritize boys' welfare over that of girls in lean times. Monica Das Gupta (1987) finds that girls in rural India have twice the mortality rate as boys, arguing that the differential is due to differences in medical care, nutrition, and clothing. Behrman (1988) and Behrman and Anil Deolalikar (1990) document biases favoring boys in nutrient allocation in Indian households during difficult times. Elaina Rose (1999) finds that the gender bias in infant mortality in India (that typically favors boys) narrows when districts experience higher rainfall. Harold Alderman and Paul Gertler (1997) find that demand for girls' medical care is more income- and price-elastic than demand for boys' medical care in rural Pakistani households. Lisa Cameron and Christopher Worswick (2001) find that, in response to crop loss, Indonesian families with girls are more likely to reduce educational expenditures than are families with boys. Seema Jayachandran (forthcoming) finds that negative shocks to air quality in Indonesia affect female more than male infant mortality. Duncan Thomas et al. (2004) show that the 1998 Indonesian economic crisis had similar effects on boys' and girls' enrollment rates, but at the same time education budget shares rose more from before to after the crisis in households with more older boys (compared to those with older girls). One notable exception is David I. Levine and Minnie Ames (2003), who find that the 1998 Indonesian crisis affected boys and girls similarly.

Section I discusses conceptual issues, and Section II reviews the evidence on the impact of rainfall on Indonesian agricultural output. Section III describes the datasets we use and provides some descriptive statistics. Section IV presents the main empirical results, while Section V conducts a variety of supplementary analyses. Section VI concludes.

I. Conceptual Issues

Starting with Michael Grossman (1972), health production functions typically consider individual health at time t , H_t , to be a function of an initial health endowment H_0 , as well as the history of health inputs N_1, \dots, N_t . Other health determinants of importance include time-invariant

demographic variables X (such as gender and age), the time histories of community infrastructure C_0, C_1, \dots, C_t , and the disease environment D_0, D_1, \dots, D_t :

$$(1) \quad H_t = h(H_0, N_1, \dots, N_t, X, C_0, C_1, \dots, C_t, D_0, D_1, \dots, D_t).$$

The initial health endowment H_0 is in part determined by genetic characteristics determined at conception G , but, in addition, environmental conditions experienced in early life R_0 , as well as early-life community infrastructure and disease environment, may have persistent effects on health:

$$(2) \quad H_0 = k(G, R_0, C_0, D_0).$$

The concept that environmental conditions in a certain sensitive period of life may have long-run, irreversible effects is known as “critical-period programming.” The term “fetal origins hypothesis” has been used to refer to programming caused by conditions experienced in the fetal stage (e.g., D. J. P. Barker 1998), but in practice the term is often taken to include effects of conditions experienced in infancy and early childhood. The nutrition literature suggests that the potential for individuals stunted in the first couple of years of life to catch up is limited, making height at age three a strong predictor of adult height (Reynaldo Martorell 1995, 1997; Martorell, L. Kettel Khan, and Dirk G. Schroeder 1994).

Our focus in this paper is on the component of individuals’ initial health endowment that is determined by environmental conditions in early life. In particular, our results identify the reduced-form relationship between early-life rainfall shocks and later-life health and socioeconomic outcomes.

A brief word is also in order regarding the likely direction of selection bias in this context. We review in the next section the evidence that higher rainfall should be interpreted as a positive shock to an Indonesian locality, leading to higher local-level crop output. An individual can be included in the data for analysis only if he is still living in 2000. A worry would be that early-life rainfall could affect the likelihood of survival through 2000, and that, in addition, those whose survival was induced by rainfall could be drawn from the lower end of the distribution of infant health. If individuals with worse infant health also have worse health as adults, such a selection effect would bias our results in a negative direction, so that any positive long-run effects of rainfall on adult outcomes would be lower bounds of the true effects.

As it turns out, however, we find no evidence that survival until inclusion in the IFLS third wave sample (2000) is statistically significantly associated with rainfall shocks in the birth place and birth year. Specifically, we test whether rainfall shocks affect the size of female and male birth cohorts who appear in our samples at the district-birth year-season level. We regress the number of individuals appearing in our IFLS sample at the birth district–birth year-season level on the birth year rainfall variable, separately for women and men. Regressions include birth year-season and district-season fixed effects, as well as district-season-specific linear time trends. The results provide no indication that birth year rainfall affects the likelihood of inclusion in our sample: coefficients on birth year rainfall for both women and men are not statistically significantly different from zero. (For details and regression results, see the online Appendix, available at <http://www.aeaweb.org/articles.php?doi=10.1257/aer.99.3.1006>.)

II. Rainfall and Agricultural Output in Indonesia

Rainfall is the most important dimension of weather variation in Indonesia. Because of its equatorial location, temperature shows very little variation in Indonesia, either within years or across them. In any particular year, the length of the wet season and the intensity of drought during the

dry season vary markedly across Indonesia's 5,100-kilometer east-west span. The specific trajectories of the monsoons vary from one year to the next, and lead to wide variation in precipitation across the archipelago both within year and across years (Library of Congress 2003).

Indonesia's climate typically consists of one wet season and one dry season each year. The distinguishing feature of the wet season is that at least 200 mm of rain falls per month. This definition is based on the minimum threshold necessary for rice production and takes into account evaporation and seepage through the soil (Kamal Kishore et al. 2000). The specific months of the wet and dry season vary across Indonesian provinces.

Levine and Yang (2006) find that deviations of rainfall from the district-level mean are positively associated with deviations of rice output from the district-level mean in Indonesian nonurban districts in the 1990s. (Years in which rainfall is unusually high have unusually high rice output, and years in which rainfall is unusually low have unusually low rice output.) Secondary reports also indicate that higher rainfall raises agricultural productivity in Indonesia (Kishore et al. 2000). Rice production in both the wet and dry seasons is particularly dependent on the timing of the monsoon. On an unpredictable basis, there is a pronounced drought in the dry season driven by the El Niño weather phenomenon. For example, there were ten long or short droughts (large-scale crop failure) between 1921 and 1954. The timing of planting during the primary (wet) season is based on reaching a threshold of accumulated rainfall. Generally, when planting is delayed, the season's crop yields are reduced. Delays in the onset of the monsoons in the wet season, as well as ongoing dry spells during that season, lead to reduced wet season harvests. Secondary crop harvests may be reduced as well during the following dry season because of the delay in harvesting in the previous wet season (e.g., the 1997–1998 El Niño event). On the other hand, in La Niña years (when rainfall is unusually high), the planting season may begin early and yield above average harvests.

Because of the importance of the seasonal cycle of rain, food security also tends to vary seasonally. Food insecurity tends to be the highest at the end of the dry season and beginning of the following wet season, when stocks of food from the previous wet season are low and physical demands are high with the initiation of planting (Robert W. Herdt 1989). Accordingly, dry season droughts amplify food scarcity.

In contrast to the emphasis on droughts, there is scant mention in the agroclimatological literature on Indonesia that floods (very high rainfall) are important causes of declines in crop production. In addition, nonparametric estimates in Figure 1 (described below) provide no indication that the benefits of rainfall diminish at very high levels of rainfall—the 95 percent confidence intervals admit a linear relationship throughout the range of rainfall variation observed.

Aside from agricultural production and household income, there may be other channels linking rainfall to child nutrition and health. The allotment of parents' time—between agricultural work and child-rearing, for example—may also be a function of precipitation. Or unusual rainfall might alter the disease environment, and disease directly affects the absorption of nutrition, particularly in the vulnerable early years of rapid growth. Fluctuations in precipitation may influence other environmental conditions correlated with economic activity and public health, such as the extent of forest fires, floods, and landslides, the availability of potable water, and agricultural pest control. Indeed, some of these channels may imply a *negative* impact of rainfall that would somewhat offset positive effects via improved crop output.

III. Data Sources and Sample Composition

A. IFLS Data

The sample consists of 4,615 women and 4,277 men born outside of urban areas between 1953 and 1974 from the third wave of the IFLS (IFLS3), which was fielded in 2000. We restrict the

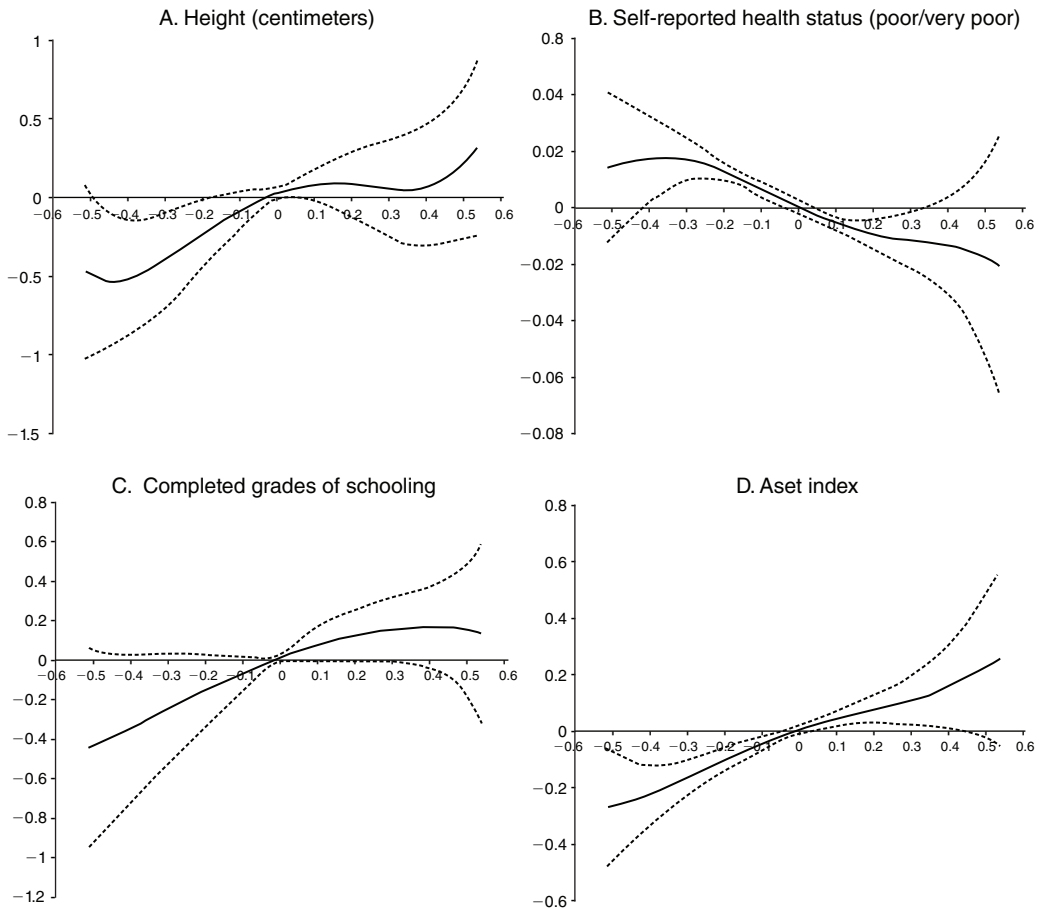


FIGURE 1. ADULT OUTCOMES ON RAINFALL IN BIRTH DISTRICT AND BIRTH YEAR

Notes: Nonparametric Fan regressions (biweight kernel, bandwidth = 0.5), conditional on birth district–season fixed effects, birth year–season fixed effects, and birth district–season-specific linear time trends. Solid line is nonparametric regression estimate. Dashed lines bound 95 percent bootstrapped confidence intervals.

sample to those born outside of urban areas because our causal factor of interest, rainfall, should mainly have an effect in agricultural areas. To ensure that the definition of urban areas is not endogenous to realized rainfall shocks in the years our sample was born, we define an urban area as a city that had 50,000 or more inhabitants according to the 1930 Indonesian census (tabulated by W. Rutz 1985). Slightly more than three-quarters of women and men in the IFLS3 were born in a district that is not an urban area.

The IFLS3 includes information on district (*kabupaten*) of birth, to which we link historical rainfall data. Sample individuals were born in 166 different districts. We use of information on month of birth to more precisely identify rainfall in the climatic season during which the person was born.³ The IFLS3 includes a variety of health variables, ranging from clinical measures to more subjective self-reported measures. Trained nurses collected lung capacity readings and anthropometric measures. Table 1 reports summary statistics.

³ The IFLS includes a “best guess” date of birth based on information across related questions within wave and across waves. The IFLS was eventually able to collect month of birth for the vast majority of respondents.

B. Rainfall Data

We obtain historical rainfall data for weather stations across Indonesia from two sources. For 1953–1995, we use publicly available the Global Historical Climatology Network (GHCN) Precipitation and Temperature Data (Version 2). We also purchased supplementary data for the years 1976–1999 directly from the Badan Meteorologi Dan Geofisika (BMG) agency in Indonesia.⁴ The data include monthly records for each station, as well as its latitude and longitude. For each month between 1953 and 1974, we use the station location information to match each birth district represented in the IFLS to the closest weather station. We matched a total of 378 stations with IFLS birth districts. Because the number of rainfall stations varies over time, data from different stations may be linked to the same district over time.

Although the IFLS includes Indonesians born throughout the twentieth century, we limit our sample to the 1953–1974 birth cohort. We choose 1953 as the first cohort for data quality reasons: while the quality of the rainfall data appears acceptable in the 1920s and 1930s (in that birth districts in the IFLS sample are rarely very far away from the nearest rainfall station), the mean distance from districts to the closest rainfall station rises substantially for about a decade after 1941, presumably reflecting upheaval during and after World War II. We therefore focus on the subsamples born in the following two decades.⁵ (Unfortunately, analysis of the 1920–1940 cohort is limited by very small samples.) The 1974 birth cohort is the last cohort in our analysis, so the youngest women in the sample are 25 or 26 when observed in 2000. This is an appropriate end cohort, as most Indonesians have completed their schooling by their mid-20s.

In calculating “rainfall in one’s year of birth,” we focus on rainfall in complete wet and dry seasons (rather than in calendar years), as these should be most closely related to agricultural cycles. We identify the “birth season” for each individual in the dataset, based on their reported birth month and birth province. We then define “rainfall in one’s year of birth” to be the sum of rainfall in one’s birth season and in the following season (total rainfall in the 12 consecutive months of an individual’s first wet and dry seasons).⁶ In analyses of the impact of birth year rainfall on adult outcomes, we focus on the *deviation* of birth year rainfall from the norm for one’s birth district. Specifically, the variable is the natural log of birth year rainfall minus the natural log of mean annual rainfall in the given district. Mean district rainfall for a particular individual is calculated over the 1953–1999 period, and excludes rainfall in the individual’s birth year. The rainfall variable should be interpreted (roughly speaking) as the percentage deviation from mean rainfall (e.g., a value of 0.05 means rainfall was approximately 5 percent higher than normal).

IV. Main Empirical Results

In examining the relationship between early-life rainfall and one’s adult outcomes, we seek to isolate deviation of one’s adult outcomes from the mean outcomes in one’s birth locale, as well as the mean outcomes of one’s national birth cohort. Because particular localities in Indonesia may be subject to long-running changes over extended periods of time (reflecting, for example, different rates of economic development), it will also be useful to isolate variation in a person’s outcomes that diverges from long-running trends in one’s birth district.

⁴ The GHCN data are available at <http://www.ncdc.noaa.gov/oa/climate/research/ghcn/ghcn.html>. Please see the online replication files for details on our contact at BMG.

⁵ Across observations born between 1953 and 1974, the median distance between the district of birth and the rainfall station during the year of birth is only 14 km., and the ninety-fifth percentile is only 70 km. The maximum is about 230 km.

⁶ For complete details, see the online Appendix.

TABLE 1—SUMMARY STATISTICS, WOMEN AND MEN BORN 1953–1974

Variables	Women					
	Mean	Standard deviation	Minimum	Median	Maximum	Observations
Self-reported health status very good (indicator)	0.08					4,613
Self-reported health status poor/very poor (indicator)	0.12					4,613
Ln (lung capacity)	5.6	0.2	4.2	5.6	6.4	4,454
Height (centimeters)	150.5	5.4	110.6	150.5	171.2	4,495
Days absent due to illness (last 4 weeks)	1.2	3.2	0.0	0.0	28.0	4,611
Years of schooling	6.4	4.4	0.0	6.0	16.0	4,598
Ln (expenditures per capita in household)	12.6	1.0	0.0	12.5	17.6	4,615
Asset index	0.0	1.5	-5.3	0.0	3.1	4,613
Ln (total assets per capita in household)	14.5	1.9	0.0	14.7	19.6	4,615
Owens television (indicator)	0.62					4,614
Owens refrigerator (indicator)	0.28					4,613
Owens private toilet with septic tank (indicator)	0.44					4,614
Owens stove (indicator)	0.62					4,614
Deviation of log rainfall from norm, year of birth	-0.03	0.30	-1.50	-0.02	0.99	4,615
Age	35.6	6.2	26.0	35.0	47.0	4,615
Expenditures per capita in household (US dollars, monthly)	64.4	160.8	0.2	32.7	5,421.6	4,614
Total assets per capita in household (US dollars)	742	1,652	0	282	39,065	4,593
Ln (annual earnings)	14.1	1.4	8.0	14.2	19.9	2,332
Variables	Men					
	Mean	Standard deviation	Minimum	Median	Maximum	Observations
Self-reported health status very good (indicator)	0.09					4,270
Self-reported health status poor/very poor (indicator)	0.09					4,270
Ln (lung capacity)	6.0	0.2	4.7	6.0	6.7	3,907
Height (centimeters)	162.0	6.0	130.0	162.0	183.4	3,924
Days absent due to illness (last 4 weeks)	1.0	3.2	0.0	0.0	30.0	4,267
Years of schooling	7.8	4.4	0.0	7.0	16.0	4,259
Ln (expenditures per capita in household)	12.6	0.9	7.6	12.6	17.6	4,277
Asset index	0.0	1.5	-5.2	0.0	3.0	4,276
Ln (total assets per capita in household)	14.5	1.9	0.0	14.7	19.4	4,277
Owens television (indicator)	0.61					4,277
Owens refrigerator (indicator)	0.27					4,276
Owens private toilet with septic tank (indicator)	0.44					4,277
Owens stove (indicator)	0.62					4,277
Deviation of log rainfall from norm, year of birth	-0.02	0.30	-1.62	0.00	0.99	4,277
Age	35.5	6.2	26.0	35.0	47.0	4,277
Expenditures per capita in household (US dollars, monthly)	65.3	158.2	0.2	34.5	5,421.6	4,277
Total assets per capita in household (US dollars)	702	1,454	0	279	31,757	4,255
Ln (annual earnings)	14.8	1.2	9.0	14.9	19.9	3,963

Notes: Sample is individuals born outside of urban areas between 1953 and 1974 inclusive. "Urban areas" are cities with 50,000 or more inhabitants in 1930. Age is based on reported year and month of birth. Asset index is first principal component of five asset variables (log total value of household assets and indicators for ownership of television, refrigerator, private toilet, and stove). Rainfall is at the birth district (*kabupaten*) level, in year of birth. Deviation of log rainfall from norm is log rainfall in year of birth minus log of district rainfall norm. Rainfall norm is birth district-specific mean from 1953 to 1999, where mean excludes current observation's birth year. Total household expenditures include food and nonfood items reported by the woman in charge of food preparation. Total assets include the household head's report of assets not used mainly for business. US dollar figures converted from rupiah at year 2000 (annual average) rate of 8,422 rupiah per US dollar.

A central challenge is that rainfall is measured with error. Rainfall is measured at the closest rainfall station to the birth district in the birth year, but this measurement is only imperfectly correlated with actual rainfall in the individual's narrowly defined birth locality. Classical measurement error in the early-life rainfall variable will lead to attenuated coefficient estimates. A solution to this problem is to instrument for early-life rainfall with alternative measures of the same variable whose errors are likely to be orthogonal to the original, instrumented variable.

Our main specification is therefore an instrumental variables regression where early-life rainfall (measured at the closest rainfall station to one's birth district in one's birth year) is instrumented with four analogous rainfall variables measured in the same birth year but in the second- through fifth-closest rainfall stations. Note that there will be measurement error to the extent that there is misreporting of the birth month, so that the instrumented estimates are still likely to understate the true empirical relationship.

We estimate the following reduced-form linear relationship between adult outcome Y_{ijst} of adult i born in district j , in season s and in year t :

$$(3) \quad Y_{ijst} = \beta R_{jt} + \mu_{js} + \gamma_{js} TREND + \delta_{st} + \varepsilon_{ijst}.$$

The coefficient of interest is β , the impact of (instrumented) birth year rainfall R_{jt} on the adult outcome. Because parents may time children to be born in particular seasons, and parents who time births in such a way may be different from those who do not,⁷ we estimate separate fixed effects for individuals born in the wet and dry season of each district: μ_{js} is a fixed effect for individuals born in district j and season s (e.g., born in district A in wet season, born in district A in dry season, etc.) Similarly, we allow the cohort effects to differ across wet and dry seasons: δ_{st} is a fixed effect for the birth year–season combination; $\gamma_{js} TREND$ is a linear time trend specific to the district-season, which absorbs long-running linear trends in the outcome that may vary depending on the district-season ($TREND$ is a linear time trend, and the coefficient γ_{js} allows the time trend to vary across district-seasons); and ε_{ijst} is a mean-zero error term. Due to serial and spatial correlation in error terms, standard errors allow for an arbitrary variance-covariance structure within birth provinces (clustering by birth province).

Inclusion of district-season fixed effects controls for persistent effects of rainfall on the localities (and households) in which children are born. Effects of rainfall shocks on long-run income of households should be common to all individuals born in the same area and so should be absorbed by the district-season fixed effects.

Rainfall in one's birth year and birth district has a positive relationship with health, educational, and socioeconomic status outcomes in adulthood. A graphical view of some of the key relationships is presented in the form of nonparametric Fan regression plots in Figure 1. Panel A examines the nonparametric relationship between early-life rainfall (on the horizontal axis) and adult height (on the vertical axis). Panels B, C, and D are similar except that the variables on the vertical axes are self-reported poor/very poor health status, completed grades of schooling, and the household asset index, respectively.⁸ In each figure, the positive relationship between early-life rainfall and the adult outcome is quite apparent.

When discussing the magnitude of estimated effects, we focus on the impact of a 0.2 log point change in the rainfall variable (deviation of log rainfall from the log of district mean rainfall).

⁷ Using African data, Elsa Artadi (2005) finds that parents time births across seasons in response to seasonality in economic conditions and disease prevalence.

⁸ Variables on the vertical and horizontal axes are partialled-out (residuals) with respect to the full set of fixed effects and time trends in equation (3). The graphs use a nonparametric Fan local regression method with a quartic (biweight) kernel and a bandwidth of 0.5. Dashed lines depict bootstrapped 95 percent confidence intervals.

The standard deviation of the residual is 0.2 when the rainfall variable is regressed on the full set of fixed effects and district-season linear time trends in equation (3), and is smaller than the standard deviation of the unadjusted rainfall variable reported in Table 1 because it is purged of cross-district variation, over-time variation, and district season-specific linear trends.

First-stage regressions predicting birth year/birth district rainfall are reported in the online Appendix, and indicate, as expected, that there is a positive and statistically significant relationship between each of the instruments (rainfall in the second- to fifth-closest districts) and rainfall in the closest district. The instruments are strong vis-à-vis conventional thresholds used in instrumental variables estimation (John Bound, David A. Jaeger, and Regina Baker 1995; James H. Stock and Motohiro Yogo 2005): in the first stage regression for women, the test of the joint significance of the instruments yields an F -statistic of 31.61, and for men the corresponding statistic is 28.80.

The instrumental variables results from estimation of equation (3) are presented in Table 2. For each outcome, the coefficient on (instrumented) birth year rainfall is presented for women (first column) and men (second column). Standard errors are presented in parentheses, and the sample size of the regression is in brackets. Coefficients for the many fixed effects and district-season linear time trends are not shown.

In the female sample, birth year rainfall has a positive impact on health, education, and socioeconomic status. Higher birth year rainfall leads to a higher propensity to report “very good” health status, a lower propensity to report “poor” or “very poor” health status, greater height in centimeters, and fewer days absent due to illness. Coefficients in three of the five health regressions (height as well as both indicators for self-reported health status) are statistically significantly different from zero at conventional levels. The coefficient in the log lung capacity regression is negative but is small in magnitude and is not statistically significantly different from zero.

The coefficient on birth year rainfall in the regression for completed grades of schooling is positive and statistically significant at the 5 percent level. Birth year rainfall also affects women’s adult socioeconomic status: it has a positive relationship with natural log household expenditures per capita, an asset index, and natural log annual earnings. The coefficient in the regression for the asset index is statistically significantly different from zero at the 5 percent level. The coefficients on birth year rainfall across the nine separate regressions are also jointly statistically significantly different from zero; a test for joint significance across the regressions has an F -statistic of 4.93 (p -value 0.000).⁹

Corresponding results for Indonesian men born in the same time span are presented in the second column. In stark contrast, there is little indication that the adult health, education, or socioeconomic status of males are affected by birth year rainfall. Most coefficients on the rainfall variables in all regressions are smaller in magnitude than the corresponding coefficients in the female regressions, and none is statistically significantly different from zero. Neither are the coefficients jointly statistically significant: a test for joint significance across the regressions has an F -statistic of 0.68 (p -value 0.731).

How large are these effects? A 0.2 log point increase in birth year rainfall leads women to be 3.8 percentage points less likely to report poor or very poor health status (compared to the base reporting propensity of 12 percent). Such an increase in birth year rainfall also leads women to have 0.57 centimeters greater height, to have attained 0.22 more completed grades of schooling, and to live in households that score 0.175 higher (0.12 standard deviation) on the asset index.

⁹ Online Appendix Table 2 reports OLS estimates that correspond to Table 2’s results, and the patterns are very similar, although (as expected) the OLS coefficients are attenuated toward zero.

V. Discussion and Additional Results

Here we extend the previous analysis to examine the relationship between rainfall in other years (before and after the birth year) and long-run outcomes. In addition, we refer to previous results and conduct additional regression analyses to provide suggestive evidence on the likely pathways through which early-life rainfall affects adult socioeconomic status.

A. *Effects of Shocks before and after the Birth Year*

The regression results thus far have focused on the relationship between rainfall in the birth year and adult outcomes. Teasing out the causal impacts of nutritional shocks at different points in the life cycle is difficult given the strong correlation of deprivation across the vulnerable periods in the life cycle (Glewwe and King 2001). In research on child nutrition, the idea that environmental conditions in a certain sensitive period of life may have long-run, irreversible effects is known as “critical-period programming.” The “fetal origins hypothesis” stresses that nutritional deprivation in utero permanently reduces body size in adulthood, while the effect of nutritional deprivation in later periods is more muted (Barker 1998, including citations on other related papers).¹⁰ More recent studies have argued that the period after weaning from breast milk until age 24–36 months may also be “critical,” as protection from the mother during pregnancy and breast-feeding ends. Glewwe and King (2001) document that malnutrition between one and two years (versus the first year of life) has a stronger relationship with cognitive development in the Philippines. Hodinott and Kinsey (2001) also find that physical growth falters between one and two years of age for cohorts born during a drought in rural Zimbabwe, but not for cohorts who were between two and five years old at the time (they do not examine the fetal stage and the first year of life). The potential for an individual stunted in the first few years of life to catch up is limited (Martorell 1995).

In this paper, we are able to estimate the impact of exogenous shocks at various points in early life to compare their impacts on outcomes in adulthood. Given the findings in previous studies, the results in Table 2 leave open the possibility that it is not rainfall in the birth year per se that matters for adult outcomes. If rainfall is serially correlated over time, then it could be that rainfall in some year before or after the birth year has the actual impact on adult outcomes. If so, the coefficients on birth year rainfall in regressions in Table 2 might simply reflect the fact that other years’ rainfall were not included in the regressions (an omitted variable problem).

Therefore, we report regression results in Table 3 where each regression includes annual rainfall variables from years -3 (three years prior to the birth year) to 3 (three years after the birth year), including birth year rainfall (year 0). These variables are defined analogously to the birth year rainfall variable as 12-month rainfall during complete wet and dry seasons. The dependent variables are for several key outcomes from previous tables: both self-reported health status indicators, height, completed grades of schooling, and the asset index.

Two facts stand out in these regression results. First, coefficients on birth year rainfall (year 0) are not substantially different from the corresponding coefficients in Table 2. The coefficients in the regressions for height and schooling have become slightly larger in magnitude, while in the other regressions the coefficients are only slightly smaller. Standard errors have risen somewhat, so levels of statistical significance are somewhat lower (the coefficient in the self-reported very good health status regression is no longer statistically significant at conventional levels, while the one in the self-reported poor health status regression is now significant at just the 10 percent

¹⁰ Economic studies highlighting the long-run impact of conditions in utero include Almond (2006) and Behrman and Rosenzweig (2004).

TABLE 2—EFFECT OF BIRTH YEAR RAINFALL ON ADULT OUTCOMES: WOMEN AND MEN BORN 1953–1974
(Instrumental variables estimates. Coefficients (standard errors) in regression of outcome on rainfall in individual's birth year and birth district. Instrumental variables for birth year/birth district rainfall are rainfall measured at second-through fifth-closest rainfall stations to respondent's birth district.)

	Women	Men
Self-reported health status very good (indicator)	0.101 (0.058)* [4,613]	−0.029 (0.072) [4,270]
Self-reported health status poor/very poor (indicator)	−0.192 (0.082)** [4,613]	−0.100 (0.098) [4,270]
Ln (lung capacity)	−0.044 (0.049) [4,454]	−0.073 (0.062) [3,907]
Height (centimeters)	2.832 (0.821)*** [4,495]	0.998 (1.795) [3,924]
Days absent due to illness (last four weeks)	−1.175 (0.831) [4,611]	0.515 (0.779) [4,267]
Completed grades of schooling	1.086 (0.453)** [4,598]	−0.474 (1.490) [4,259]
Ln (expenditures per capita in household)	0.095 (0.204) [4,615]	−0.274 (0.301) [4,277]
Asset index	0.876 (0.324)** [4,613]	−0.279 (0.507) [4,276]
Ln (annual earnings)	0.065 (0.988) [2,332]	−0.202 (0.350) [3,963]

Notes: Number of observations in brackets. Sample is individuals born outside of urban areas between 1953 and 1974 inclusive, observed in year 2000. "Urban areas" are cities with 50,000 or more inhabitants in 1930. Each coefficient (standard error) is from a separate regression of the dependent variable on birth year rainfall (deviation of log rainfall in birth district from log of 1953–1999 district mean rainfall). Standard errors clustered by province of birth. All regressions include fixed effects for birth year–season, birth district–season, and birth district–season-specific linear time trends. Asset index is first principal component of five asset variables (log total value of household assets and indicators for ownership of television, refrigerator, private toilet, and stove).

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

level). The fact that coefficients on birth year rainfall are largely unchanged after inclusion in the regressions of rainfall in adjacent years indicates that birth year rainfall matters in and of itself, and not simply because it may be correlated with other years' rainfall.

Second, in each regression, the coefficients on rainfall in adjacent years are all smaller in magnitude than the coefficient on birth year rainfall, and in most cases substantially smaller. Across regressions, not one of the 30 coefficients on rainfall in adjacent years is statistically significantly different from zero. For all the regressions of Table 3, tests of the joint significance of rainfall in the years -1 , -2 , and -3 together, and in years 1 , 2 , and 3 together, do not reject the hypothesis that the coefficients on early-life rainfall in those groups of years are jointly insignificantly different from zero at conventional levels.

The lack of an effect of rainfall in the years prior to the birth year provides no indication that shocks in utero are importantly influencing our results, in comparison to shocks experienced in infancy. The variable for birth year rainfall is defined to potentially include a few months of rainfall prior to birth (as far back as the start of one's birth season), but because harvests typically

TABLE 3—EFFECT OF RAINFALL IN YEARS BEFORE AND AFTER BIRTH: WOMEN BORN 1953–1974
(Instrumental variables estimates. Rainfall in individual's birth year and birth district instrumented with rainfall measured at second- through fifth-closest rainfall stations to respondent's birth district.)

Dependent variable	Self-reported health status very good (indicator)	Self-reported health status poor/very poor (indicator)	Height (centimeters)	Completed grades of schooling	Asset index
Coefficient on rainfall in:					
Year -3	0.025 (0.084)	-0.114 (0.120)	1.505 (1.572)	-0.065 (0.992)	0.003 (0.424)
Year -2	-0.037 (0.103)	-0.013 (0.075)	0.854 (1.813)	-0.852 (1.670)	-0.426 (0.721)
Year -1	-0.080 (0.123)	-0.045 (0.088)	3.338 (2.155)	0.104 (1.332)	-0.380 (0.530)
Year 0	0.090 (0.067)	-0.179 (0.093)*	3.833 (1.420)**	1.598 (0.675)**	0.750 (0.399)*
Year 1	-0.008 (0.053)	-0.096 (0.067)	0.676 (1.592)	1.083 (0.769)	0.203 (0.272)
Year 2	-0.041 (0.043)	-0.015 (0.068)	1.666 (0.984)	0.117 (0.840)	-0.229 (0.452)
Year 3	-0.020 (0.116)	-0.104 (0.067)	1.996 (1.774)	-0.135 (0.802)	0.088 (0.232)
Observations	4,613	4,613	4,495	4,598	4,613

Notes: Each column presents coefficients (standard errors) from a separate regression of the dependent variable on various years' rainfall (deviation of log rainfall from log of 1953–1999 district mean rainfall). Year 0 is birth year, year -1 is year prior to birth year, year 1 is year after birth year, etc. All regressions include fixed effects for birth year–season, birth district–season, and birth district–season-specific linear time trends. See Table 2 for notes on sample composition and variable definitions.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

occur at the end of seasons, birth year rainfall is best thought of as affecting postbirth household income. This finding may be taken as supporting evidence for the hypothesis that gender bias in household resource allocation explains why only girls' long-run outcomes are affected by birth year rainfall. In the absence of technologies for determining a child's gender in the womb, discrimination cannot take place until after birth and the gender of the child is revealed.

While these results confirm that a rainfall shock during the first year of life has the most important influence on women's long-run outcomes, it may be that the nutritional deprivation that follows is in the postweaning period (roughly the second year of life). This is because there is likely to be a lag between negative rainfall shocks and the resulting nutritional deprivation, for several reasons. First, the declines in crop output due to a drought will occur only at harvest time, some months later. Second, food scarcity after a drought tends to peak just before the harvest that follows the drought-diminished harvest. Third, households may have stores of food, and so may have some ability to delay the period of diminishing nutrition following a drought-related fall in farm output. So our results could very well be consistent with the importance placed on the postweaning period in the existing literature, if indeed drought-associated malnutrition in Indonesia occurs with a lag of a year or so.

B. The Initial Effect of Early-Life Rainfall

It is most plausible that the *initial* direct effect of birth year rainfall is on the health of infant girls. For early-life shocks to have long-run effects on individuals, they must affect some characteristic of individuals that persists over time. The results in Table 3 indicate that the effect of birth

year rainfall on adult female outcomes is essentially unchanged when controlling for rainfall in subsequent years, and rainfall variables in subsequent years have little or no relationship with adult female outcomes. The only persistent characteristics of individuals that could plausibly be thought to be determined in the birth year are those having to do with their health human capital: crucial stages in physical development occur in infancy that can have long-lasting health consequences (critical-period programming).

The strong relationship that we document between birth year rainfall and various adult health outcomes supports the notion that health investments in infancy vary with early-life rainfall. In particular, the impact of birth year rainfall on adult height is telling. It is well known that nutritional deprivation in early life can result in stunting that persists into adulthood. Indeed, adult height has been taken to reflect early-life resource availability in numerous economic studies at the micro and macro levels, as in, for example, John Strauss and Thomas (1998), Richard H. Steckel (1995), Robert Fogel (1994), and T. Paul Schultz (2002 and 2005).

By contrast, it is implausible to think that the initial direct effect of birth year rainfall is on some nonhealth-related aspect of human capital, such as schooling. School entry does not start until several years after birth, so one would have to imagine that rainfall was highly serially correlated and that the coefficient on birth year rainfall was picking up the effect of rainfall nearer the year of school entry. But if this hypothesis were true, then the coefficient on birth year rainfall in the completed grades of schooling regression should decline in magnitude when rainfall in subsequent years is included in the regression, and coefficients on rainfall in subsequent years should be positive and statistically significantly different from zero. In fact, Table 3 shows that the opposite is true: the coefficient on birth year rainfall changes little (compared to Table 2) when controlling for rainfall in subsequent years, and rainfall variables in subsequent years have no statistically significant effects on completed grades of schooling. Therefore, the reduced-form effect that we find of birth year rainfall on completed grades of schooling is most likely mediated by birth year rainfall's effects on infant health that persist until one's school years.

C. Subsequent Pathways to Adult Socioeconomic Status

If the initial direct impact of early-life rainfall is on the health of infant girls, how do these infant health impacts eventually affect adult women's socioeconomic status? We provide suggestive regression-based evidence here on subsequent pathways, focusing on the roles of adult health and education in influencing eventual adult socioeconomic status (as measured by the asset index). In principle, early-life rainfall affects infant health, which in turn affects educational achievement and adult health. Adult health and educational achievement can then have direct effects on adult socioeconomic status.

The approach we use involves regressing the asset index on birth year rainfall for the female sample, and then successively including as controls key variables representing adult health and educational human capital. We then compare results across specifications to gain insight on the intermediate pathways that are operative. If inclusion of a set of variables X leads to declines in the coefficient on birth year rainfall and substantial increases in R -squared, this would suggest that the variables in X represent an important pathway toward adult socioeconomic status. In addition, if inclusion of a set of control variables X causes coefficients on other control variables Y to decline in magnitude and statistical significance, this would suggest that some part of Y 's effects on adult socioeconomic status may be occurring via Y 's effects on X . Without question, these regressions are open to potential concerns about omitted variables, data quality, and reverse causality. The results should therefore only be taken as suggestive.

Regression estimates are presented in Table 4. In all regressions, we include only observations with complete data on all control variables. We first present the baseline regression without

controls in the first column. As in Table 2, the coefficient on birth year rainfall, 0.762, is positive and statistically significant at the 5 percent level.

In columns 2 and 3, the control variables for health and education (respectively) are included in the regression. Some subset of these variables enters significantly into the regressions, and with the expected signs. But the effects of these different variable groups on the coefficient on birth year rainfall and on R -squared differ. The largest effects come from inclusion of the completed years of education variable in column 3. Its inclusion leads the coefficient on birth year rainfall to decline in magnitude by roughly one-quarter (to 0.566), while R -squared rises from 0.33 to 0.48. Inclusion of the health variables by themselves (column 2) leads to a smaller decline in the magnitude of the birth year rainfall coefficient, to 0.660, and a negligible increase in R -squared to 0.34.

In column 4, both types of control variables are included in the regression. Unsurprisingly, coefficient estimates on all the control variables become smaller in magnitude and generally see declines in their levels of statistical significance. The largest effect is on the health variables: two coefficients that were previously (in column 2) large in magnitude and statistically significant (on lung capacity and height) have become much closer to zero, and one coefficient (on lung capacity) in column 4 is no longer statistically significant. The health coefficient that remains statistically significant in column 4, that on height, has declined in magnitude by more than two-fifths (from 0.028 to 0.016). By contrast, the statistically significant coefficient on completed grades of schooling in column 3 is essentially unchanged (declining only marginally from 0.173 to 0.170) in column 4, and remains statistically significant at the 1 percent level. It is also telling that between columns 3 and 4, the coefficient on birth year rainfall does not decline much further (only from 0.566 to 0.505), and R -squared remains stable at 0.48. All told, these results provide suggestive evidence that educational attainment is the more important intervening pathway between birth year rainfall and adult socioeconomic status.

D. Additional Analyses and Robustness Checks

Supplementary analyses available in the online Appendix help confirm the robustness of the empirical results. First of all, the OLS version of Table 2's IV results shows very similar patterns (online Appendix Table 2). Coefficients on birth year rainfall in the IV regressions are also statistically significantly different from zero in OLS. In addition, in the OLS results birth year rainfall also enters statistically significantly in the regressions for self-reported very good health status and for log expenditures per capita in the household. The main difference is that OLS coefficient estimates are mostly attenuated toward zero compared to the IV estimates.

It is important to consider whether selection into our sample might confound the results. To help rule out selection concerns, we show that rainfall shocks have no statistically significant relationship with the size of birth district–birth year–season cohorts in the IFLS (Appendix Table 3).¹¹ While it may seem surprising that we do not find that birth year rainfall affects the cohort sizes in the data (given the effects on adult health and other outcomes documented above), this result is consistent with other studies that examine population gender ratios and find little evidence of “missing girls” in Indonesia either today or in past decades (Michael Kevane and Levine 2001; United Nations 2001). Gender bias in the allocation of household resources may simply not be extreme enough in Indonesia for fluctuations in girls' nutrition to lead to differential mortality in drought years.

¹¹ Consistent with these results, we also find that subsequent migration out of one's birth province has no statistically significant relationship with the individual's birth year rainfall, either for women or men (results available from authors on request).

TABLE 4—CONTROLLING FOR CHANNELS LINKING EARLY-LIFE RAINFALL TO ADULT OUTCOMES: WOMEN BORN 1953–1974

(Instrumental variables estimates. Rainfall in individual's birth year and birth district instrumented with rainfall measured at second- through fifth-closest rainfall stations to respondent's birth district.)

Dependent variable	Asset index			
Deviation of log rainfall from norm, year of birth	0.762 (0.331)**	0.660 (0.313)**	0.566 (0.303)*	0.505 (0.293)*
Self-reported health status very good (indicator)		0.018 (0.085)		0.037 (0.096)
Self-reported health status poor/very poor (indicator)		-0.084 (0.065)		-0.018 (0.063)
Log lung capacity		0.365 (0.122)***		0.015 (0.104)
Height (centimeters)		0.028 (0.006)***		0.016 (0.004)***
Days absent due to illness (last four weeks)		-0.008 (0.009)		-0.006 (0.009)
Completed grades of schooling			0.173 (0.007)***	0.170 (0.006)***
Observations	4,436	4,436	4,436	4,436
R^2	0.33	0.34	0.48	0.48

Notes: Each column presents coefficients (standard errors) from a separate regression. See Table 2 for notes on sample composition and variable definitions.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

In addition, to alleviate concern over positive selection of *parents* of sample individuals who are born in good rainfall years, we show that there is no statistically significant relationship between a person's birth year rainfall and the characteristics of his or her parents (online Appendix Table 4).

Finally, as a robustness check, we run regressions analogous to those in Table 2, but this time for the sample of individuals born in urban areas (areas with a population greater than 50,000 in the 1930 census). Results are in online Appendix Table 5. For those born in more urban areas, the results reveal little relationship between early-life rainfall and adult outcomes (and, if anything, a negative relationship for some outcomes). The two regressions that yield statistically significant coefficients on birth year rainfall are the regression for $\ln(\text{lung capacity})$ for women and days absent due to illness for men, where coefficients are significant at the 10 percent level and with signs implying negative effects of birth year rainfall (higher birth year rainfall leads to lower lung capacity for women and more days absent due to illness for men). The urban results may reflect that rainfall has a negative impact on early-life environmental conditions in urban areas, perhaps via increases in water-borne diseases or in those carried by mosquitoes. It is possible that such negative health effects also occur among individuals born in rural areas (those analyzed in the main paper), but these negative impacts are more than offset by the positive impact of rainfall on rural household incomes. Of course, this interpretation needs to be made with caution, because only 2 out of 18 coefficients are statistically significantly different from zero and thus the results could simply be due to sampling variation.

E. Magnitude of the Effects

One way to put our results in context is to compare the estimated impact of a moderate positive rainfall shock on adult outcomes with the impact of specific development interventions. In

terms of impacts on schooling, the benefits of higher rainfall are on par with the effects of direct educational interventions. Perhaps most relevant for this paper, Esther Duflo (2001) documents the impact of building 61,000 primary schools in Indonesia between 1974 and 1978, around the time the youngest women in our IFLS sample were born. Each new primary school built per 1,000 children increased years of schooling by 0.12–0.19, on average. Outside of the Indonesian context, Grant Miller (2007) finds that a family planning program in Colombia raised women's education by 0.15 years by delaying age at first birth.

These schooling impacts are similar in magnitude to the impact of 20 percent higher rainfall in the year and location of birth, which we estimate in this paper to be 0.22 years. Of course, the total welfare impact of higher birth year rainfall on Indonesian women would also include direct effects on other outcomes, such as adult health.

The estimate of rainfall's effects can also be used to estimate the net present value of the future costs to Indonesia of having a unusually dry rainy season. These calculations require a number of assumptions and so should be interpreted with considerable caution. Nonetheless, it is useful to gauge the magnitude of the consequences of a year of poor rainfall.

For the purpose of this calculation, we focus on the impact on schooling and assume that it generates increases in earnings as estimated in other work on the impact of schooling on wages in Indonesia (Duflo 2001), ignoring the other channels (e.g., adult health) through which rainfall has long run effects (so this will underestimate the total effect). We consider the cohort at the midpoint of our sample of birth years, the 1963 cohort. We discount the future costs back to 1963 in order to compare the figure with Indonesia's GDP in that year.

Detailed assumptions and a description of the calculation are provided in the online Appendix, but we provide an outline here. To calculate the net present value (in 1963) of a year of poor rainfall for the cohort born in that year, we start with the number of women born in 1963 who are living in rural areas in the 1971 Indonesian census (about 1.6 million). Our goal is to track this cohort's earnings over time, and calculate the net present value of the decline in earnings associated with 0.2 lower log rainfall. We assume that the women work from age 16 to 65 (years 1979 to 2028). Some of these women will migrate to urban areas, and so we allow earnings to vary across rural and urban areas and over time.

We use actual census data on rural women born in 1963 in a series of Indonesian censuses, alongside calculations and assumptions regarding female mortality rates over time to estimate the number still living in each year and their apportionment across rural and urban areas. We then assign individual earning levels for women in this rural 1963 birth cohort in each year from 1979 to 2028, allowing annual earnings to vary across rural and urban areas by making assumptions as to the labor share of GDP, its apportionment across rural and urban areas, and rural versus urban population trends. Combined with estimates of the cohort's size in rural and urban areas, this allows us to calculate total earnings for the 1963 rural female birth cohort over their entire assumed working lives, 1979–2028.

We then consider the impact of 0.2 lower log rainfall in the birth year for this cohort. Our estimates indicate that rainfall lower by this amount leads to 0.22 fewer years of schooling. Duflo's (2001) midpoint estimate is that each year of schooling raises wages by 8.7 percent, so 0.22 fewer years of schooling would lower wages by 1.9 percent. We therefore multiply total earnings in each year by 1.9 percent to get total lost earnings associated with 0.2 lower birth year rainfall, and discount each amount back to 1963 (using a 5 percent discount rate). The sum of these figures across years is the net present value of lost future wages due to 0.2 lower log rainfall in the birth year.

The net present value in 1963 is \$77.3 million (in 2000 US dollars). This amount equals 0.4 percent of Indonesia's GDP in 1963. This number suggests that if some way could have been found to shield female infants born in that year from suffering the nutritional deprivation

and other negative effects of low rainfall, it would have been worth spending 0.4 percent of Indonesian GDP at that time to do so.

An additional use of this \$77.3 million estimate is to divide it by the number of infants born in 1963. It is not known how many infants were born in 1963, but we can start with the 1,581,963 rural females reported in the 1971 census and project backward using relevant infant and child mortality rates to estimate the initial 1963 birth cohort size. We estimate that 1,817,350 rural female infants were born in 1963. Dividing the \$77.3 million cost estimate by this number obtains a figure of \$43 per female infant born in rural Indonesia in 1963. This number represents the highest amount it would have been cost-effective to spend on each female infant born in rural areas on an intervention that shielded them from the impacts of log rainfall 0.2 lower than the norm. This amount is nontrivial, amounting to 21.8 percent of Indonesian per capita GDP in 1963.

VI. Conclusion

This paper finds that the long-run well-being of Indonesian women is highly sensitive to the environmental conditions they experienced early in life. We examine the effect of rainfall variation around the time of birth on the health, education, and socioeconomic outcomes of Indonesian adults born between 1953 and 1974. Higher early-life rainfall has positive effects on the adult outcomes of women, but not of men, which may reflect gender biases in household resource allocation. Women with 20 percent higher rainfall in their year and location of birth are 3.8 percentage points less likely to self-report poor or very poor health, attain 0.57 centimeters greater height, attain 0.22 more completed grades of schooling, and live in households that score 0.12 standard deviations higher on an asset index.

The most plausible explanation for these results, suggested by the patterns in our data, is that rainfall has a positive impact on agricultural output, and leads to higher household incomes and therefore better health for infant girls. Eventual benefits for adult women's socioeconomic status appear to be mediated more strongly by improved schooling attainment, and not as importantly by women's adult health.

These results also relate to a substantial literature in development economics that documents household efforts to smooth consumption in the face of idiosyncratic shocks via transfers among geographically dispersed kin networks (Rosenzweig 1993; Rosenzweig and Oded Stark 1989) or via asset accumulation and drawdown over time (Rosenzweig and Kenneth I. Wolpin 1993). The evidence in this paper of long-term effects of local weather shocks should not be taken to imply that consumption smoothing mechanisms were not operative in rural areas in Indonesia during the time our study population was born. Rather, this paper's results suggest that any consumption smoothing mechanisms were only partial: they were not able to completely shield female infants from the impacts of weather shocks on average.¹²

These results have important implications for policy. Our findings point to a group—infant girls—that is particularly vulnerable to fluctuations in economic and environmental conditions. The long-run effects of early-life conditions on health, schooling, and socioeconomic outcomes several decades later should be factored into cost-benefit analyses of programs targeting this subpopulation. As such, our findings provide additional justification for interventions—such as weather insurance, social insurance schemes, public health investments, or policies ensuring food security—that shield infants from the health consequences of temporary environmental and economic shocks.

¹² Existing research provides evidence of incomplete consumption smoothing in Indonesia. Gertler and Jonathan Gruber (2002) find that families are not able to fully insure consumption over periods of major illness, while David Newhouse (2005) documents the persistence of transient income shocks.

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