Articles

Welfare Dependence Within and Across Generations

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A central question in the debate about the effects of welfare programs is whether their intended positive results—providing needed resources to recipients and their children—outweigh any unintended negative results—for example, the breaking up of families, reduction in work effort, or the fostering of a welfare "culture" that is passed on from parent to child. Recent research shows that although work effort is affected adversely by the generosity of welfare programs, effects on family structure appear quite weak, most welfare experiences are relatively short, and the majority of women who grew up in homes heavily dependent on welfare do not rely on those programs when they are young adults.

FEW SOCIAL ISSUES GENERATE MORE CONCERN AND DEBATE than the question of how our country should assist its poorest citizens. During the past several decades, growth in total spending on assistance programs, in the number of families headed by women, and in the perceived size of the urban "underclass" has combined with stubbornly persistent poverty rates, especially among children, to fuel speculation that the assistance programs themselves are responsible for such trends. In his 1986 State of the Union Address, President Reagan charged that poverty programs have created "a spider web of dependency," fostering a welfare culture in which the "breakdown of the family . . . has reached crisis proportions" (*1*).

Many programs that provide benefits to families with low incomes and assets fall under the "welfare" rubric. Our focus is on the best known and most criticized program: Aid to Families with Dependent Children (AFDC). The AFDC program offers assistance to families with children, primarily those families headed by a single parent (usually the mother). States have considerable freedom in setting benefit levels and other program features; this results in maximum monthly grants varying (in January 1987 for a family of four) from $144 in Mississippi to $706 in New York. Some states extend AFDC benefits to two-parent families in which the principal wage earner is unemployed, but these instances amount to a small percentage of the total caseload. In 1986, expenditures on AFDC totaled nearly $18 billion, and payments were received by 3.8 million families.

The argument that welfare fosters dependence arises from two concerns: (i) that the welfare system alters the choices people face and encourages them to behave in ways that increase their likelihood of receipt; and (ii) that the welfare system fosters a welfare culture by creating dependence and discouraging self-sufficiency in both recipient parents and their children. Either or both may result in welfare having adverse effects on childbearing, marital and family ties, and work effort. Counterbalancing this negative view is the idea that welfare is an investment in children that provides additional resources to parents to improve the health and enhance the education of their children.

In this article, we examine the issues involved in the welfare debate, using a number of recent studies on AFDC receipt within and across generations. A decade ago there were virtually no sources of nationally representative information on long-run welfare experiences, but now there are several. The primary sources include longitudinal survey studies that have followed nationally representative samples of both recipients and nonrecipients and their children for 15 or more years. Others draw their data from welfare caseload records.

In summarizing the current state of knowledge about each of these issues, we first discuss patterns of welfare receipt, turn next to findings on the effects of welfare on behavior, attitudes, and values, and conclude with evidence about the effects of welfare on the attainments of children.

Patterns of Welfare Receipt

Some case studies of families receiving welfare provide vivid and memorable accounts of long-term dependence. But such case studies are selected to illustrate an instance of long-term dependence. Whether they represent the experiences of typical recipients is an issue that needs to be addressed first of all. If most welfare receipt is long term, then the issue of welfare dependence arises, and it is important to determine whether the welfare system itself plays any causal role in creating that dependence. But if most people ever receiving welfare do so for only a short time, then the welfare system might better be regarded as providing most recipients with short-term insurance against income losses, such as those resulting from unemployment or divorce.

Estimates of total time on welfare can be calculated either for all individuals who ever received welfare or for individuals on welfare at a given point in time (*2*). Table 1 shows the distribution of time on AFDC for individuals who first entered the welfare rolls between the mid-1960s and the late 1970s, a sample of "ever on" recipients. The estimates of total time on welfare indicate that about 30 percent of recipients received welfare for 1 or 2 years, and a similar proportion had eight or more total years of receipt. The median length of receipt was less than 4 years. Clearly, long-term welfare usage characterizes only a minority of recipients.

Table 1 also shows results for a point-in-time sample that presents a very different picture of the typical pattern of receipt. Very short

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Table 1. Distribution of length of total time on AFDC. The data are compiled from Ellwood (*2*) and are based on 736 welfare spells observed in the Panel Study of Income Dynamics (*23*).

Time (years)	Persons ever on AFDC (%)	Persons on AFDC at a given time (%)
1 to 2	30	7
3 to 7	40	28
≥8	30	65
Total	100	100

periods of receipt characterize 7 percent of point-in-time recipients, whereas nearly two-thirds are in the midst of long-term welfare usage, totaling eight or more years. Thus longer term recipients account for the bulk of individuals receiving welfare at a particular time.

While the large difference between the two methods of calculation may seem paradoxical, it is easily explained and, indeed, is characteristic of other phenomena such as poverty, unemployment, or hospitalization. The difference occurs because the probability of being in a given status (for example, on welfare) at any point in time is necessarily higher for individuals who occupy that status longer. Thus, point-in-time samples of welfare recipients yield biased information on the typical experiences of welfare recipients.

Welfare experiences differ markedly among different AFDC recipients. For example, among the recipients who when first on AFDC were 25 years of age or older and had previous work experience and a high school degree, fewer than one in seven eventually received AFDC for as many as 9 years (*3*). On the other hand, total duration of welfare receipt is quite long for younger, never-married recipients. More than 40 percent of the never-married women with young children who first received AFDC before age 25 received it for nine or more years. Whether welfare plays a much less benign role in affecting the behavior and attitudes of this latter set of women is a crucial, and as yet largely unanswered, question.

The economic position of women before and after their periods of welfare receipt is quite diverse (*4*). Divorce is the most common event associated with the beginning of a period of receipt, typically drawing women whose predivorce family incomes were in the bottom half of the income distribution. A substantial minority of women who stop receiving welfare have incomes below the poverty level at least once in the years following receipt; such poverty experiences are especially prevalent among women who stopped receiving welfare because their families no longer contained minor children.

Does Welfare Affect Behavior?

That many brushes with the welfare system are short-lived indicates that receiving welfare does not lead inevitably to long-term dependence. However, to assess the welfare system properly, one needs to go beyond descriptive evidence on patterns of usage and consider whether the welfare system itself adversely affects the work, family structure, and other behavior of recipients and their children, particularly the minority who are long-term recipients. Consider, for example, the types of events that initiate periods of welfare usage. Most involve changes in family structure, with divorces and separations accounting for nearly half and out-of-wedlock births accounting for one-third of all beginnings of periods of welfare receipt (*5*). If the availability or generosity of welfare causes these demographic events to occur more frequently, then concerns about adverse effects of welfare are bolstered, especially if the impact is substantial.

The evidence compiled to date on these behavioral effects suggests that welfare has little systematic impact on family structure, although it does indeed seem to reduce work effort.

Welfare and work hours. The economic theory of labor supply suggests that welfare programs such as AFDC should reduce the work effort of potential recipients. Such programs simultaneously increase unearned income and, by reducing benefits for added dollars of earned income, lower the recipient's net hourly wage rate.

Evidence consistently indicates that income transfer programs do indeed reduce labor supply, but estimates vary widely as to the size of the effect. According to one recent review of the evidence, AFDC reduces the average annual work effort among female heads of households by 180 hours (*6*).

Welfare and family structure. Because AFDC benefits are generally available only to women heading households with dependent children, they are alleged to encourage marital instability and illegitimate births, while discouraging marriage and remarriage.

The many studies of the possible effects of AFDC on family structure are not entirely conclusive. One of the most recent and comprehensive studies examines a lengthy list of family structure variables with several sources of data (*7*). Amounts of AFDC payments are found to have no measurable impact on births to unmarried women and only a modest effect on rates of divorce, separation, or female head-of-household status. The biggest impact is on a relatively unnoticed family decision—the living arrangements of single mothers. Living in a state with high AFDC benefit amounts raised the relative chances that young, unmarried mothers would be living independently rather than in the home of a parent. Thus AFDC appears to have its greatest impact on less (socially) significant decisions such as living arrangements, with no measurable impact on the most significant and far-reaching family decision—the birth of a child.

Does Welfare Affect Values and Attitudes?

Quite apart from possible effects on the relative attractiveness of work and family choices, welfare programs are also thought to induce dependence by changing the attitudes and values of recipients and their children. In this respect, arguments about a welfare "culture" share a great deal with theories of poverty "cultures" that attained prominence in the 1960s. Proponents of such cultural views held that the poor exhibit a number of psychological traits—weak sense of control over events, orientation toward the present rather than the future—and behaviors that leave them unable to take advantage of opportunities and keep them mired in poverty. Furthermore, these undesirable traits and behaviors are allegedly passed on from parent to child, perpetuating dependence across generations (*8*). These views regarding the poor in the 1960s have resurfaced in recent analyses of welfare recipients. Although rich with predictions, theories of welfare dependence that posit an important role for personality factors within and across generations are only beginning to be tested in a systematic way.

Attitudes and values of adults. In assessing the effects of welfare on adults, it is not enough to observe that the attitudes and values on long-term welfare recipients are somehow "worse" than those of other people. Although such attitudinal differences may indeed have been caused by welfare receipt, they may instead have preceded and caused the welfare receipt. Or it may be that both the psychological traits and the welfare receipt are caused by some other factor such as a disability or living in a high unemployment area.

A truly consistent linkage between welfare receipt and psychological characteristics would require meeting three criteria: (i) that recipients have measurably "worse" values and attitudes, (ii) that attitudes and values are affected adversely by the receipt of welfare,

and (iii) that the initially worse values and attitudes increase the likelihood of future dependence.

With nationally representative survey data, a number of researchers have attempted to identify attitudes that are changed by the receipt of welfare and that affect the likelihood of further receipt. Social-psychological measures available in these data sets include personal efficacy (the extent to which a person feels in control of events), orientation toward the future, and more basic achievement motives such as challenge, power, and affiliation.

The research has found evidence of a bivariate association between welfare and some negative attitudes of recipients. Women, especially white women, who receive income from welfare feel less in control of their lives and are less oriented toward the future than those not receiving welfare (*9*). But evidence from several studies, although not conclusive, shows no causal role for welfare in producing these attitudes; also these attitudes were not shown to affect subsequent economic success. There is no consistent evidence that experience with AFDC caused significant change in either sense of control or future orientation (*10*). In addition, women with lower initial scores on the psychological measures usually have subsequent welfare and labor market experiences indistinguishable from those of other women.

Intergenerational transmission of welfare dependence. There is great interest in possible intergenerational effects of welfare receipt—especially the extent to which children growing up in welfare-recipient households are themselves more likely to receive welfare when they become adults. Theories of poverty have often included an intergenerational component, and this has fostered beliefs of a similar process in welfare use. In his writings on the culture of poverty in the late 1960s, Lewis observed that slum children by age 6 or 7 "have usually absorbed the basic values and attitudes of their subculture and are not psychologically geared to take full advantage of the changing conditions or increased opportunities that may occur in their lifetime" (*11*).

In the debate over the culture-of-poverty theories, some scholars aligned themselves with either the cultural perspective or the structural perspective (*12*). The most extreme cultural view held that counterproductive values and attitudes of parents are passed to their children through early socialization and these persist into adulthood. A somewhat less deterministic cultural view not only extended the socialization role to the wider environment such as the neighborhood in which the children are raised and covers the entire childhood period, but also argued that these childhood experiences guide development into adulthood. In either case, to the extent that welfare processes are similar to poverty processes, the cultural perspective suggests an important role for a welfare "culture" in the values and attitudes of children raised in dependent homes.

The structural view of the relation between welfare dependence across generations holds that the values and attitudes of children being raised in dependent homes or in neighborhoods with high concentrations of welfare families are not significantly different from those of other children. Instead, according to this view, these children develop values and attitudes that are different from those of others when they later encounter the same kinds of structural impediments to jobs and marriages (such as discrimination or poor employment opportunities) that had blocked their parents.

The data needed to sort out cultural and structural explanations consist of measurements of attitudes and values, of welfare use, and of environmental conditions for both parents and children taken at several points in the children's lives, from birth to adulthood. Such data do not currently exist for the United States. Indeed only in the past several years have there been reliable measurements from a national sample of the simple associations between the welfare dependence of parents and their grown children. But even descriptive intergenerational information can help by providing a more accurate perspective for some of the graphic case studies of intergenerational dependence that periodically appear in the media.

Table 2. Intergenerational patterns of AFDC receipt (*23*).

Dependence of parents (%)	Dependence of daughters (%)				Unweighted number of cases
	No	Moderate	High	Total	
No	91	6	3	100	811
Moderate	62	22	16	100	127
High	64	16	20	100	147

Table 2 presents bivariate evidence on the intergenerational transmission of AFDC status; information from a 19-year longitudinal study of the economic fortunes of a large and representative sample of American families were used in the calculations. The subsample used for the figures presented in Table 2 consists of 1085 daughters whose parents' economic status was observed while the daughters were between the ages of 13 and 15; the economic status of the daughters was observed later, when they were between 21 and 23 years of age. The early teenage years are thought to be crucial for the socialization of children to adult roles and the formation of expectations that will guide future behavior, whereas the period between ages 21 and 23 should be indicative of the paths that the young women are following in early adulthood. For each of those two 3-year periods, "AFDC dependence" was defined according to whether AFDC income was reported in none of the years (no dependence), in 1 or 2 years (moderate), or in all 3 years (high). These categories are less precise than the terms may imply because of the sporadic nature of many families' welfare use.

Despite the impression given by case studies focusing on multigeneration welfare use, the majority of daughters who grew up in highly dependent homes did not share the fate of their parents. Only one out of five (20 percent) of the daughters from highly dependent parental families were themselves highly dependent on AFDC in their early 20s; more than three out of five (64 percent) of the daughters with dependent backgrounds received no AFDC during the 3-year period (*13*). The stereotype of heavy welfare dependence being routinely passed from mother to child is thus contradicted by these data. Indeed, the diversity of attainments of children from disadvantaged backgrounds emerging from these data shows up in other longitudinal data sources as well (*14*).

But at the same time, the data in Table 2 also show a higher incidence of dependence on welfare among women with welfare backgrounds. The fraction of daughters from highly dependent homes who themselves become highly dependent (20 percent) is much greater than the fraction of daughters from nonrecipient families who become highly dependent (only 3 percent) (*15*). And while more than three out of five of the daughters who grew up in AFDC-dependent homes received no AFDC themselves, more than nine-tenths of those who grew up in nonrecipient families received no AFDC in their early adult years.

An obvious problem in using these figures to draw inferences about intergenerational transmission of welfare dependence is that they fail to adjust for other aspects of parental background and environment that may also affect the likelihood of AFDC receipt. Children from AFDC-dependent homes generally have fewer parental resources available to them, live in worse neighborhoods, go to lower quality schools, and so forth. Any of these factors could have an effect on their chance of receiving AFDC that is independent of the effect of their parents' AFDC receipt.

Consider, for example, what happens when we apply the same types of demographic restrictions to daughters from nonrecipient

families that apply to most daughters from recipient families. If we look at daughters from low-income, nonrecipient parental families (income less than twice the official federal poverty line), the percentage highly dependent on welfare as adults rises to 7 percent, more than double the level for all daughters from nonrecipient families. The percentage dependent as adults doubles yet again, to 14 percent, if the sample is restricted to daughters having grown up in low-income, mother-only, nonrecipient families. Clearly the welfare dependence of these daughters as adults is affected by factors other than the welfare dependence of their parents, but, as yet, more elaborate attempts to estimate the extent to which welfare dependence is transmitted between generations controlling for other factors have been inconclusive (*16*).

Does Welfare Help or Hurt Children?

The more general intergenerational question is how income from welfare programs and other sources affects a variety of outcomes for children, such as their schooling, work effort, and career attainments. Children growing up in families with higher incomes appear to complete more schooling and gain higher paying jobs, even after taking account of differences in parental schooling and occupational attainment (*17*). Does income from welfare have a similar positive effect?

A handful of recent studies of the links between parental welfare receipt and the success of children based on nationally representative data found various effects on children's schooling, earnings, and work effort. Studies of the completed schooling of children and their adult hourly earnings found mixed evidence that welfare income was as beneficial as other sources of income (*18*). An investigation of the effects of parental welfare on the work effort of sons found no consistent effects (*19*). Not enough is known, but the recent availability of background information at both the family and neighborhood level promises to add greatly to our understanding of how these factors interact to affect children's lives.

Can Dependence Be Reduced?

An important question is whether anything can be done to reduce dependence on welfare, particularly among long-term recipients, who account for the bulk of expenditures. Since only about one in five AFDC recipients receives child support from an absent father, an obvious strategy is more rigorous enforcement of existing child support awards, although one estimate suggests this would reduce the number of AFDC recipients by only 5 percent. More ambitious schemes combining child support enforcement with guaranteed minimum support payments would reduce caseloads much more (*20*).

Other approaches include preventing the onset of AFDC receipt for likely long-term recipients and lessening the future dependence of current recipients. Programs aimed at preventing initial receipt (for example, by reducing the number of out-of-wedlock births or increasing the number of "at risk" children completing high school) have not proved consistently successful (*21*). However, there is mounting evidence that a variety of job search and training programs for long-term recipients have results that are cost-effective, although substantively modest.

The brevity of most AFDC experiences makes the task of evaluating intervention programs especially difficult. If directed at first-time applicants, even ineffective programs might appear successful since the duration of welfare use for many women is so short. Random assignment between treatment and control groups is crucial for a proper evaluation of intervention programs and has been incorporated into a number of job search and training programs (*22*). Taken together, these evaluations suggest that (i) both job search and training programs increase the employment and earnings of individuals participating in them relative to control-group individuals; (ii) the increases in employment and earnings are, however, modest (the fraction of individuals with jobs increases by 3 to 9 percentage points, and individuals' annual earnings increase by $100 to $600, the equivalent of 8 to 36 percent gains); (iii) programs directed at long-term recipient women are typically more successful than programs directed at unemployed men or at women with recent work experience; and (iv) programs administered in rural areas, particularly those areas with very high unemployment, are less successful than programs administered in more benign economic environments. A major open question concerns the relative benefits of lower cost job search programs versus more expensive training programs.

Concluding Remarks

The current debate over welfare programs generates strikingly different opinions about relative costs and benefits of public assistance. To what extent does welfare reduce recipient motivation to work or to marry, encourage recipients to have children, impair their attitudes, or otherwise trap them into dependence? How important are the benefits that result from welfare providing needed resources to low-income families?

Evidence on the nature of welfare experiences overall shows that a surprisingly large proportion of welfare experiences are only short-lived, that the typical total length of welfare receipt is less than 4 years, and that most children growing up in heavily dependent homes do not become heavily dependent as adults. Taken together, this evidence suggests that the welfare system does not foster reliance on welfare so much as it acts as insurance against temporary misfortune.

Although long-term recipients constitute a minority of all individuals who ever receive welfare, the fact that more than 2 million families are persistently dependent on welfare raises questions of whether welfare itself promotes divorce or out-of-wedlock births, discourages marriage, erodes work effort, or instills counterproductive attitudes and values that encourage reliance on welfare. Although welfare programs do indeed appear to reduce work effort to some extent, sparse evidence fails to show any connection between welfare and attitudes. As yet unresolved questions include the extent to which welfare affects family decisions and whether dependence during childhood, either within families or neighborhoods, creates dependence in adulthood.

REFERENCES AND NOTES

1. Transcript of President's speech to Congress on the State of the Union, *New York Times*, 5 February 1986, p. 10. That such concerns transcend ideology and time is reflected in Reagan's quotation from President Roosevelt's 1935 State of the Union Address: "Welfare is a narcotic, a subtle destroyer of the human spirit."
2. Estimates of total time on welfare are taken from D. Ellwood ["Targeting the would-be long-term recipient of AFDC: Who should be served?" (Mathematica Policy Research, Princeton, NJ, January 1986)]. They are simulations of the likely total number of years of receipt of welfare during the 25-year period following initial receipt. M. J. Bane and D. Ellwood ["The dynamics of dependence: The routes to self-sufficiency" (Urban Systems Research and Engineering, Cambridge, MA, 1983)] were the first researchers to cast welfare experiences in terms of completed periods of receipt and to develop many of the insights included in our discussion.
3. The estimates in this paragraph are from Ellwood (*2*, table IV.2).
4. Economic status after welfare receipt is analyzed by Bane and Ellwood (*2*) and C. Murray ["According to age: Longitudinal profiles of AFDC recipients and the poor by age group," paper prepared for the Working Seminar on the Family and American Welfare Policy, Washington, DC, September 1986]. The links between economic status, welfare receipt, and divorce are analyzed by G. Duncan and S.

Hoffman [in *Horizontal Equity, Uncertainty and Well-Being*, M. David and T. Smeeding, Eds. (Univ. of Chicago Press, Chicago, 1985), pp. 427–467].
5. Studies of distinct periods of welfare receipt include Bane and Ellwood (*2*); Ellwood (*2*); and J. O'Neill, D. Wolf, L. Bassi, and M. Hannan ["An analysis of time on welfare" (The Urban Institute, Washington, DC, June 1984)]. The figures for family-related events come from Bane and Ellwood (*2*).
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7. D. Ellwood and M. J. Bane, in *Research in Labor Economics*, R. Ehrenberg, Ed. (JAI Press, Greenwich, CT, 1985), vol. 7, pp. 137–207.
8. The debate on the cultural view is reviewed in J. T. Patterson, *America's Struggle Against Poverty 1900–1980* (Harvard Univ. Press, Cambridge, MA, 1981).
9. See, for example, M. S. Hill *et al.*, *Motivation and Economic Mobility* (ISR Research Report Series, Survey Research Center, Ann Arbor, MI, 1985), table 5.2.
10. These conclusions were reached in the two most comprehensive studies that use representative survey data—Hill *et al.* (*9*) and O'Neill *et al.* (*5*). Although the two studies agree in finding little consistent effect of efficacy and future orientation on subsequent success, there was some evidence in the Hill *et al.* study that the challenge motive (not measured in the O'Neill *et al.* study) did affect the subsequent success of black women and their children. The O'Neill *et al.* study found no evidence that experience with AFDC reduced either sense of control or future orientation; the Hill *et al.* study found marginally significant effects of AFDC receipt on changes in sense of control for white women.
11. O. Lewis, *La Vida, a Puerto Rican Family in the Culture of Poverty: San Juan and New York* (Panther Books, London, 1968), pp. 5–6.
12. The cultural and structural models of poverty are contrasted by J. House [in *Social Psychology: Sociological Perspectives*, M. Rosenberg and R. Turner, Eds. (Basic Books, New York, 1981), pp. 525–561].
13. Patterns in Table 2 are consistent with intergenerational information based on longer intervals and different definitions of dependence used by Hill *et al.* (*9*).
14. One notable example is a 17-year follow-up study of teenage mothers who grew up in a poor neighborhood in Baltimore, described by F. Furstenberg, Jr., J. Brooks-Gunn, and J. P. Morgan [*Adolescent Mothers in Later Life* (Cambridge Univ. Press, New York, 1987)].
15. This and all other differences cited in the text about the figures in Table 2 are statistically significant at the 5 percent probability level.
16. Hill *et al.* (*9*) and M. S. Hill and M. Ponza ["Does welfare dependence beget dependency?" (Institute for Social Research, University of Michigan, Ann Arbor, MI, 1984)] find insignificant effects, while S. McLanahan (*Demography*, in press) finds more significant effects.
17. This result has been obtained with a number of different intergenerational data sets that contain reliable measures of parental income; see, for example, W. Sewell and R. Hauser [*Education, Occupation and Earnings: Achievement in the Early Career* (Academic Press, New York, 1975)] and M. S. Hill and G. J. Duncan [*Soc. Sci. Res.* **16**, 39 (1987)].
18. Hill and Duncan (*17*) examine the effects of welfare on both completed schooling and wages, and S. McLanahan [*Am. J. Sociol.* **90**, 873 (1985)] focuses on schooling activities.
19. See Hill and Ponza (*16*).
20. See I. Garfinkel and S. McLanahan [*Single Mothers and Their Children* (The Urban Institute, Washington, DC, 1986)] and P. Robins [*Am. Econ. Rev.* **76**, 768 (1986)] for a discussion of the child support system and proposals for reform.
21. National Research Council Panel on Adolescent Pregnancy and Childbearing, *Risking the Future: Adolescent Sexuality, Pregnancy, and Childbearing* (National Academy Press, Washington, DC, 1987).
22. Findings from variety of such programs are reviewed in J. Gueron [*Work Initiatives for Welfare Recipients: Lessons from a Multi-State Experiment* (Manpower Demonstration Research Corporation, New York, 1986)] and J. Grossman *et al.* ["Reanalysis of the effects of selected employment and training programs for welfare recipients" (Mathematica Policy Research, Princeton, NJ, 1985)].
23. The data in Table 2 were calculated by the authors from data in the Panel Study of Income Dynamics [*User Guide to the Panel Study of Income Dynamics* (Inter-university Consortium for Political and Social Research, University of Michigan, Ann Arbor, MI, 1984)].
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Evolution of Polygonal Fracture Patterns in Lava Flows

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Cooling-induced fractures, also known as columnar joints, divide basaltic lava flows into prismatic columns with polygonal cross sections. The regularity and symmetry of the fracture patterns have long fascinated naturalists. In view of the recent selection of two candidate nuclear waste sites in areas where polygonally fractured volcanic rocks are located, a better understanding of the fracture patterns is required. Field data indicate that the tetragonal networks at flow surfaces evolve systematically to hexagonal networks as the joints grow inward during solidification of lava. This evolution occurs by the gradual change of most orthogonal intersections to nonorthogonal intersections of about 120 degrees. The surface features and intersection geometries of columnar joints show that joint segments at any given level form sequentially yet harmoniously.

MANY VOLCANIC ROCKS, ESPECIALLY BASALTIC LAVA flows, are divided by fractures into slender prismatic columns (Fig. 1a). In plan view, these column-bounding fractures, also called columnar joints, form remarkable polygonal patterns that vary from being tetragonal (Fig. 1b) to nearly hexagonal (Fig. 1c). The regular and distinctive geometry of columnar joints has long impressed scientists and laymen, who have observed this phenomenon in remote areas such as the Devils Postpile in California, the Devils Tower in Wyoming, and the Giant's Causeway in Northern Ireland. These sites have recently been designated national parks. In addition to the aesthetic qualities of columnar joints, however, recent efforts in the planning of a national repository for high-level nuclear waste necessitate a detailed understanding of factors that control the length, spacing, and pattern of these

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