Education and Intergenerational Mobility: Evidence from a Natural Experiment in Puerto Rico *

John C. Bluedorn
University of Oxford

Elizabeth U. Cascio
University of California, Davis and NBER

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Abstract

The existence of intergenerational spillovers to public investments in schooling is often assumed in policy discussions regarding economic development. However, few studies to date have forwarded convincing evidence that externalities exist for developing countries. In this paper, we address this issue using the arguably exogenous schooling consequences of a major hurricane strike on Puerto Rico in the 1950s. Using data from the U.S. Census of Population for Puerto Rico, we first find that individuals on the margin of school entry at the time of the storm and residing in the most exposed regions of the island had significantly lower levels of education as adults than their counterparts in less exposed regions. Using the interaction of wind speed and age at the time of the storm as an instrument, we then find that maternal education is related to the probability that a child speaks English. Our estimates imply an additional year of education raises the probability that a child speaks English by between 4.3 and 4.5 percentage points, or approximately 24 to 28 percent. We find no conclusive evidence that parental education increases the probability that a child is enrolled, literate, or in an age-appropriate grade. On balance, these findings suggest that education is responsible at least in part for the persistence of human capital across generations.

Keywords: education, intergenerational mobility, natural experiment, hurricane
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I. Introduction

The intergenerational correlation in human capital in developing countries is well documented. Children with more educated parents tend to be healthier and to attain higher levels of education (Strauss and Thomas, 1995). However, does this imply that increasing access to schools today will raise the productivity of the next generation? The existence of such an externality to public investments in schooling is often assumed in policy discussions regarding the developing world, but few studies to date have forwarded convincing evidence that intergenerational spillovers exist in this context (Breierova and Duflo, 2004; Chou, Liu, Grossman, and Joyce, 2004).[1] Identifying the causal relationship between parent's education and a child's human capital is challenging: parents with higher levels of education are arguably of higher ability, making it difficult to disentangle the contribution of inheritable endowments on child outcomes from that of the knowledge and skills that might be obtained through education. The same factors that make it difficult to identify the private returns to education (outlined by Card, 1999) thus also make it difficult to identify the social returns.

In this paper, we estimate the extent to which the arguably exogenous schooling consequences of a natural disaster in a low-income country are transmitted across generations. The focus of our analysis is Puerto Rico, an island Commonwealth of the United States since 1898. In 1956, Hurricane Betsy (known locally as "Santa Clara") made landfall on Puerto Rico, one of only five hurricanes to have done so in the past 50 years.[2]

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[1] For example, the UN Millennium Development Project has as goals: 1) the achievement of universal primary education, and 2) gender equity in primary and secondary schooling, with eventual equity at all levels of education (United Nations, 2005; goals 2 and 3). Such goals are motivated in part by a desire to increase economic productivity and improve countries' development paths.

[2] When Hurricane Betsy struck Puerto Rico, it looked much like a developing country today. In 1950, for example, the median level of completed schooling in the country was approximately 3 years, approximately two thirds of employed men worked in agriculture, and the majority of houses lacked indoor toilets and electricity. Puerto Rico arguably still does look like a developing country today. For example, Puerto Rico's per capita

Betsy's path across the island was largely unpredictable given pre-existing characteristics of the local population and housing stock. As a result, the considerable damages to schools along the storm path—and the associated consequences for schooling attainment of the school-aged population—were effectively random. We use this natural experiment in educational attainment to estimate the effect of parental schooling on several measures of children's human capital, including school enrollment, grade for age, literacy, and English fluency.

To motivate our identification strategy further, it is useful to consider a stylized example, where randomly selected schools are damaged or destroyed. In affected areas, the costs of school attendance would be prohibitively high for most children of school age until schools (or homes) were rebuilt.[3] For example, longer distances to intact schools and congestion effects would generate a temporary upward shift in the costs of a family sending a child to school. If there are fixed costs to beginning school, the increase in schooling costs might be disproportionately felt by children on the margin of school entry. Regardless, some randomly-selected group of children would then on average have lower levels of completed education as adults, provided that school-leaving decisions are made at least in part on the basis of age.[4] Education would in effect be randomly assigned among potential parents: along all dimensions besides completed schooling, the affected and unaffected populations would be on average identical.

Although the intensity of Hurricane Betsy was largely unpredictable, the resulting school destruction was not assigned as in this stylized example. Where more schools were

PPP-adjusted income was one-third of U.S. per capita PPP-adjusted income in 1998 (Penn World table v. 6.1, 2005).

[3] The destruction of homes can have a similar effect, particularly if schools are used as shelters while homes are rebuilt.

[4] This is equivalent to there being some irreversibility in human capital investment.

lost as a result of the storm, losses to both crops (hence household income) and the housing stock (hence household wealth) were generally greater and the marginal rate of return to education more dramatically altered. Each of these changes in the household's (or individual's) optimization problem have had independent effects on human capital acquisition, generating differences between the affected and unaffected populations along dimensions besides educational attainment. However, these other effects were unlikely to have been concentrated among children who are relatively young at the time of the storm, as is the case with school destruction.

This is our point of departure. We identify the intergenerational impacts of education by exploiting the divergence in educational attainment from trend among parents who were on the margin of school entry in 1956 and residing in regions that arguably received considerable damage to schooling infrastructure during the storm. The first stage model is a generalized differences-in-differences framework, where the instrument is the interaction between a region's storm intensity (a function of maximum sustained wind speed) and age in 1956. Similar identification strategies have been used in studies of school construction programs (Duflo 2001, 2002; Breierova and Duflo 2004; Chou, Liu, Grossman, and Joyce, 2004). However, a distinguishing feature of this analysis is that our control group includes children who were either very young in 1956 (likely to have been of age to enter school *after* schools were rebuilt) or relatively old (and less likely to have been affected). Given that our preferred model includes cohort and region fixed effects and smooth region-specific trends, we are thus identified off of true deviation from a longer-run trend, rather than one abrupt shift upward in educational attainment that could be correlated with other government policies.

We use data from the 1980 U.S. Census of Population for Puerto Rico for our analysis. We first find that individuals between the ages of 4 and 7 in 1956 and residing in regions experiencing high winds during the storm have relatively low levels of education as adults. Our estimates imply that individuals on the margin of school entry, so defined, and residing in the hardest hit regions of the island completed approximately 0.9 fewer years of schooling by 1980 than their counterparts in minimally hit regions. No comparable difference in education across regions is detected at younger ages (1 to 3 in 1956) or older ages (8 to 10 in 1956). The reductions in schooling appear to have been associated with true reductions in skill, as the affected cohorts in affected regions are less likely to be able to read and write as adults, and a disproportionate share report never attending school. Although we cannot observe region of education in the Census, several pieces of evidence suggest that we have not picked up a spurious correlation due to selective migration.

Our evidence regarding the next generation is mixed, but on balance suggests that education is responsible at least in part for the persistence of human capital across generations. Using the interaction between (squared) wind speed and age in 1956 as an instrument, we find that maternal education is positively related to the probability that a child speaks English. Estimates imply an additional year of education raises the probability that a child speaks English around 24 to 28 percent. For all other dimensions of children's human capital that we consider (school enrollment, literacy, and the probability of being below grade for age), our TSLS estimates are of a reasonable magnitude but too imprecise to be distinguished from zero.

The paper proceeds as follows. In the next section, we present a simple model of human capital's intergenerational dynamics, which shows how familial human capital externalities may arise and might be identified. In Section III, we discuss past research into this question and give some background on Hurricane Betsy in Puerto Rico. Section IV presents a discussion of the U.S. Census data for Puerto Rico employed in our analysis. The impact of Hurricane Betsy on the first generation is considered in Section V, while the intergenerational human capital consequences of Hurricane Betsy are put forth in Section VI. In Section VII, we discuss the implications of our analysis and conclude.

II. Theoretical Background

In this section, we present an overlapping generations' model which leads to a simple characterization of intergenerational dynamics in education. The purpose of the model is twofold. First, the model illustrates the identification problem that arises when attempting to estimate the effect of parental education on children's attainment. If innate ability affects the amount of education which an individual obtains, then educational attainment will appear to be persistent across generations. Persistence of education across generations alone does not therefore provide evidence that investments in education have intergenerational spillovers. Second, the model demonstrates the channels through which a natural disaster, such as Hurricane Betsy, might generate such a shock to educational attainment in the younger generation. This shock is carried forward in the lifetime and might be passed along to future generations.

A. A Simple Model of Intergenerational Mobility

Consider a family dynasty (hereinafter simply referred to as a family) which has a two-period overlapping generations' structure.[5] In the first period, the agent works and receives

[5] The model here is motivated by Drazen (1978) and Becker and Tomes (1986). Baland and Robinson (2000) present a model with a similar structure, but adapted to consider the issue of child labor. Similar model (though without bequests) in Solon (1999).

labor income, which is a function of human capital, which is at the outset taken as given. He chooses how much to consume, how much to save for his retirement, and how much to invest in the human capital of his offspring. Children arise parthenogenetically at the rate of replacement.[6] In the second period, the agent is retired and lives off of savings made in the first period and a bequest from his parent. He also chooses how much of a bequest to leave to his child. This bequest can be either positive or negative. A parent discounts their child's utility (which they assume is optimally chosen) at the same rate as they discount their own second period utility. The individual treats factor returns and the cost of human capital investment as given.[7]

The generation *t* agent's problem is thus:

$$\max_{c_t^Y, c_{t+1}^O, k_{t+1}, h_{t+1}, b_{t+2}} U_t = u\left(c_t^Y\right) + \beta u\left(c_{t+1}^O\right) + \beta U_{t+1}^*$$
$$\text{s.t. } c_t^Y = w_t h_t - k_{t+1} - \int_0^{h_{t+1}} g\left(i\right) di$$
$$c_{t+1}^O = \left(1 + r_{t+1}\right)\left(k_{t+1} + b_{t+1}\right) - b_{t+2}$$
$$k_{t+1} + b_{t+1} \geq 0, c_t^Y \geq 0, c_{t+1}^O \geq 0,$$

where *t* indexes time, *Y* denotes a period when the agent is young, *O* denotes a period when the agent is old, *c* is consumption, *w* is the return to human capital (wage), *r* is the return to retirement saving and bequests, *g(·)* is the convex marginal human capital investment cost function, and *u(·)* is an increasing, concave period utility function (assumed to be identical across generations and time). β is the agent's time discount factor and is identical to the discount factor applied to their child's utility. Human capital h_t is the amount of human

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[6] Growth in the population can easily be accommodated by an appropriate normalization. We abstract from issues of assortative mating and fertility. Becker and Tomes (1986) discuss how the presence of assortative mating and variable fertility can generate greater intergenerational mobility; persistent familial differences in consumption and wealth are reduced. Becker and Barro (1985) and Becker and Tomes (1984) address these issues more fully.

[7] Although presented as a two period model, a third period implicitly exists for each generation – the period when they receive their human capital, but do not have utility independent of their parent. Thus, the three periods are: 1) born and receive human capital, 2) young and work, and 3) old and retired.

capital owned/supplied by the generation that is young at time t, chosen by the previous generation (their parent).[8] A child's human capital level is thus the outcome of a family decision. Retirement saving k_{t+1} is the amount saved by the generation that is old at time $t+1$ (young at time t). Bequest b_{t+1} is the bequest left by the generation that is old at time t to their child who is old at time $t+1$ (b_{t+2} is similarly defined). U^{*}_{t+1} is the child's lifetime utility, which is optimally chosen given their parent's human capital investment and bequest.

The constraints on retirement saving and consumption are non-binding at the optimum. The first order conditions for this problem generate the following Euler equations, which describe the evolution of the family:

$$
\begin{aligned}
u'\left(c_t^Y\right) &= \beta\left(1+r_{t+1}\right)u'\left(c_{t+1}^O\right) \\
u'\left(c_t^Y\right) &= \frac{\beta w_{t+1}}{g\left(h_{t+1}\right)}u'\left(c_{t+1}^Y\right) \\
u'\left(c_{t+1}^O\right) &= \beta\left(1+r_{t+2}\right)u'\left(c_{t+2}^O\right).
\end{aligned}
$$

The first Euler equation is the classic consumption Euler equation, which determines the optimal choice for retirement saving. The second and third equations describe the intergenerational evolution of consumption, implicitly defining the optimal human capital investment and the optimal bequest respectively.[9]

Combining the Euler equations across generation, we can see that:

$$u'\left(c_{t+1}^O\right) = u'\left(c_{t+1}^Y\right), \text{ and so } \frac{w_{t+1}}{g\left(h_{t+1}\right)} = 1 + r_{t+1}.$$

Taking factor returns as given, a parent will choose to invest in their child's human capital up until the point where the wage over the marginal cost of human capital investment equals

[8] For simplicity, human capital is assumed to be continuous.

[9] If the parent discounted their child's utility by a factor different than β, then that discount factor is what would appear in the second and third Euler equations. Assuming that the discount factor is the same as the parent's time discount factor will simplify the analytics later. It is not essential to the underlying results.

the gross return to retirement saving. If the marginal cost of human capital investment rises, the parent will reduce human capital investment in their child, but compensate the child by increasing the bequest which they leave. When a bequest is allowed to be either positive or negative, intergenerational consumption is perfectly smoothed. Furthermore, human capital investment will be a function only of contemporaneous variables: $h_{t+1} = g^{-1}\left(\frac{w_{t+1}}{1+r_{t+1}}\right)$. The level of human capital investment today does not depend upon the level of human capital investment yesterday.

B. Intergenerational Mobility with Credit Market Imperfections (Liquidity Constraints)

If bequests are required to be non-negative, then the above results will not generally hold. The presence of a liquidity constraint on parents means that a wedge will exist between a parent's marginal utility when old and their child's marginal utility when young:

$$u'\left(c_{t+1}^{O}\right) = \beta\left(1+r_{t+2}\right)u'\left(c_{t+2}^{O}\right) - \frac{\zeta}{\beta}$$
$$\Rightarrow u'\left(c_{t+1}^{O}\right) = u'\left(c_{t+1}^{Y}\right) - \frac{\zeta}{\beta},$$

where ζ is the Lagrange multiplier on the bequest non-negativity constraint ($\zeta \geq 0$). When the bequest constraint is binding ($\zeta > 0$), parents will reduce their own consumption and human capital investment in their children relative to the unconstrained optimum. The liquidity constraint inhibits intergenerational mobility, as constrained families will have persistently lower human capital than unconstrained families precisely because they are more resource-constrained. Lower human capital in one generation may then have long-lived effects upon the human capital path of the family. Since the non-negative bequest constraint may bind for some generations and not for others, the agent generally faces an extremely complicated problem.

The path dependence of human capital under liquidity constraints is illustrated most vividly if we suppose that parents are unable to leave any bequest to their children ($b = 0$). Then, only the first two Euler equations will be operative: the first equation governs the intertemporal evolution of consumption, while the second equation governs the intergenerational evolution of consumption. Parents may only help their children via human capital investment. Furthermore, suppose that:

1. the period utility function is isoelastic, so that $u(c) = \dfrac{c^{1-1/\sigma}}{1-1/\sigma}$.
2. the net rate of return to retirement saving *r* and the wage *w* are constant.[10]
3. the marginal cost of human capital investment is constant, so that $g(i) = \gamma$.[11]

Under these assumptions, the relevant equations are:

$$
\begin{aligned}
c_t^Y &= \left[\beta(1+r)\right]^{-\sigma} c_{t+1}^O \\
c_t^Y &= \left[\frac{\beta w}{\gamma}\right]^{-\sigma} c_{t+1}^Y \\
c_t^Y &= w h_t - \gamma h_{t+1} - k_{t+1} \\
c_{t+1}^O &= (1+r) k_{t+1}
\end{aligned}
$$

The general solution to the resulting second-order linear difference equation in human capital is:

[10] If the family dynasty is embedded in a small, open economy with a constant world real interest rate and with a constant returns-to-scale production technology, then the rate of return to retirement saving and the wage would both be constant.

[11] For more general marginal human capital investment cost functions (e.g., h^{γ}), an analytical solution will not typically exist (they lead to non-linear difference equations). However, the intuition generated by the constant marginal cost function carries through.

$$h_{t+1} = c_0 \left[\frac{\beta w}{\gamma} \right]^{\sigma t} + c_1 \left[\frac{w}{\gamma} \right]^{t},$$

where c_0 and c_1 are constants given by the initial conditions for human capital (determined by grandparental and parental human capital levels).[12] As can be seen from this equation, human capital is negatively related to the cost of human capital investment, γ. So, if γ rises, the amount of human capital accumulated by future generations will be lower. Notice that even if γ is only temporarily higher, there might be a long-run level effect upon human capital. This arises because the initial conditions, c_0 and c_1, for a given generation are lower than they would have been in the absence of the increase in investment costs.[13] There is an externality because future generations' human capital depends upon past generations' human capital, provided that the liquidity constraint continues to bind.[14]

C. Discussion

The model described above is helpful in seeing the partial equilibrium consequences of a hurricane shock. The shock might lower familial resources (by decreasing the wage and wealth) and raise the cost of education (by increasing direct schooling costs and the opportunity cost of schooling). Inheritable ability has implicitly been subsumed in the factor returns. Families which have high ability and thus high wealth would be expected to have

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[12] A general equilibrium model would allow for the wage rate and the cost of human capital investment to vary endogenously in a manner such that the economy would converge to a steady-state where in fact $w = \gamma$. In the limit, the constant wage and constant marginal human capital investment cost function are not consistent with the existence of a steady-state.
[13] Clearly, such an effect would be mitigated somewhat if the agent knew that the movement in human capital investment costs was temporary.
[14] Note that the simple model here requires that human capital investment be subject to an irreversibility – all human capital investment must occur prior to entry into working life. When individuals can move back and forth between working and schooling, then an individual may choose to work in order to accumulate the assets required to overcome any liquidity constraint, allowing them to afford more human capital investment later. A hurricane shock still has an effect on human capital through time-discounting, but it is lower than it would be under human capital investment irreversibility.

human capital paths which are less sensitive to shocks, precisely because they are not likely to be subject to binding liquidity constraints. Hence, there should be little intergenerational effect of a hurricane shock for wealthy families. The marginal family is one that was not subject to a liquidity constraint prior to a hurricane shock, but is subject to such a constraint after a hurricane shock. By leveraging the differences in hurricane damage across comparable populations in Puerto Rico, we will be able to identify the intergenerational effect of human capital for this marginal family.[15] If the shock is severe enough, however, liquidity constraints might become binding even for those who are relatively wealthy. This is useful, since identification will not therefore arise from a highly non-representative (i.e., exceptionally poor) subpopulation.

Would the human capital effects of a hurricane shock be more evident in some cohorts than others? The simple model considered here is unable to predict an age-education relationship, since all investment in human capital occurs in a single period. However, if the cost of education varies by age, and/or if a hurricane shock affects the cost differently across ages, then one would expect that the cohort that experiences the largest cost increase would also be that which shows the largest reduction in educational attainment. In section V, we present evidence of Hurricane Betsy's differential impact across cohorts in Puerto Rico. The evidence suggests that there were in fact different effects across cohorts, with the greatest costs born by those on the margin of starting school. The cohort-specific shocks to costs, combined with geographic variation in storm intensity, provide the basis for our identification strategy.

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[15] The importance of liquidity constraints in family behavior is emphasized in a study by Edmonds (2004). Employing age-based access to pension funds in South Africa to identify the marginal family, he finds that liquidity constraints significantly contribute to higher levels of child labor.

III. Identification Strategy: Further Background

A. Previous Literature

To date, two studies in the development literature have attempted to identify the causal impact of parental schooling on child outcomes using the sharp increases in schooling that accompany school construction programs. Breierova and Duflo (2004) examine the intergenerational consequences of a primary school construction program in Indonesia in the 1970s. They find that the education of both husbands and wives reduces child mortality. Chou, Liu, Grossman, and Joyce (2005) explore whether the expansion of junior high schools in Taiwan during the 1960s affected infant health and mortality. They find that both maternal and paternal education reduce the probability that infants are low birthweight or born prematurely. They also find tentative evidence that father's education reduces child mortality.

The critical identifying assumption in these studies is that trends in educational attainment across regions would have been similar in the absence of the programs. In theory if not in practice, however, these programs have been compensatory, building more schools in regions that initially had fewer. Regions where a relatively large number of schools were built might therefore have contributed to different trajectories in child outcomes.[16] This study is arguably less subject to such a criticism, since we derive identification from the differential impact of an exogenous hurricane shock. Below we present evidence that supports the unpredictability of the hurricane. Further, the hurricane was temporary—affecting only a subset of cohorts—while school construction programs tend to be permanent, affecting all cohorts entering school after they are established. Although validity

[16] In their analyses, both Duflo and Breierova (2004) and Chou, Liu, Grossman, and Joyce (2004) control for interactions of cohort fixed effects with region specific-variables, such as the school enrollment rate. Including these controls appears to have little impact on the substantive conclusions of the papers.

of identification strategies based on school construction programs can be tested (namely, there should be no effect of the program before it is established), the identification strategy employed here is unique in that control cohorts can be both older *and* younger than the treatment cohorts.

For developed countries, the literature on the causal role of schooling in the intergenerational transmission of human capital is more extensive. Two studies examine infant health, and the results are mixed. Currie and Moretti (2003) compare outcomes of children born to mothers in places with different levels of access to higher education. This identification strategy reveals effects of maternal education on birthweight and gestational age, as well as on behaviors that arguably promote infant health, such as smoking and prenatal care. McCrary and Royer (2005) look along a different margin, comparing birth outcomes among mothers who themselves have birthdays near school entry cutoff dates. Mothers with birthdays after these cutoffs tend to leave school with lower levels of education that mothers with birthdays immediately prior, who are arguably of the same innate ability. Unlike Currie and Moretti (2005), they uncover no evidence that maternal education affects infant health.

The key remaining studies in the literature on developed countries have employed changes in compulsory schooling requirements (e.g., from 7 to 8 or 9 years of required education) to identify the effect of parental education on children's schooling outcomes. Here, too, the findings are mixed. Black, Devereux, and Salvanes (2005) examine the intergenerational transmission of education using variation across municipalities and over time in implementation of new compulsory schooling requirements in Norway. They find little evidence that parents receiving higher levels of education as a result of the reform have children who also receive higher levels of education. Oreopoulos, Page, and Stevens (2003) take a similar approach for the United States, but unlike Black, etal. (2005), find evidence of a large impact of parent's schooling on children's grade retention and high school dropout. Chevalier (2004) derives identification from a compulsory schooling reform in Britain in the 1950s. He too finds evidence that parental (specifically, maternal) education on children's education.

It is unclear whether the results of these studies for developed countries readily generalize to developing countries, where changes in access would likely be occurring at even lower levels of education. Moreover, school quality in developing countries tends to be relatively poor, making it even less clear that school attendance bestows skills that are beneficial for parenting. Although Puerto Rico is affiliated with the United States, its educational system—particularly during the 1950s—is arguably comparable to that in a developing country today. For example, in the spring of 1950, only about 68 percent of school-aged Puerto Ricans were enrolled in school, and more than half of those enrolled were attending one of grades 1 through 3 (U.S. Bureau of the Census, 1953b). Even in the late 1950s, the "basic aim" of educational reform was to provide "at least a 6-year education to every child" (Hunter, 1959). Average educational attainment among the cohorts affected by Hurricane Betsy is also substantially lower than what is seen in data for most developed countries. Further, as noted above, our identification strategy relies upon binding liquidity constraints, and as such is likely to derive power from relatively poor families, depending on the storm's severity.

B. Hurricane Betsy

The basis of our study is Hurricane Betsy (known locally as "Santa Clara"), which struck Puerto Rico in 1956. Hurricane Betsy was one of the few hurricanes to make landfall on the island during the 20th century.[17] It was also one of the most devastating, estimated to have caused over $40 million in damage (roughly 5% of annual GDP), to have left between 11 and 16 individuals dead, and to have destroyed approximately 15,000 homes—more than 4 times the entire housing stock in the average Puerto Rican municipality (county) and roughly 3 percent of the island's entire housing stock in 1950 (Puerto Rico Planning Board, 1950; Picó, 1974; Rodriguez, 1997; U.S. Census Bureau, 1953). It is also reported to have blown down at least 156 schools and to have damaged another 315 (*El Mundo*, August 20, 1956). The National Oceanic and Atmospheric Administration (NOAA) Hurricane Hugo of 1989 to Hurricane Betsy, with Hugo being one of the most destructive hurricanes to strike the Caribbean in recent memory (Rodriguez, 1997).

On August 10, 1956, Hurricane Betsy was upgraded from a tropical storm to a category 3 hurricane on the Saffir-Simpson scale, with sustained winds between 111-130 miles per hour. The hurricane first made landfall on August 12 in the municipality of Maunabo, located in Puerto Rico's southeast corner.[18] It then swept across the island in a northwesterly direction, departing from the municipality of Arecibo between three and four hours after first landfall. While moving over the island, Hurricane Betsy slowed and was downgraded to a category 1 hurricane, with sustained wind speeds over 90 miles per hour (Picó, 1974; pp. 170, 173). After exiting Puerto Rico and moving over the ocean, the storm regained strength. From August 13 to August 16, it was designated a category 2 hurricane, with sustained wind speeds between 100-110 miles per hour.

Figure 1 shows a map of Puerto Rico overlaid with the path of Hurricane Betsy. Municipalities are shaded according to the maximum sustained wind speed experienced at

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[17] The others are San Felipe (1928), San Nicholas (1931), San Cipriano II (1932), Hugo (1989), Hortense (1996), and Georges (1998) (Picó, 1974; Rodríguez, 1997; National Climatic Data Center, 2003).

[18] Hurricane Betsy bounced 2-3 times off the coast of Maunabo before crossing into the island proper, inflicting heavy damage on this municipality (Rodriguez, 1997).

the municipality centroid during the course of the storm, with the darker shading indicating stronger winds. The municipality-specific wind speeds are calculated using the distances and angles of the municipality centroid to the hurricane path.[19] Municipalities with the greatest exposure experienced wind speeds of roughly 46 meters per second (approximately 103 miles per hour) during Hurricane Betsy's passage over the island. These municipalities lie along the storm path. Municipalities with the least exposure to the storm experienced winds of only seven meters per second (approximately 16 miles per hour) and are in general the most distant from the storm path. However, holding constant distance, wind speeds are generally higher to the east of the storm path, as shown in the figure. This asymmetry is due to the counterclockwise motion of the hurricane in the Northern hemisphere, which arises through the action of the Coriolis force.

In the analysis below, we use functions of maximum sustained wind speed to proxy for property loss as a result of Betsy.[20] Together, wind speed and age in 1956 will then determine an individual's exposure to the storm. Before turning to this discussion, it is useful to confirm more formally that the intensity of property damage, where observable, is related to wind speed, particularly since the mechanism of interest (increases in the costs of educational investment) involves property destruction. Moreover, since we form treatment and control regions on the basis of wind speed, we also attempt to demonstrate that wind speed would have not been *ex ante* predictable on the basis of municipality-level observables. Given that we also use across-cohort variation in exposure to the storm, it is not necessary, however, that the storm be random in this way.

[19] The calculation and its motivation are explained in Appendix A.

[20] We focus on wind speed instead of actual property damage for two reasons. First, although we do have data on storm-related property damage (see below), it is not available for all municipalities. Second, the actual level of property damage as a result is likely to be in part endogenous, or related to other municipality-level characteristics that could have direct effects on subsequent trends in educational attainment.

B.1. Wind Speed and Property Damage

Sustained wind speeds during hurricanes and tornados have been shown to be strongly related to property damage (Fujita, 1971). The relationship between wind speed and damages is highly non-linear. Filliben et al. (2002) present evidence that damage probabilities show a strong non-linear relationship with wind speed, with the level of property damage accelerating as wind speed rises. When estimating insured losses from a hurricane, insurance companies also employ vulnerability curves which specify that damages are an exponential function of wind speed (Meyer et al., 1997).[21]

Boose, Serrano, and Fisher (2004) have forwarded evidence of the relationship between property damage and wind speed directly for Puerto Rico. They adapt Fujita's wind speed-damage scale to Puerto Rico's storm history.[22] Using damage data from 85 hurricanes striking Puerto Rico since the first European settlement of the island, they document that wind speeds of between 18 to 25 m/s (40 and 56 mph) have generally led to only minor damage to wood or masonry buildings on the island. By contrast, hurricane wind speeds of between 36 to 47 m/s (80 and 105 mph) have historically been associated with extensive damage to buildings, including complete destruction of wooden homes and other structures with metal roofs—the most common form of construction during the period of interest.[23] Consistent with the anticipated nonlinearity of property damage in wind speed, intermediate wind speeds (26 to 35 m/s, or 57 to 79 mph) have in general been associated with relatively superficial forms of damage, including roof loss, downed chimneys, and broken windows.

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[21] Intuitively, since kinetic energy is related to the square of wind speed and damages are positively related to kinetic energy, damages show a non-linear, accelerating relationship with wind speed. To appropriately account for this acceleration, we use the approximate squared wind speed as our instrument (derived from the kinetic energy calculation described in appendix A).

[22] Fujita's rough classification is: F0 (minor damage), 18-25 m/s; F1 (some damage), 26-35 m/s; F2 (major damage), 36-47 m/s; and F3 (catastrophic damage), 48-62 m/s. See Fujita, 1971 for a derivation.

[23] In 1950, sixty-six percent of Puerto Rican homes were wooden with metal roofs (U.S. Census of Housing, 1953a).

The non-linearity of property damage in wind speed is suggested by Figure 2, which shows the fraction of homes destroyed or damaged by Hurricane Betsy by municipality. Estimates were constructed using housing counts from the 1950 U.S. Census of Housing for Puerto Rico and reports of storm-related property damage in the Puerto Rican newspapers *El Mundo*, *El Imparcial*, and the *Puerto Rican World Journal* between August 13 and August 21, 1956.[24,25] The newspaper reports unfortunately do not offer coverage of all municipalities and might be subject to reporting biases.[26] Nonetheless, the pattern of property damage is striking. Whereas wind speed dissipated gradually in moving away from the storm path, the degree of property damage declined much more rapidly. Indeed, nearly all reported damage is for areas with the darkest shading in Figure 1.

Though suggestive, Figure 2 does not take into account the possibility that municipalities differed in their vulnerability to storm winds. Table 1 therefore presents results from a series of regressions of housing damage on maximum sustained wind speed, indicators of geography, and characteristics of the housing stock and population in 1950.[27] In a model that includes a quadratic in wind speed, we cannot distinguish the linear term in wind speed from zero, though the squared term is positive and statistically significant in all but the fully-saturated specification (column 3 of Panel A). The acceleration is suggested by the fitted property damage values, given in Panel B. Predicted property damage is low at median wind speeds (24 m/s), ranging between 2.4 and 5.6 percent. By contrast, predicted property damage ranges between 27.4 and 41.7 percent, depending upon the specification.

[24] These data were used by Boose, Serrano, and Fisher (2004).
[25] The newspaper reports give numbers of homes destroyed or damaged by the storm. We normalize these figures using housing counts by municipality from the 1950 U.S. Census of Housing for Puerto Rico. Ideally, we would look separately at the fraction of homes destroyed and the fraction of homes damaged. However, the relevant numbers of homes in each category are not reported for all municipalities.
[26] Municipalities that are lightly shaded report having some property damage, but specific figures are not given.
[27] See notes to Table 1 for a detailed list of controls. The relatively high mean level of damage (relative to that earlier presented for the island as a whole), derives from the fact that data are missing for municipalities where damage rates were relatively low.

These results show that the degree of damage to the housing stock from Hurricane Betsy was accelerating in wind speed. Although we cannot confirm it with the available data, a similar finding would arguably hold for schools, which were built of the same materials during this period.[28] In addition, where housing losses were extensive, schools may have been used as shelters until houses were rebuilt, as has been the case after more recent hurricanes in Puerto Rico.[29]

B.2. Sustained Wind Speed and Pre-Existing Characteristics

A negative shock to schooling infrastructure from Hurricane Betsy, as discussed above, would have led to abrupt increases in the costs of acquiring formal schooling. Were these shocks to schooling infrastructure, the housing stock, and the costs of formal schooling random, i.e., *ex ante* unpredictable on the basis of municipality's characteristics? If so, then individuals from regions experiencing relatively low speed winds might be reasonable controls for those from regions experiencing relatively high speed winds—and significant property damage—during the storm.

Table 2 presents regression estimates of the quadratic specification in wind speed for a collection of population and housing characteristics for Puerto Rican municipalities in 1950. Underlying data are from published Census data, and all averages and regressions are weighted to reflect the size of the underlying population. At the outset, it is worth noting

[28] Unfortunately, although we have aggregate loss figures from the newspaper reports, we do not have a municipality-level breakdown of school damage and destruction as a result of the storm. However, it is worth noting that even in more recent storms, Puerto Rican schools have not been robust enough to withstand high winds. For example, Hurricane Hugo (1989) unroofed schools in the municipalities of Luquillo and Fajardo (Aguirre, 1994).

[29] In more recent storms, this process of rebuilding has been a lengthy one, and schools have been used as shelters for long periods of time. For example, in the aftermath of Hurricane Hugo, schools were used as shelters for so long that "a significant part of the educational system on the island was paralyzed and the semester of an estimated 150,000 students was disrupted" (NOAA, 1990 in Rodriguez, 1997; p. 135). Because they continued to be used as shelters, schools were still closed months after the hurricane strike (Aguirre, 1994).

just how little human capital had been accumulated by the average Puerto Rican in 1950. Panel B column (1) shows that, at mid-century, many Puerto Rican children of school age (ages 7 to 13) were not enrolled in school, and a substantial fraction of Puerto Ricans over the age of 10 were not literate. Median educational attainment in the adult population was approximately 3 years, and it was common for adults to have never attended school. Employment rates of women were low, and most employed men worked in agriculture. Column (1) of Panel C shows that the quality of the housing stock was also poor at this time, with the average structure lacking piped water and electricity.

The remaining columns present coefficients on the linear and quadratic wind speed terms. What is most striking is that although linear wind speed does show a significant relationship with several of the characteristic variables (largely because large urban areas, like San Juan and Ponce, were little affected by the storm), quadratic wind speed generally does not. The "treatment" variable is thus generally unrelated to a host of characteristic variables. Quadratic wind speed does show some positive correlation with the municipality's fraction of 7-13 year olds enrolled in 1950, the fraction of women employed, and the fraction of houses built in the 1930s, while having a slight negative correlation with the fraction of houses built in the 1940s. Nonetheless, taken as a whole, the regressions suggest little systematic relationship between quadratic wind speed—and ostensibly, property damage—and pre-existing municipality characteristics.

IV. Data

Our estimation samples are drawn from the 5 percent Public Use Microdata Sample (PUMS) from the 1980 Census of Population for the United States, a self-weighting sample based on a population survey of U.S. states and outlying areas conducted every ten years.

Puerto Rico has participated in the Census of Population since 1910 (Bohme, 1989), and the associated microdata are available from 1970 forward. The Census data for Puerto Rico are rarely used by economists, though they provide a wealth of information on schooling and labor market outcomes, as well as on other measures of human capital, such as literacy and English language ability. The individual-level Census data for Puerto Rico also tend to be more geographically disaggregated than they are for U.S. states.

Our baseline sample (hereinafter referred to as the "cohort sample") consists all of native-born Puerto Ricans residing in Puerto Rico in 1980 and born between 1946 and 1955. These birth years correspond to individuals between the ages of 1 and 10 at the time of Hurricane Betsy in 1956. They were between the ages of 24 and 34 when the Census was conducted 1980. We focus on this limited range of cohorts for several reasons. First, all individuals in the sample would have already been born by the time that Hurricane Betsy struck the island. We thus avoid problems of selective fertility in the aftermath of the storm. Second, during the 1948 to 1949 academic year, there was a major reform to the language of instruction in Puerto Rican schools, which may have had a direct impact on the educational attainment of the population (Bou, 1966).[30] While we do not anticipate that such an effect will be correlated with the intensity of Hurricane Betsy, we restrict attention to cohorts that would have entered school well into the post-reform period.[31]

We use the cohort sample to estimate the human capital impacts of the storm for the population at large. Educational attainment is measured as highest grade completed in the 1980 Census. As mentioned above, the PUMS for Puerto Rico contains other measures of

[30] The language reform established Spanish as the official language for elementary grades, and introduced English in junior high school. Prior to the reform, instruction was in English in most grades of the system (Bou, 1966).

[31] For descriptive purposes, we extend the cohort sample to include individuals between the ages of 11 to 14 in 1956. The oldest child in the extended sample would have been around age 6 at the start of the 1948-49 academic year.

human capital, such as whether an individual can read and write (presumably in Spanish) and whether (and how well) an individual speaks English.[32] In 1980, not all native-born Puerto Ricans in the cohorts of interest were literate, and a substantial fraction could no speak English, even with difficulty. These outcomes are therefore margins upon which we might expect to see effects, so we do not restrict attention to educational attainment.

Characteristics of the cohort samples are shown in the first two columns of Table 3. Average educational attainment for the chosen cohorts is on the order of 10 to 11 years—approximately the average level of education in this age group 20 years prior in the mainland United States. Around 93 percent of the sample is able to read and write, and over half can speak English, either easily or with difficulty. Twenty-one percent of men claim to have been in the U.S. at some point over the prior decade, while the comparable figure for women is only 16 percent. Men are also less likely to be married in 1980 than women in the same age group. This, along with delayed family formation among men, presents challenges to investigating the intergenerational transmission of the storm through fathers. We return to this point in more detail below.

To investigate the intergenerational impacts of the storm, we use the family relationship variables in the Census to match each individual in the cohort sample to all resident children and to a resident spouse, if available. The unit of observation in this data set is the child, so a given family can be observed multiple times in the data set (hereinafter referred to as the "child sample").[33] Given universes on the child outcome measures, we restrict the estimation sample to children who were between the ages of 5 and 14 in the spring of 1980. Since the cohorts under investigation were relatively young in 1980 and

[32] A small fraction of adults have allocated literacy variables. Literacy is allocated using a hot-decking procedure. There are no allocation flags provided for ability to speak English.

[33] We only use matches of children to householders and/or their spouses.

their families were still growing, restricting the sample in this way has the potential to introduce sample selection bias. Before restricting the child sample, we therefore create a series of measures of household composition and fertility, which we then merge back onto the cohort sample to assess sample selection issues.

Table 3 shows that, relative to the population at large, parents tend to be negatively selected. As shown in columns (3) and (4), parents are slightly older than the population at large. Mothers have slightly lower levels of education, though the education of fathers is slightly higher. Parents with children in the estimation sample (columns (5) and (6)) are negatively selected, regardless of gender. Mothers have on average 10.3 years of education, and are less likely to speak English than the cohort sample overall. Fathers have on average 10.5 years of education. Even though fathers are on average older than mothers in the same cohorts, their children are on average younger, reflecting the fact that men tend to marry younger women.[34]

The child sample is used to estimate the reduced form impact of Hurricane Betsy on the second generation, and to what extent the shock is transmitted through changes in education in the first. We consider four child outcomes. Our first measure is an indicator for whether a child is enrolled in a grade below where he should be given his age (in October of the previous year) and perfect grade progression.[35] In a validation study using U.S. data from the October Current Population Survey, Cascio (2003) finds this measure is highly correlated with self-reports of grade retention.[36,37] Further child outcomes we consider

[34] The average difference in age between matched spouses in this sample is 4 years.
[35] Specifically, among the enrolled, children are classified as below grade if highest grade attended is less than age in October – 5. Children who are not currently enrolled are also classified as below grade if their highest grade completed satisfies this inequality.
[36] If anything, misclassification in this variable should bias coefficients toward zero. This is the standard result when there is misclassification in a binary dependent variable (Hausman, 2001).
[37] This proxy for retention has been used in other studies employing Census data for the United States (Oreopoulos, Page, and Stevens, 2003; Cascio, 2004; Page, 2005).

include indicators for school enrollment, literacy, and ability to speak English. Panel B of Table 3 shows average values of these variables for children in our estimation sample. Less than 80 percent of 5 to 14 year olds are literate, and 15 percent or less can speak English, depending upon the sample. Around 90 percent of children are enrolled, and 22 percent are below grade.

Unfortunately, the Census contains no information on where an individual's education was obtained. Instead, we observe only region of residence. Census regions in Puerto Rico ("municipality groups") are collections of generally contiguous municipalities with populations of approximately 100,000.[38] In the 1980 Census, there were 22 municipality groups for the island, which is approximately the size of Delaware in land area. This affords us a considerable amount of variation in wind speed.

It is worth noting that our ability to observe only region of residence will introduce noise into our estimates. Further, to the extent that migration patterns are systematically related to storm intensity, our estimates could be biased. We control for a crude proxy for migration below. We also provide several pieces of evidence that selective migratory responses to Hurricane Betsy are not occurring.

V. Effects on Human Capital in the First Generation

A. Event Study Estimates for Education

For descriptive purposes, we begin by estimating an event study model for education similar in spirit to that previously considered in studies of school construction programs

[38] When not all municipalities in the group are bordering, included municipalities are in the same general area of the island. Only four municipalities are directly identifiable from the municipality group codes: Carolina, Caguas, Ponce, and San Juan. Because of its large population size, San Juan is divided into four municipality groups (it contains the capital city). Only one municipality, Hatillo, is divided into two separate municipality groups, but it is not directly identifiable.

(Duflo, 2001, 2002; Breierova and Duflo, 2004; Chou, Liu, Grossman, and Joyce, 2004). The model is given by:

$$(3) \qquad S_{icj} = \lambda_1 + \sum_{a=1}^{14} \gamma_1^a A_c^a W_j^2 + \alpha_{1c} + \beta_{1j} + \delta_{1j} c + \varepsilon_{icj}$$

where S_{icj} denotes years of completed schooling of individual *i*, born in year *c* and residing in region (municipality group) *j* in 1980; $A_c^a = 1[1956 - c = a]$ is an indicator for the age of individuals in cohort *c* in 1956; W_j is maximum sustained wind speed in meters per second (divided by 10) in municipality group *j*;[39] α_{1c} and β_{1j} are cohort and municipality group fixed effects, respectively; and $\delta_{1j} c$ is a linear inter-cohort trend at the municipality group level. Notice that we have added slightly older (aged 11 to 14) individuals to the sample for this part of the analysis.

The coefficients of interest in equation (3) are the γ_1^a, $a = 1, \ldots, 14$. Each component of this vector, γ_1^a, gives the deviation of educational attainment from trend for individuals aged *a* at the time of the storm and residing in municipalities experiencing relatively high winds. Assuming that $E[\varepsilon_{icj} \mid A_c^a W_j, \alpha_{ic}, \beta_{1j}, \delta_j] = 0$, the marginal impact of wind speed on expected educational attainment for an individual aged *a* at the time of the storm is given by $2\gamma_1^a W_j$. By using the square of wind speed as a measure of storm intensity, we thus capture in a parsimonious way whether changes in education associated with the storm are accelerating in wind speed. Such acceleration appeared in the property damage estimates presented above, and to find it here would provide a useful validity check.

[39] This variable and the enrollment rate variable used below are based on municipality-level data from the 1950 Census of Population and Housing are population weighted averages of their analogs at the municipality level.

Each coefficient, γ_1^a, thus uncovers the age-specific, reduced form impacts of Hurricane Betsy on completed schooling for individuals in particular regions. However, differences in the effects *across* ages *within* any given region provide some insight into whether school destruction is in fact the primary channels through Betsy changed a family's optimization problem. If there are not fixed costs to school entry, we might expect losses in schooling to be proportional to age-specific school enrollment rates in 1956 and subsequent school years, while homes and schools are rebuilt. If there are fixed costs to school entry, the effects might be relatively large for those on the margin of entering school. Regardless, deviations from trend in this case should be unambiguously negative, given the associated increases in the marginal cost of human capital investment. On the other hand, if changes in the marginal rate of return to schooling had a lasting impact, we might find relatively large deviations of education from trend among relatively old children in the sample, namely those on the margin of leaving school. These deviations could be positive or negative, depending on whether the storm increased or decreased labor demand in its wake.[40]

Figure 3 plots the least squares estimates of γ_1^a separately for men and women in the cohort sample.[41] Coefficients are connected with a solid line, and bounds on 90 percent confidence intervals on the estimates are connected with dotted lines. So that the model is identified, we omit the interaction for individuals aged 3 at the time of the storm, $A_c^3 D_j$. All coefficients should therefore be interpreted in relation to this age group. For women (Panel A), the reduced form effects of the storm are negative and statistically significant among

[40] There might also be changes in labor supply. However, there was little loss of life as a result of Hurricane Betsy, so the effects on labor supply might be small.

[41] The unit of observation in the underlying regression is the individual. In this and all subsequent regressions, standard errors are consistent for error correlation between individuals born in the same year and residing in the same municipality group. They were calculated using the cluster option to STATA's regression command. The estimated standard errors are similar when conduct the analysis on data collapsed to cohort-municipality group means. Standard errors tend to be smaller when we cluster on municipality group in these cell mean level regressions.

those who were between the ages of 4 and 7 in 1956. For those younger than age 3 and older than age 8 in 1956, deviations of educational attainment from trend are in magnitude close to zero and not statistically significant. For men (Panel B), the coefficients are noisier but exhibit a similar pattern until around age 9. However, there are significant reductions in schooling among men residing in relatively high wind regions who were aged 11 or 12 at the time of the storm. This suggests that the storm raised the opportunity cost of schooling for men enough to induce early school exit.[42]

To provide a better sense of variation in the magnitude of the schooling effects across regions, Figure 4 plots, by age in 1956, estimates of γ_1^a times W_j^2 for three different regions of Puerto Rico: those experiencing maximum wind speeds for the island (approximately 46 m/s); those experiencing median wind speeds (approximately 24 m/s); and those experiencing minimum wind speeds (approximately 9 m/s).[43] These graphs make more plainly evident the fact that reductions in schooling were concentrated in regions earlier shown to have sustained large property losses during Hurricane Betsy. For example, in municipality groups experiencing the strongest winds, girls aged 4 to 7 in 1956 had on average between 0.85 and 1.35 years fewer schooling as adults than would have been predicted by trend and when compared to individuals of the same age and residing in minimally hit regions. By contrast, the predicted loss in education fluctuates between 0.2 and 0.35 years for individuals in regions experiencing median wind speeds during Betsy.

These event study findings suggest that Hurricane Betsy did in fact have a lasting effect on education for a generation of Puerto Rican schoolchildren. Children aged 4 to 7 in 1956 and residing in high-wind regions appear to have completed fewer years of schooling as

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42 That no similar result is seen for women is not surprising, given that the (market) employment rates of women were low prior to the storm (see Table 2).

43 The minimum, median, and maximum are based on weighted average wind speeds in the municipality groups.

adults than individuals in the same cohorts residing in lower-wind regions. Furthermore, *within* hard hit municipalities, there appears to be no significant deviation from trend in educational attainment—at least for women—among those slightly younger or slightly older at the time of the storm.

Although we cannot rule out other causal mechanisms given the lack of data, these results suggest that destruction of schooling infrastructure and/or the use of schools for purposes besides instruction were the primary cause of the loss in schooling. Since the effects appear to be concentrated among children on the margin of school entry, the findings also suggest that there might have been large fixed costs to beginning school. During the 1950s, Puerto Rican children generally entered school at age 6 or 7 (U.S. Bureau of the Census, 1953a; U.S. Bureau of the Census, 1963). If destruction was extensive—making it difficult for schools and homes to be rebuilt immediately—slightly younger children (i.e., those ages 4 and 5) could have easily been affected. A long delay is in fact suggested by the magnitude of the predicted effects on education for regions experiencing maximum wind speeds. We provide further evidence in support of this hypothesis below.

B. Restricted Estimates for Education

For the remainder of the analysis, we designate individuals between the ages of 4 and 7 in 1956 as treatment cohorts. We then use the slightly younger *and* slightly older individuals in the sample as controls in estimating restricted versions of equation (3). This is likely a conservative definition of treatment and control cohorts: as demonstrated above, older children appear to have been affected (albeit to a much lesser extent) by the storm. That these older children appear were affected to some extent is consistent with rising costs of school attendance.[44] By including these individuals as controls, we are likely to understate the true effect of the storm on the first generation, as well as its pass-through to the second. We also make a further simplification to the analysis: because there appear to be men who are treated by the storm at older ages—though for potentially different reasons—we return to the original sample of individuals aged 1 to 10 to in 1956. By not using storm-induced variation in educational attainment among older children, we attempt to focus exclusively on the school destruction channel between Betsy and educational attainment.

Our first model restriction forces the coefficients on all $A_c^a W_j^2$ for the treatment cohorts to be zero, i.e., $\gamma_1^a = 0$ for $a \leq 3$ and $a \geq 8$. The model in equation (3) thus becomes:

$$(4) \qquad S_{icj} = \lambda_1 + \sum_{a=4}^{7} \gamma_1^a A_c^a W_j^2 + \alpha_{1c} + \beta_{1j} + \delta_{1j} c + \varepsilon_{icj}$$

The second restriction on the model forces the coefficients on the included $A_c^a W_j^2$ interactions to be constant across all treatment cohorts. The model is thus further simplified to:

$$(5) \qquad S_{icj} = \lambda_1 + \gamma_1 A_c W_j^2 + \alpha_{1c} + \beta_{1j} + \delta_{1j} c + \varepsilon_{icj}$$

where $A_c \equiv \sum_{a=4}^{7} A_c^a = 1[4 \leq 1956 - c \leq 7]$ is an indicator equal to one if a person was between the ages of 4 and 7 in 1956, and all other variables are as previously defined. Below, we refer to equation (5) as specification 1 and to equation (4) as specification 2.

[44] As noted above, this is an effect we would expect to see, provided that the change in marginal costs to education as a result of school destruction is no smaller for these cohorts. When we do not control for linear trends, this effect on older cohorts is more apparent, particularly for women. However, given the strong trends in educational attainment in Puerto Rico at this time—and the fact that they could be very different across municipality groups depending upon their urban/rural composition, it seems relatively more important to remove any potential bias by including the municipality group trends.

Table 4A and Table 4B present estimates of specifications 1 and 2 for women and men, respectively. Focus first on estimates of specification 1, given in Panel A. The first column drops trends, controlling only for cohort and municipality group fixed effects. The second column adds back in the municipality group cohort trends. For both men and women, reduced-form effects of the storm are roughly the same in both cases. The estimates imply that individuals aged 4 to 7 at the time of the storm and residing in regions experiencing maximum wind speeds have on average about 0.84 to 0.9 fewer years of schooling than individuals in the same age group residing in minimum wind speed regions.[45] Coefficients on the individual age interactions with wind speed (Panel B) are each negative and similar in magnitude to what we gave in the more restricted specification. As expected, coefficients on the age-wind speed interactions are all jointly significant, at least for women. For men, the pooling across cohorts is helpful in detecting effects.

The next column adds further controls to the model. We first add our crude control for one's tendency to migrate—an indicator for whether a person reports having resided in the United States at any point over the past 10 years. This control, which is available for all individuals in the estimation sample, is one way of examining the possibility that selective migration is driving the results. We also add a series of interactions between the exhaustive set of age (cohort) indicators, A_c^a , and the municipality group's 1950 school enrollment rate. Although Table 2 did not suggest that these characteristics were "accelerating" in wind speed, the enrollment rate was one dimension along which we did a significant relationship. The initial enrollment rate might also be related to subsequent trends in educational attainment. Including these interactions thus helps us to avoid falsely attributing to the storm educational effects that are in fact due to other region-specific factors.

[45] The figures reported are $\hat{\gamma}_1\left(W_{\max}^2 - W_{\min}^2\right)$ and $\hat{\gamma}_1\left(W_{\max}^2 - W_{median}^2\right)$, respectively.

If anything, adding these controls strengthens the results. For women, the coefficient and standard error on the squared wind speed term in specification 1 is essentially unchanged; for men, the coefficient rises in magnitude by more than the standard error. For both men and women, coefficients on the squared wind speed interactions in specification 2 are jointly significant.

We use these specifications as first stage equations in estimating the causal impact of parental schooling on child outcomes in the next section. The final two columns of the table therefore give estimates of the fully saturated model for men and women included in the child sample. So that the results are useful in interpreting the results below, we let the child be the unit of observation and control for the full set of additional controls used in the child model.[46] For the subsample of mothers, there is still a reduced-form impact on the storm on educational attainment, though estimates are somewhat noisier than they were for the full sample. The same is true for the subsample of all men with matched children (column (4)). However, for the subsample of men with children in the target age range (column (5)), there is no longer a relationship.

At first blush, the lack of a result for fathers is perplexing. However, as shown in Table 3, there are relatively few men in the cohort sample who have children in this age range (about 36%), and the children that they do have are on average almost a year and a half younger than those born to women in the same age range. The fact that there is a relationship between wind speed and educational attainment for men overall is, however, somewhat reassuring. It suggests that, if only we could observe these men at slightly older ages, we would be able to investigate whether losses in education among fathers have

[46] These include indicators for child age interacted with indicators for child gender, and indicators for child age interacted with indicators for municipality group.

repercussions for their children. However, this is impossible given the available data.[47] Below, we focus only on women in the analysis of intergenerational effects.

C. *Is School Destruction Behind These Effects?*

Are our results for the first generation in fact driven by abrupt increases in the marginal costs of families investing in the education of their children? Were the increases in marginal costs greater for children on the margin of school entry, those for whom we are finding the greatest effects? The age profile of the storm's effects suggests that this is the case, but it is useful to provide further evidence.

Figure 5 demonstrates the storm's impacts at every level of education for women and men in the cohort samples.[48] Each point on the solid line is the coefficient on $A_c W_j^2$ in a linear probability model, where the dependent variable is an indicator for the level of education given on the horizontal axis. The 90 percent confidence bounds on these estimates are connected with the dotted lines. The most salient feature of these graphs is the coefficient on in the model where the dependent variable is an indicator for no completed schooling (highest grade completed=0). For women and men alike, children aged 4 to 7 in high wind speed regions are significantly more likely to have not completed any schooling. Apply the same metric as was used above, the estimates imply that in regions experiencing maximum wind speeds, the fraction of individuals with no education is 3 percentage points higher than in regions experiencing minimum wind speeds, and around 2.2 percentage points higher than in regions experiencing median wind speeds.

[47] In 1990, when the next Census is conducted, both mothers and fathers might be too old to observe a representative sample of matched children.

[48] Regressions include the full set of controls, as in column (3) of Tables 4A and 4B. Results are similar in the other specifications.

This finding implies that it was relatively more common for children in the hardest hit areas *never* to start school, and that there was in fact some fixed cost to school entry that was dramatically exacerbated by Hurricane Betsy. Beyond this, the distributional effects are not particularly striking. There appears to be a shift in the distributions toward lower levels of education (else perhaps we would not see an impact at the mean), but no effects (save at the highest levels of education for men) can be distinguished from zero. This, too, might be expected: for everyone else (particularly those who had already begun school), the likely effect of the storm would be for students to leave school at around the same age they would have otherwise, but with fewer years completed.

Table 5 replicates the results for the zero schooling indicator for parents in the child sample. The table also presents coefficients on $A_c W_j^2$ in linear probability models where indicators for basic literacy (columns (3) and (4)) and ability to speak English (columns (5) and (6)) are the dependent variables.[49] The results for zero schooling are much weaker for mothers, and non-existent for fathers (column (2)). However, for the population at large, there appears to have been strong effects of the storm on basic skills, such as literacy, which would arguably be gained in the earliest years of school. The fraction of men and women who are literate is 5 to 6 percentage points lower in the hardest hit areas. Mothers in affected cohorts and in affected areas are also less likely to be literate. Hurricane Betsy also appears to have had an impact on the English-speaking skills of males, but not that of females.

Finally, we might not expect to see any schooling impacts of Hurricane Betsy if there were immediate and strong migratory responses to the storm. By comparing the distribution

[49] Once again, regressions include the full set of controls, as in column (3) of Tables 4A and 4B. Results are similar in the other specifications.

of municipality of residence conditional upon municipality of birth before and after Hurricane Betsy in 1956, we can get some sense of whether there was such a migratory response. The U.S. Censuses contain cross-tabulations of the number of individuals per municipality of residence from a particular municipality of birth, allowing us to calculate the distribution described above for 1950 and 1960.[50] Applying the Kolmogorov-Smirnov test for the equality of distributions, only 18 out of 76 municipalities reject equality of the 1950 and 1960 distributions (at the 5% level). Furthermore, the correlation between an indicator variable denoting test rejection and squared wind speed is approximately -0.08. Such a small and negative correlation runs counter to what would be expected if there was a migration response to Hurricane Betsy. A migration response that is larger in more damaged municipalities should lead to a greater likelihood of rejecting the equality of distributions.

D. Is Selective Migration Driving These Results?

One final concern is selective migration over the longer run. As noted above, we cannot observe municipality of birth or education in the 1980 U.S. Census. If those affected by Hurricane Betsy were more or less mobile, then the estimated impact of the storm on educational attainment by municipality could be biased. For example, suppose that individuals with high educational attainment moved from municipalities which experienced greater hurricane damages to municipalities which did not experience such large damages, or to the United States. Then, an estimate of Hurricane Betsy's impact based upon municipality of residence would spuriously show a fall in mean educational attainment by municipality.

[50] Ideally, this cross-tabulation would be given by single year age categories. It is not.

Table 6 presents the reduced form relationship between Hurricane Betsy and several measures of mobility that we have at our disposal. The dependent variable in the first two columns is an indicator for whether an individual has resided in the U.S. during the past 10 years, used above in Tables 4 and 5. In the last two columns, the dependent variable is an indicator for whether an individual resides in the same municipality as he did 5 years prior, which is available for a subsample of Census respondents. Along the second migration margin, there is no effect: in general, Puerto Ricans seem to be fairly immobile, with around 80 percent residing in the same municipality ostensibly over a five year period. While municipality of residence five years ago is not necessarily the same as municipality of education or birth, there is likely to be a high degree of correlation between the two regions, particularly in such a young sample. There is therefore arguably a strong "signal" of where an individual received his education in municipality of residence.

The noise is likely due more to migration to the United States than to migration across municipalities within Puerto Rico. Here, we do see a significant relationship between the storm and mobility, but only for women. However, the magnitude of the effect is likely too small to explain the observed effect on education, particularly in light of the fact that Puerto Rican migrants to the United States tend to be negatively selected.[51]

VI. Intergenerational Impacts of Hurricane Betsy

A. Identification

The results presented above show that Hurricane Betsy had a lasting effect on educational attainment among those on the margin of school entry in 1956. It is highly

[51] In 1980, average educational attainment of Puerto Rican women residing in the United States is 10.37 years (compared to 11.07 years for native-born Puerto Rican women in Puerto Rico). For Puerto Rican men on the U.S. mainland, average educational attainment is 10.58 years (compared to 10.71 years for native-born Puerto Rican men in Puerto Rico).

doubtful that this "lost" education is due to some deviation from trend in innate ability. First, such a deviation in innate ability would have to be systematically related to the intensity of winds during the storm.[52] This seems unlikely given the relationship between wind speed and pre-existing municipality characteristics presented above. Second, if anything, the nature of migration from Puerto Rico to the United States—the only dimension along which we saw any relationship between the storm and migration—is likely biasing us *against* finding an effect. Third, we have presented several pieces of evidence consistent with the hypothesis that school destruction is the proximate cause of the relatively low observed levels of education in these cohorts.

Hurricane Betsy thus provides an instrument that might be used to uncover whether education contributes to the intergenerational correlation in human capital. The model of interest is

$$(6) \qquad Y_{icjag} = \lambda_2 + \theta S_{icj} + \alpha_{2c} + \beta_{2j} + \delta_{2j} c + \mu_{ja} + \tau_{ga} + \nu_{icja}$$

where i indexes the individual child; a indexes child age and g the child's gender; j remains an index for the municipality group and c an index for the parent's year of birth; Y_{icjag} denotes one of the child outcomes described in Section IV; S_{icj} stands for a parent's (mother's) educational attainment; α_{2c} and β_{2j} are cohort and municipality group fixed effects, respectively; and $\delta_{2j}c$ is a linear (parent) cohort trend at the municipality group level. The remaining fixed effects, μ_{ja} and τ_{ga}, allow for different age profiles in the child outcome variables by child gender and place of residence.

[52] For example, although it cannot be confirmed with the available data, individuals in the treated cohorts are likely to have had siblings in the control cohorts.

Although equation (6) contains a large number of fixed effects, there is no guarantee that OLS can uncover an unbiased estimate of θ. Innate ability is likely subsumed in the error term, v_{icjag}. We therefore anticipate that OLS estimates of θ will be upward biased. Instead, we use (4) and (5) as first stage equations (with the addition of the new fixed effects) in estimating (6) using two-stage least squares (TSLS). Given that there is a non-trivial first stage (at least for mothers), the effects of education on child outcomes will be identified if the interaction of parent age and wind speed is not related to unobserved shocks to child outcomes. In the case of specification 1, for example, θ is identified if $E\left[\left(A_c W_j^2\right) v_{icjag} \mid \alpha_{2c}, \beta_{2j}, \delta_{2j} c, \mu_{ja}, \tau_{ga}\right] = 0$. The evidence presented thus far suggests that this assumption might be satisfied.

As noted above, data constraints preclude us from investigating whether educational attainment of fathers is passed along to future generations in this application. We therefore focus exclusively on mothers and their children from here forward.

B. Effects on Children's Human Capital

Table 7 presents the TSLS and OLS estimates of the effect of parental education on child outcomes for mothers and all children in the target age range (Panel A), mothers and their daughters (Panel B), and mothers and their sons (Panel C). Because the results are independently interesting, we also present the reduced-form effects of the storm on child outcomes in the just-identified case (specification 1) in the first column.[53]

Consider first the OLS estimates, given in column (5). The OLS relationships between maternal education and each child outcome are statistically significant. Effects on

[53] All specifications include the full set of controls. The substantive findings are not altered in more parsimonious models.

human capital investments and/or child skills that are close to universal are, however, relatively low. For example, in the match of mothers to all children, a one year increase in mother's education is associated with a 0.007 point in the probability of being enrolled in school and a 0.01 point increase in the probability of being able to read and write. These are small effects, given that 91 percent of the child sample is enrolled and 79 percent is literate. On the other hand, the universal nature of school enrollment and literacy suggests that it might be unreasonable to see large correlations between education and these outcomes.

OLS effects on other child margins are more substantial. An additional year of maternal education is estimated to reduce the likelihood of being below grade by around 2.2 percentage points. Approximately 22.3 percent of children are below grade, so the effect size is around 10 percent.[54] An effect of a similar magnitude is seen for whether a child can speak English. Only 15 percent of the child sample has some English proficiency, and an additional year of maternal education is estimated to raise the likelihood that a child speaks English by around 1.4 percentage points. While larger than the effects observed for enrollment and literacy, these effects are still not large. This suggests that Puerto Rico might be a more economically mobile society that one would have thought *a priori*.

Now consider the TSLS estimates, given in column (3) for specification 1 and in column (4) for specification 2. For the sample overall, specification 2 uncovers a marginally significant effect of maternal education on a child's English-speaking ability.[55] However, the

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[54] This is a smaller effect than that observed for approximately the same measure in the United States. Oreopoulos, Page, and Stevens (2003) present OLS estimates of around 3 or 4 percentage points, an effect size approximately 20 to 27 percent of the overall fraction below grade in their sample. Page (2005) presents OLS estimates for the U.S. that are slightly smaller in magnitude, but still larger than those observed here.

[55] The $\chi^2_{(3)}$ statistic on the test of over-identifying restrictions is 1.949 (p-value=0.583) in the model where English speaking ability is the dependent variable. We therefore fail to reject the over-identifying restrictions at conventional levels of significance. We also fail to reject the over-identifying restrictions for all over-identified TSLS specifications given in Table 7.

remainder of the TSLS estimates are (relatively) large and indistinguishable from their OLS counterparts, as well as from zero.

A comparison of the TSLS results in Panels B and C, however, suggests that the effects of maternal education on basic skills and human capital investments (literacy and school enrollment) are larger for daughters than for sons. While it is impossible to rule out that the coefficients are identical, differences in the magnitudes of the coefficients are striking. For girls, a one year increase in a mother's educational attainment is estimated to increase the probability of school enrollment by 0.069 to 0.076 points and the probability of being able to read and write by around 0.07 points. For boys, by contrast, estimates for literacy and school enrollment are very close to zero in magnitude. For school enrollment among daughters, the reduced form impacts of the storm are statistically significant (column (2)). The relative imprecision of the TSLS estimates is driven primarily by a surprisingly imprecise first stage.

In an attempt to achieve more precise estimates, Table 8 presents estimates for the same series of specifications given in Table 7, but for an extended child sample, which adds in children of women who were between the ages of 11 and 14 in 1956. Adding these additional control cohorts aids identifying the effect of maternal education on a child's ability to speak English.[56] Comparing across the two child samples, an additional year of education is estimated to increase the probability that a child speaks English by between 24 and 28 percent. The reduced form effect of the storm on daughter's school enrollment remains highly significant, suggesting that the loss in skills among mothers as a result of the storm might have been manifested in lower levels of human capital investment in daughters.

[56] The $\chi^2_{(3)}$ statistic on the test of over-identifying restrictions is 1.590 (p-value=0.662) in the model where English speaking ability is the dependent variable, so that we fail to reject the over-identifying restrictions at conventional levels of significance. We also fail to reject the restrictions for all over-identified TSLS specifications presented in Table 8.

However, the first stage remains too weak to conclude that this effect is operating through losses in education *per se*.

Could these results be biased by sample selection? Table 9 suggests not. Having any matched children (column (1)) appears to be positively associated with the storm, though not significantly so in the first specification. The probability of having any matched children in the target age range (column (2)) is not significantly related to the storm in either specification.

VII. Discussion and Conclusion

There is a strong correlation between endowments and human capital acquisition in both developed countries (Solon, 1999) and developing countries (Strauss and Thomas, 1995). Recent research has attempted to uncover the causes of this relationship, emphasizing the role of education. There has been a flurry of studies using natural experiments to examine the role of parental education for child health (Currie and Moretti, 2003; McCrary and Royer, 2005; Breierova and Duflo, 2004; Chou, Liu, Grossman and Joyce, 2004) and schooling (Black, Devereux, and Salvanes, 2005; Oreopoulos, Page and Stevens, 2003; Chevalier, 2004; Page, 2005). However, evidence on the intergenerational spillovers of education is perhaps most lacking where it is most urgently needed: the developing world.

In this paper, we have examined the human capital consequences of a massive hurricane strike in a low-income country. Hurricane Betsy made landfall on the island of Puerto Rico in August of 1956, generating large, arguably exogenous reductions in completed education among those residing in areas exposed to high-speed storm winds on the margin of school entry at the time. The proximate cause of the reductions in schooling was not the loss in family income or changes in opportunity costs of schooling that surely accompanied the storm, but rather property destruction, which temporarily raised the cost to families of sending their children to school. The loss in education carries forward into parenthood for mothers and fathers alike. However, only for mothers with children in the target age range (5 to 14) does the relationship remain strong enough for us to consider intergenerational spillovers.[57]

Did these losses in education persist through the next generation? For school enrollment, literacy, and the probability of being below grade, our TSLS estimates of the effect of maternal education are larger than their OLS counterparts, but too imprecise to be distinguished from zero. However, we do find evidence that women completing fewer years of education as a result of the storm have children who are less likely to speak English. Our estimates imply an additional year of education raises the probability that a child speaks English by between 4.3 and 4.5 percentage points, or approximately 24 to 28 percent. The ability to speak English among Puerto Ricans is not universal, though it arguably plays an important role in their well-being given the now long-standing relationship between Puerto Rico and the United States. We also uncover a strong, negative reduced form impact of Hurricane Betsy on the school enrollment of daughters, but we are unable to conclusively tie this finding to losses in maternal education.

Collectively, our findings suggest that education is responsible, at least in part, for the persistence of human capital across generations. Further research is in particular needed for developing countries, which must make difficult public investment choices across myriad deserving priorities.

[57] As noted above, this appears more an artifact of data constraints than an indictment of the identification strategy.

VIII. References

Baland, Jean-Marie and James A. Robinson. 2000. "Is Child Labor Inefficient?" *Journal of Political Economy*. Vol. 108, No. 4: 663-679.

Becker, Gary S. and Robert J. Barro. 1988. "A Reformulation of the Economic Theory of Fertility." *Quarterly Journal of Economics*. Vol. 103, No. 1, (February), pp 1-25.

Becker, Gary S. and Nigel Tomes. 1984. "Human Capital and the Rise and Fall of Families." Economics Research Center/NORC Discussion Paper No. 84-10.

Becker, Gary S. and Nigel Tomes. 1986. "Human Capital and the Rise and Fall of Families." *Journal of Labor Economics*, Vol. 4., No. 3, Part 2: The Family and the Distribution of Economic Rewards (July), S1-S39.

Black, Sandra, Paul Devereux, and Kjell Salvanes. 2005. "Why the Apple Doesn't Fall Far: Understanding the Intergenerational Transmission of Education," *American Economic Review*, forthcoming.

Bohme, Frederick G. 1989. *200 years of U.S. census taking : population and housing questions,1790-1990*. U.S. Dept. of Commerce, Bureau of the Census: Washington D.C.

Boose, Emery R., Mayra I. Serrano, and David R. Foster. 2004. "Landscape and Regional Impacts of Hurricanes in Puerto Rico." *Ecological Monographs*. Vol. 72, No. 2: 335-352.

Bou, Ismael Rodriguez. 1966. "Significant Factors in the Development of Education in Puerto Rico." *Status of Puerto Rico: Selected Background Studies*. United States-Puerto Rico Commission on the Status of Puerto Rico: Washington D.C.

Breierova, Lucia and Esther Duflo. 2004. "The Impact of Education on Fertility and Child Mortality: Do Fathers Really Matter Less Than Mothers?" *NBER Working Paper* 10513.

Card, David. "The Causal Effect of Education on Earnngs." *Handbook of Labor Economics, Vol. 3A*. O. Ashenfelter and D. Card, eds. Elsevier Science, Amsterdam and New York.

Cascio, Elizabeth. 2003. "School Progression and the Grade Distribution of Students: A Validation Study Using the Current Population Survey." Mimeo, University of California, Davis, July.

Cascio, Elizabeth. 2004. "Schooling Attainment and the Introduction of Kindergartens into Public Schools." Mimeo, University of California, Davis, April.

Chevalier, Arnaud. 2004. "Parental Education and Child's Education: A Natural Experiment." *IZA Discussion Paper* No. 1153.

Chou, Shin-Yi, Jin-Tan Liu, Michael Grossman, and Theodore Joyce. 2004. "Parental Education and Child Health: Evidence from a Natural Experiment in Taiwan." Mimeo*,* City University of New York.

Currie, Janet and Enrico Moretti. 2003. "Mother's Education and the Intergenerational Transmission of Human Capital: Evidence from College Openings." *Quarterly Journal of Economics*, Vol. 118, No. 4.

Drazen, Allan. 1978. "Government Debt, Human Capital, and Bequests in a Life-Cycle Model." *The Journal of Political Economy*, Vol. 86, No. 3, (June), pp. 505-516.

Duflo, Esther. 2001. "Schooling and Labor Market Consequences of School Construction in Indonesia: Evidence from an Unusual Policy Experiment." *American Economic Review*. Vol. 91, No. 4: 795-813.

Duflo, Esther. 2002. "The Medium Run Effects of Educational Expansion: Evidence from a Large School Construction Program in Indonesia." *NBER Working Paper* 8710.

Edmonds, Eric. 2004. "Does Illiquidity Alter Child Labor and Schooling Decisions? Evidence from Household Responses to Anticipated Cash Transfers in South Africa." *NBER Working Paper 10265*.

Filliben, J. J., K. Gurley, J. P. Pinelli, E. Simiu, and C. Subramanian. 2002. "Fragility Curves, Damage Matrices, and Wind Induced Loss Estimation." In *Risk Analysis III: Third International Conference on Computer Simulation in Risk Analysis and Hazard Mitigation*, ed. C. Brebbia. WIT Press: Southampton.

Fujita, T. Theodore. 1971. "A proposed characterization of tornadoes and hurricanes by area and intensity." *SMRP Paper* 91, University of Chicago.

Hausman, Jerry. 2001. "Mismeasured Variables in Econometric Analysis: Problems from the Right and Problems from the Left." *Journal of Economic Perspectives*. Vol. 15, No. 4: 57-68.

Heston, Alan, Robert Summers, and Bettina Alan. 2002. *Penn World Table Version 6.1*. Center for International Comparisons at the University of Pennsylvania (CICUP), October.

Hunter, Robert. 1959. Puerto Rico: A Survey of Historical, Economic, and Political Affairs. Washington, D.C.: U.S. GPO.

McCrary, Justin and Heather Royer. 2005. "The Effect of Maternal Education on Fertility and Infant Health: Evidence From School Entry Policies Using Exact Date of Birth." Working Paper, University of Michigan.

Meyer, Peter et al. 1997. "Tropical Cyclones." Swiss Reinsurance Corporation Risk Perception Brochure, PM/CP/4000e/5.97.

Oreopoulos, Philip, Marianne E. Page, and Ann Huff Stevens. 2003. "Does Human Capital Transfer from Parent to Child? The Intergenerational Effects of Compulsory Schooling." *NBER Working Paper* 10164.

Page, Marianne. 2005. "Fathers' Education and Children's Human Capital: Evidence from the World War II G.I. Bill." Mimeo, University of California, Davis, January.

Picó, Rafael. 1974. *The Geography of Puerto Rico*. Aldine Publishing Company: Chicago.

Puerto Rico Planning Board. 1950. *Economic Report to the Governor*. Estado Libre Asociado de Puerto Rico, Oficina del Gobernador, Junta de Planificación: San Juan.

Puerto Rico Reconstruction Administration. 1940. "Education." *Puerto Rico: A Guide to the Boriquén*. The University Society, New York, 120-129.

Rodríguez, Havidán. 1997. "A Socioeconomic Analysis of Hurricanes in Puerto Rico: An Overview of Disaster Mitigation and Preparedness." *Hurricanes: Climate and Socioeconomic Impacts*. Henry R. Diaz and Roger S. Pulwarty, eds. Springer-Verlag, Berlin: 121-143.

Solon, Gary. "Intergenerational Mobility in the Labor Market." *Handbook of Labor Economics, Vol. 3A*. O. Ashenfelter and D. Card, eds. Elsevier Science, Amsterdam and New York: 1761-1800.

Strauss, John and Duncan Thomas. 1995. "Human Resources: Empirical Modeling of Household and Family Decisions." *Handbook of Development Economics, Vol. 3A*. Jere Behrman and T. N. Srinivasan, eds. North-Holland, Amsterdam: 1885-2023.

United Nations. "Millennium Project Development Goals." URL: http://www.unmillenniumproject.org/goals/. Last Accessed: 3 April, 2005.

U.S. Department of Commerce, Bureau of the Census. 1953a. *Census of Housing: 1950, Vol. I.* General Characteristics, Part 7, Alaska, Hawaii, Puerto Rico, Virgin Islands of the United States. Washington, D.C.: U.S. GPO.

U.S. Department of Commerce, Bureau of the Census. 1953b. *Census of Population: 1950, Vol. II.* Characteristics of the Population: Number of Inhabitants, General and Detailed Characteristics of the Population, Parts 51-54, Territories and Possessions. Washington, D.C.: U.S. GPO.

U.S. Department of Commerce, Bureau of the Census. 1963. *Census of Population: 1960, Vol. I.* Characteristics of the Population: Number of Inhabitants, General Population Characteristics, General Social and Economic Characteristics, and Detailed Characteristics, Part 53, Puerto Rico. Washington, D.C.: U.S. GPO.

U.S. Department of Commerce, Bureau of the Census. 1985. *Census of Population and Housing, 1980.* Public Use Microdata Sample (A Sample): 5-Percent Sample Computer file. From Inter-university Consortium for Political and Social Research (ICPSR), Ann Arbor, MI, 1997.

U.S. Geological Survey. 2002. *County Boundaries of the United States, 2001*. USGS: Reston, VA. URL: http://nationalatlas.gov/atlasftp.html.

U.S. National Hurricane Center. 2003. *Atlantic Hurricane tracks file 1851-2003*. URL: http://www.nhc.noaa.gov/tracks1851to2003_atl.txt.

Appendix A: Construction of the Hurricane Intensity Measure for Puerto Rico

The hurricane intensity measure for each municipality is the maximum kinetic energy experienced at the municipality's geographic centroid during Hurricane Betsy's passage.[58] This is roughly the maximum wind speed squared at the municipality's centroid. The following assumptions are necessary to calculate experienced storm energy based on the data available in the U.S. National Hurricane Center's Atlantic basin historical hurricane tracks file:

1. Let the linear velocity vector be denoted $\vec{v}$. Maximum wind speed occurs at the righthand side of the storm, parallel to the direction of motion of the storm, when the intrinsic linear velocity vector (at the eyewall) and the storm velocity vector are parallel and pointing in the same direction. The maximum intrinsic wind speed at the eyewall is the magnitude of the following vector:

$$\overrightarrow{v_M} = \overrightarrow{v_I} + \overrightarrow{v_S}$$
$$\Rightarrow \left\|\overrightarrow{v_I}\right\| = \left\|\overrightarrow{v_M}\right\| - \left\|\overrightarrow{v_S}\right\|,$$

where *M* denotes the overall maximum hurricane wind speed, *I* denotes the intrinsic wind speed, and *S* denotes the forward speed of the hurricane. In the absence of forward motion, assume that the eyewall (or any circle about the axis of rotation of the storm) has a constant angular speed, so that $\|\omega\| = \frac{\left\|\overrightarrow{v_I}\right\|}{\|r\|} = c_1$, some constant.

Essentially, the eyewall behaves similar to a bicycle wheel.

[58] Of course, the hurricane intensity measure calculation outlined here could be done for any hurricane and locality. Municipality centroids were calculated from U.S. Geological Survey (2002) data on Puerto Rico's municipality boundaries using MapInfo Professional v. 7.

2. Let linear momentum be denoted $\vec{p} = m\vec{v}$, where m is mass. Angular momentum is given by $\vec{l} = \vec{r} \times \vec{p} = m(\vec{v} + \vec{r})$, where $\vec{r}$ is the radial vector from the axis of rotation of the storm. The conservation of angular momentum of the storm implies that $\|\vec{l}\| = m\|(\vec{v} + \vec{r})\| = m\|\vec{v}\|\|\vec{r}\| \sin\theta = c$, for each parcel of air (c is some constant). Here, θ is the smallest angle between the two vectors, $\vec{r}$ and $\vec{v}$.

First, the velocity vector for each point on the circle of maximum intrinsic wind speed must be calculated. All angles are calculated relative to the axis parallel to the direction of motion of the storm. Consider a velocity vector $\overrightarrow{v_E}$ (for eyewall). We know that:

$$\overrightarrow{v_E} = \overrightarrow{v_I} + \overrightarrow{v_S}\text{, where}$$
$$\overrightarrow{v_S} = \left\|\overrightarrow{v_S}\right\| i = \left\|\overrightarrow{v_S}\right\| \cos[0] i \text{ and}$$
$$\overrightarrow{v_I} = \left\|\overrightarrow{v_I}\right\| \cos[\phi] i + \left\|\overrightarrow{v_I}\right\| \sin[\phi] j.$$

The angle ϕ is the angle in radians of the intrinsic velocity vector relative to the axis of

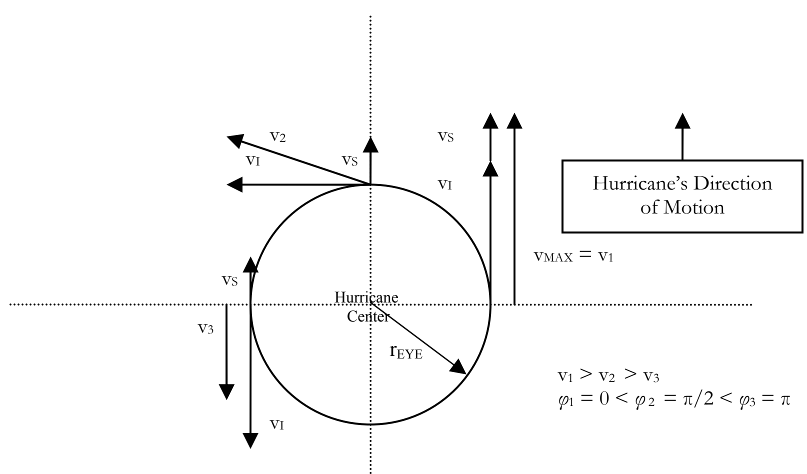


Figure A: Velocity Vectors at the Hurricane Eyewall motion.[59] The consequences of the vector addition can be seen in Figure A.

Hence, we can see that:

$$\overrightarrow{v_E} = \left\{\left\|\overrightarrow{v_I}\right\|\cos[\phi] + \left\|\overrightarrow{v_S}\right\|\right\} \cdot i + \left\{\left\|\overrightarrow{v_I}\right\|\sin[\phi]\right\} \cdot j, \text{ and}$$

$$\left\|\overrightarrow{v_E}\right\| = \sqrt{\left\{\left\|\overrightarrow{v_I}\right\|\cos[\phi] + \left\|\overrightarrow{v_S}\right\|\right\}^2 + \left\|\overrightarrow{v_I}\right\|^2 \sin^2[\phi]}$$
$$= \sqrt{\left\|\overrightarrow{v_I}\right\|^2 \cos^2[\phi] + \left\|\overrightarrow{v_S}\right\|^2 + 2\left\|\overrightarrow{v_I}\right\|\left\|\overrightarrow{v_S}\right\|\cos[\phi] + \left\|\overrightarrow{v_I}\right\|^2 \sin^2[\phi]}$$
$$= \sqrt{\left\|\overrightarrow{v_I}\right\|^2 + \left\|\overrightarrow{v_S}\right\|^2 + 2\left\|\overrightarrow{v_I}\right\|\left\|\overrightarrow{v_S}\right\|\cos[\phi]}$$

With the wind speed for each point on the circle of maximum intrinsic wind speed, the conservation of angular momentum implies that:

$$m\left\|\overrightarrow{v_E}\right\|\left\|\overrightarrow{r_E}\right\|\sin\theta = m\left\|\vec{v}\right\|\left\|\vec{r}\right\|\sin\theta$$
$$\left\|\vec{v}\right\| = \left\|\overrightarrow{v_E}\right\|\frac{\left\|\overrightarrow{r_E}\right\|}{\left\|\vec{r}\right\|}.$$

Here, we are looking at vector $\vec{v}$ which has the same angle relative to $\vec{r}$, as $\vec{v}_E$ does relative to $\overrightarrow{r_E}$. Thus, all that differentiates the two points is their distance from the eye.

The magnitude of the energy experienced where the velocity vector $\vec{v}$ is located can then be calculated from the formula for the kinetic energy of an air parcel:

[59] The vector components are given by the coefficients of i and j. Vector addition is easily performed using this notation. Furthermore, vector magnitudes are readily calculated, by translating between polar and rectangular coordinates using the Pythagorean Theorem.

$$K = \frac{1}{2} m \left\| \vec{v} \right\|^2$$

$$= \frac{1}{2} m \left\{ \left\| \overrightarrow{v_E} \right\| \frac{\left\| \overrightarrow{r_E} \right\|}{\left\| \vec{r} \right\|} \right\}^2$$

$$= \frac{1}{2} m \left\{ \frac{\left(\sqrt{\left\| \overrightarrow{v_I} \right\|^2 + \left\| \overrightarrow{v_S} \right\|^2 + 2 \left\| \overrightarrow{v_I} \right\| \left\| \overrightarrow{v_S} \right\| \cos[\phi]} \right) \left\| \overrightarrow{r_E} \right\|}{\left\| \vec{r} \right\|} \right\}^2$$

Assume that each parcel of air has identical mass, such that $\frac{1}{2} m = a$, some constant at every location. Using kinetic energy as an approximation of the amount of damage experienced by a location, we then have that:

$$K = a \frac{\left(\left\| \overrightarrow{v_I} \right\|^2 + \left\| \overrightarrow{v_S} \right\|^2 + 2 \left\| \overrightarrow{v_I} \right\| \left\| \overrightarrow{v_S} \right\| \cos[\phi] \right) r_E^2}{r^2}.$$

Notice how $\frac{r_E^2}{r^2}$ is unit free, since the numerator has the same units as the denominator.

Thus, the units of kinetic energy here are $kg \frac{m^2}{s^2}$, where velocity is measured in meters per second. The fundamental quantities for this calculation are thus:

1. $v_M = \max v_E$, the maximum recorded wind speed (assumed to occur at the eyewall).

2. v_S, the speed of the storm (how quickly it advances).

3. ϕ, the angle between the axis and the relevant velocity vector on the eyewall.

4. r_E, the radius of the eye.

5. r, the distance of the location relative to the eye center.

A further assumption will be that kinetic energy at a location can be no greater than the kinetic energy at the corresponding location on the eyewall. This means that if $\frac{r_E}{r} > 1$, set $\frac{r_E}{r} = 1$. Otherwise, the kinetic energy of an air parcel could be infinite at the eye center.

How can this approximate measure of experienced hurricane intensity (and hence damage) be implemented for a municipality? First, we will assume that each municipality's general kinetic energy measure is approximated by the kinetic energy measure calculated at the geographic centroid of the municipality. Second, the kinetic energy measure varies with the point on the hurricane path against which it is calculated. The hurricane path must be broken down into discrete points, and then a series of kinetic energy measures calculated for each municipality relative to all of these hurricane path points. The maximum kinetic energy measure from this series then best embodies the experienced hurricane intensity in the municipality.

TABLE 1 - WIND SPEED AND PROPERTY DAMAGE AS A RESULT OF HURRICANE BETSY

Dependent Variable:	Fraction of Homes Destroyed or Damaged (Weighted Mean = 0.082)		
	(1)	(2)	(3)
A. Regression Results			
Constant	0.023		
	(0.080)		
Wind Speed /10	-0.042	-0.059	-0.071
	(0.065)	(0.066)	(0.115)
Wind Speed ^{2}/100	0.021	0.023	0.027
	(0.011)	(0.012)	(0.019)
N	63	63	63
R^2	0.39	0.42	0.59
B. Predicted Impacts			
Maximum wind speed (≈46 m/s)	0.274	0.301	0.417
Median wind speed (≈24 m/s)	0.024	0.017	0.056
Minimum wind speed (≈9 m/s)	0.002	0.002	0.045
C. Controls			
Geography		X	X
Housing Stock (1950)			X
Population (1950)			X

Notes: Standard errors are given in parentheses. All regressions are weighted by the number of housing structures in the municipality in 1950. Population and housing controls are listed in Panels B and C of Table 2. Controls for geography include indicators for whether the municipality is on the coast, has island components, or is entirely comprised of an island. Wind speed is in meters per second.

TABLE 2 - MAXIMUM SUSTAINED WIND SPEED DURING HURRICANE BETSY (1956) AND MUNICIPALITY CHARACTERISTICS IN 1950

		Regression Covariate					
		Wind Speed/10			Wind Speed ^{2} / 100		
	Mean	Coeff.	s.e.		Coeff.	s.e.	
A. Storm Damage							
Frac. houses destroyed or damaged	0.082	-0.042	(0.065)		0.021	(0.011)	*
B. Population Characteristics, 1950							
Frac. of 7-13 year olds enrolled	0.684	-0.085	(0.036)	**	0.013	(0.006)	**
Frac. can read and write (ages 10+)	0.747	-0.060	(0.024)	**	0.006	(0.004)	
Frac. can speak English (ages 10+)	0.257	-0.033	(0.043)		0.002	(0.007)	
Frac. with no education (ages 25+)	0.345	0.076	(0.035)	**	-0.007	(0.006)	
Frac. with ≤ 2 years of education (ages 25+)	0.429	0.076	(0.037)	**	-0.007	(0.006)	
Frac. with ≤ 4 years of education (ages 25+)	0.547	0.073	(0.045)		-0.006	(0.008)	
Frac. with ≤ 8 years of education (ages 25+)	0.894	0.027	(0.031)		-0.001	(0.005)	
Frac. men employed (ages 14+)	0.663	0.011	(0.026)		-0.001	(0.004)	
Frac. women employed (ages 14+)	0.196	-0.140	(0.037)	***	0.020	(0.006)	***
Frac. in agriculture (men ages 14+)	0.343	0.069	(0.086)		-0.002	(0.015)	
Frac. urban (all)	0.390	-0.067	(0.164)		-0.003	(0.029)	
Frac. residing in municipality of birth (all)	0.731	0.008	(0.085)		0.008	(0.015)	
C. Housing Characteristics, 1950							
Frac. with no piped water	0.421	0.079	(0.120)		-0.003	(0.021)	
Frac. with no bath or shower	0.754	0.074	(0.070)		-0.005	(0.012)	
Frac. with no electricity	0.533	0.070	(0.108)		-0.002	(0.019)	
Frac. built 1919 or earlier	0.128	-0.037	(0.032)		0.003	(0.006)	
Frac. built 1920-29	0.151	-0.047	(0.025)	*	0.006	(0.004)	
Frac. built 1930-39	0.227	-0.062	(0.019)	***	0.009	(0.003)	***
Frac. built 1940-49	0.486	0.147	(0.057)	**	-0.019	(0.010)	*
Frac. wood exterior with metal roof	0.673	-0.133	(0.061)	**	0.018	(0.011)	
Frac. wood exterior with other roof	0.122	0.019	(0.032)		0.001	(0.006)	
Frac. other exterior (not concrete)	0.096	0.080	(0.042)	*	-0.008	(0.007)	
Number of Municipalities (Panel A)				63			
Number of Municipalities (Panels B and C)				75			

Notes: Standard errors are given in parentheses. All regressions include a constant and are weighted by the number of housing structures in the municipality in 1950. Wind speed is measured in meters per second. *** significant at the 1% level ** significant at the 5% level * significant at the 10% level

TABLE 3 - SUMMARY STATISTICS FOR CENSUS SAMPLES

			Child Sample			
	Cohort Sample		Any Matched Children		Any Matched Children 5-14	
	Women	Men	Mothers	Fathers	Mothers	Fathers
Variable	(1)	(2)	(3)	(4)	(5)	(6)
A. First Generation						
Age and Human Capital						
Age in 1956	5.50	5.48	5.87	6.03	6.42	6.89
	(2.88)	(2.88)	(2.81)	(2.78)	(2.65)	(2.49)
Age in 1980	28.75	28.74	29.13	29.28	29.68	30.15
	(2.91)	(2.92)	(2.85)	(2.81)	(2.69)	(2.52)
Highest Grade Completed	11.07	10.71	10.76	10.91	10.26	10.53
	(3.83)	(3.99)	(3.65)	(3.66)	(3.61)	(3.67)
Can Read/Write	0.936	0.924	0.944	0.939	0.938	0.931
Can Speak English	0.507	0.543	0.472	0.553	0.444	0.543
In U.S. Past 10 Years	0.160	0.213	0.169	0.223	0.184	0.223
Ever Married	0.844	0.791	0.985	0.999	0.984	0.998
Child Match Variables						
Number Matched Children	1.71	1.34	2.48	2.25	2.79	2.69
	(1.52)	(1.38)	(1.20)	(1.07)	(1.19)	(1.05)
Number Matched Children 5-14	0.99	0.61	1.44	1.02	1.93	1.71
	(1.22)	(0.97)	(1.23)	(1.08)	(1.03)	(0.88)
Any Matched Children 5-14	0.513	0.355	0.744	0.597		
Any Matched Children	0.690	0.595				
Observations	11327	9880	7810	5879	5812	3512
B. Second Generation						
Age and Human Capital						
Age in 1980			6.17	4.79	8.46	7.73
			(4.11)	(3.71)	(2.58)	(2.34)
Female			0.488	0.483	0.485	0.477
Can Read/Write					0.788	0.737
Speak English					0.151	0.132
Enrolled in School					0.910	0.883
Below Grade					0.223	0.218
Observations			19386	13217	11234	5988

Notes: Data are from the 1980 Decennial Census PUMS for Puerto Rico. Samples underlying the statistics in Panel A include native-born Puerto Ricans between the ages of 1 and 10 in 1956. The adult is the unit of observation. Samples underlying the statistics in Panel B consist of children of native-born Puerto Ricans aged 1 to 10 in 1956. Standard deviations are given in parentheses.

TABLE 4A - REDUCED FORM IMPACTS OF HURRICANE BETSY ON EDUCATIONAL ATTAINMENT OF WOMEN IN THE FIRST GENERATION

		Dependent Variable: Highest Grade Completed, 1980				
		All Women			With Children	With 5-14 Year-Olds
		(1)	(2)	(3)	(4)	(5)
A. Specification 1						
Age 4-7 in 1956 * Wind Speed ^{2} / 100		-0.045	-0.044	-0.044	-0.038	-0.049
		(0.014)	(0.013)	(0.013)	(0.015)	(0.016)
R^2		0.06	0.06	0.06	0.14	0.12
Predicted impact at maximum (46 m/s)		-0.95	-0.94	-0.94	-0.81	-1.04
Predicted impact at median (24 m/s)		-0.26	-0.26	-0.26	-0.22	-0.28
Predicted impact at minimum (9 m/s)		-0.04	-0.04	-0.04	-0.03	-0.04
B. Specification 2						
Wind Speed ^{2} / 1000 *	Age 4 in 1956	-0.048	-0.059	-0.055	-0.067	-0.079
		(0.020)	(0.020)	(0.021)	(0.022)	(0.027)
	Age 5 in 1956	-0.042	-0.046	-0.035	0.002	-0.004
		(0.027)	(0.027)	(0.027)	(0.024)	(0.020)
	Age 6 in 1956	-0.032	-0.028	-0.034	-0.039	-0.039
		(0.022)	(0.022)	(0.023)	(0.023)	(0.021)
	Age 7 in 1956	-0.056	-0.045	-0.052	-0.052	-0.071
		(0.020)	(0.020)	(0.020)	(0.025)	(0.025)
R^2		0.06	0.06	0.06	0.14	0.12
P-value on joint significance		0.016	0.008	0.011	0.010	0.002
Observations		11327	11327	11327	19386	11234
C. Controls						
Municipality Group Trends (Linear)			X	X	X	X
Migration Control				X	X	X
Cohort Fixed Effects * 1950 Enrolllment Rate				X	X	X
Child Controls					X	X

Notes: Robust standard errors are in parentheses. All regressions include municipality group and cohort fixed effects. Regressions in columns (1)-(3) include women between the ages of 1 and 10 in 1956. The regressions in column (4) include all women between the ages of 1 and 10 in 1956 with any matched children, and the regressions in column (5) include all women between the ages of 1 and 10 in 1956 with any matched children between the ages of 5 and 14 in April 1980. The unit of observation in columns (4) and (5) is the child. The migration control (columns (3)-(5)) is an indicator for whether an individual has been in the United States at some point during the past 10 years. The child controls (columns (4) and (5)) include fixed effects for child's age interacted with municipality group fixed effects, and fixed effects for child age interacted with fixed effects for child gender. Predicted impacts at maximum, median, and minimum wind speeds (Panel A) are calculated as the coefficient times squared wind speed divided by 100.

TABLE 4B - REDUCED FORM IMPACTS OF HURRICANE BETSY ON EDUCATIONAL ATTAINMENT OF MEN IN THE FIRST GENERATION

		Dependent Variable: Highest Grade Completed, 1980			
		All		With Children	With 5-14 Year-Olds
	(1)	(2)	(3)	(4)	(5)
A. Specification 1					
Age 4-7 in 1956 * Wind Speed ^{2} / 100	-0.041	-0.041	-0.046	-0.040	0.002
	(0.016)	(0.016)	(0.017)	(0.018)	(0.024)
R^2	0.05	0.05	0.05	0.11	0.13
Predicted impact at maximum (46 m/s)	-0.87	-0.87	-0.96	-0.84	0.04
Predicted impact at median (24 m/s)	-0.24	-0.24	-0.26	-0.23	0.01
Predicted impact at minimum (9 m/s)	-0.03	-0.03	-0.04	-0.03	0.00
B. Specification 2					
Wind Speed ^{2} / 1000 * Age 4 in 1956	-0.036	-0.033	-0.036	-0.079	-0.039
	(0.022)	(0.023)	(0.024)	(0.031)	(0.041)
Age 5 in 1956	-0.055	-0.053	-0.052	-0.027	0.014
	(0.021)	(0.021)	(0.020)	(0.021)	(0.040)
Age 6 in 1956	-0.043	-0.044	-0.051	-0.050	-0.003
	(0.040)	(0.039)	(0.042)	(0.035)	(0.034)
Age 7 in 1956	-0.034	-0.036	-0.046	-0.014	0.010
	(0.029)	(0.029)	(0.030)	(0.028)	(0.034)
R^2	0.05	0.05	0.05	0.11	0.13
P-value on joint significance	0.065	0.061	0.051	0.094	0.884
Observations	9880	9880	9880	13217	5988
C. Controls					
Municipality Group Trends (Linear)		X	X	X	X
Migration Control			X	X	X
Cohort Fixed Effects * 1950 Enrolllment Rate			X	X	X
Child Controls				X	X

Notes: See notes to Table 4A.

TABLE 5 - REDUCED FORM IMPACTS OF HURRICANE BETSY ON OTHER FORMS OF HUMAN CAPITAL IN THE FIRST GENERATION

	Dependent Variable:					
	No Schooling (=1)		Can Read/Write (=1)		Can Speak English (=1)	
	All	With 5-14 year olds	All	With 5-14 year olds	All	With 5-14 year olds
	(1)	(2)	(3)	(4)	(5)	(6)
A. Women						
Mean	0.017	0.015	0.936	0.927	0.507	0.406
Age 4-7 in 1956 * Wind Speed ^{2} / 100	0.0014	0.0009	-0.0026	-0.0035	-0.0018	-0.0026
	(0.0006)	(0.0010)	(0.0009)	(0.0016)	(0.0015)	(0.0019)
R^2	0.01	0.03	0.01	0.04	0.09	0.13
Predicted impact at maximum (46 m/s)	0.030	0.02	-0.06	-0.07	-0.04	-0.06
Predicted impact at median (24 m/s)	0.008	0.01	-0.02	-0.02	-0.01	-0.02
Predicted impact at minimum (9 m/s)	0.001	0.00	0.00	0.00	0.00	0.00
P-value on joint significance (spec. 2)	0.211	0.301	0.015	0.100	0.513	0.682
Observations	11327	11234	11327	11234	11327	11234
B. Men						
Mean	0.020	0.008	0.924	0.927	0.543	0.522
Age 4-7 in 1956 * Wind Speed ^{2} / 100	0.0014	-0.0002	-0.0024	-0.0023	-0.0057	-0.0032
	(0.0007)	(0.0007)	(0.0011)	(0.0019)	(0.0016)	(0.0028)
R^2	0.01	0.12	0.01	0.07	0.11	0.17
Predicted impact at maximum (46 m/s)	0.030	0.00	-0.05	-0.05	-0.12	-0.07
Predicted impact at median (24 m/s)	0.008	0.00	-0.01	-0.01	-0.03	-0.02
Predicted impact at minimum (9 m/s)	0.001	0.00	0.00	0.00	0.00	0.00
P-value on joint significance (spec. 2)	0.005	0.238	0.046	0.001	0.014	0.406
Observations	9880	5988	9880	5988	9880	5988

Notes: Robust standard errors are in parentheses. All regressions include municipality group fixed effects, cohort fixed effects, linear municipality group cohort trends, an indicator for whether the individual has resided in the U.S. at some point over the past ten years, and cohort fixed effects interacted with the 1950 municipality group enrollment rate. Regressions in columns (2), (4), and (6) also include fixed effects for child age interacted with municipality group fixed effects and a child gender indicator. The unit of observation in the columns labeled "with 5-14 year olds" is the child. Predicted impacts at maximum, median, and minimum wind speeds are calculated as the coefficient times squared wind speed divided by 100.

TABLE 6 - REDUCED FORM RELATIONSHIP BETWEEN HURRICANE BETSY AND MIGRATION

	Dependent Variable:			
	In U.S. Past 10 Years (=1)		Lived in Same Municipality 5 Years Ago (=1)	
	All	With 5-14 year olds	All	With 5-14 year olds
	(1)	(2)	(3)	(4)
A. Women				
Mean	0.160	0.187	0.795	0.815
Age 4-7 in 1956 * Wind Speed ^{2} / 100	0.0020	0.0054	0.0007	0.0007
	(0.0011)	(0.0018)	(0.0019)	(0.0024)
R^2	0.02	0.04	0.03	0.08
Predicted impact at maximum (46 m/s)	0.043	0.114	0.015	0.014
Predicted impact at median (24 m/s)	0.012	0.031	0.004	0.004
Predicted impact at minimum (9 m/s)	0.002	0.004	0.001	0.001
P-value on joint significance (spec. 2)	0.359	0.042	0.393	0.850
Observations	11327	11234	5467	5451
B. Men				
Mean	0.213	0.227	0.807	0.816
Age 4-7 in 1956 * Wind Speed ^{2} / 100	0.0004	0.0009	0.0016	-0.0004
	(0.0013)	(0.0029)	(0.0015)	(0.0035)
R^2	0.02	0.08	0.04	0.12
Predicted impact at maximum (46 m/s)	0.008	0.018	0.033	-0.008
Predicted impact at median (24 m/s)	0.002	0.005	0.009	-0.002
Predicted impact at minimum (9 m/s)	0.000	0.001	0.001	0.000
P-value on joint significance (spec. 2)	0.167	0.012	0.686	0.556
Observations	9880	5988	4766	2875

Notes: Robust standard errors are in parentheses. All regressions include municipality group fixed effects, cohort fixed effects, linear municipality group cohort trends, and cohort fixed effects interacted with the 1950 municipality group enrollment rate. The unit of observation in the columns labeled "with 5-14 year olds" is the child. Predicted impacts at maximum, median, and minimum wind speeds are calculated as the coefficient times squared wind speed divided by 100.

TABLE 7 - THE EFFECT OF MATERNAL EDUCATION ON CHILDREN'S HUMAN CAPITAL
(Sample: Children Aged 5-14 with Mothers Aged 1-10 in 1956)

		Coefficients							
	Mean	RF (Spec. 1)		TSLS (Spec. 1)		TSLS (Spec. 2)		OLS	
Dependent Variable	(1)	(2)		(3)		(4)		(5)	
A. Mothers and Children Aged 5-14									
Highest Grade Completed	9.670	-0.0491	***						
		(0.0161)							
Child Enrolled in School	0.910	-0.0019	*	0.038		0.013		0.007	***
		(0.0011)		(0.025)		(0.017)		(0.001)	
Child Below Grade	0.223	0.0018		-0.037		-0.029		-0.022	***
		(0.0015)		(0.032)		(0.025)		(0.001)	
Child Can Read and Write	0.788	-0.0009		0.019		0.023		0.010	***
		(0.0015)		(0.030)		(0.025)		(0.001)	
Child Can Speak English	0.151	-0.0016		0.032		0.043	*	0.014	***
		(0.0014)		(0.028)		(0.022)		(0.001)	
Observations	11234	11234		11234		11234		11234	
B. Mothers and Daughters Aged 5-14									
Highest Grade Completed	9.649	-0.0440	*						
		(0.0233)							
Child Enrolled in School	0.914	-0.0033	***	0.076		0.069		0.006	***
		(0.0012)		(0.047)		(0.044)		(0.001)	
Child Below Grade	0.193	0.0019		-0.043		-0.057		-0.020	***
		(0.0018)		(0.046)		(0.044)		(0.002)	
Child Can Read and Write	0.793	-0.0031		0.071		0.070		0.010	***
		(0.0020)		(0.059)		(0.053)		(0.002)	
Child Can Speak English	0.162	-0.0013		0.030		0.038		0.014	***
		(0.0018)		(0.042)		(0.042)		(0.002)	
Observations	5466	5466		5466		5466		5466	
C. Mothers and Sons Aged 5-14									
Highest Grade Completed	9.690	-0.0578	***						
		(0.0201)							
Child Enrolled in School	0.907	-0.0009		0.015		-0.009		0.007	***
		(0.0016)		(0.028)		(0.017)		(0.001)	
Child Below Grade	0.252	0.0024		-0.041		-0.026		-0.024	***
		(0.0020)		(0.035)		(0.018)		(0.002)	
Child Can Read and Write	0.783	0.0004		-0.007		-0.006		0.010	***
		(0.0018)		(0.031)		(0.021)		(0.002)	
Child Can Speak English	0.140	-0.0015		0.026		0.024		0.013	***
		(0.0015)		(0.026)		(0.014)		(0.001)	
Observations	5788	5788		5788		5788		5788	

Notes: Robust standard errors are in parentheses. All regressions include fixed effects for parent's age in 1956 and municipality group of residence, municipality-group parent cohort trends (linear), parent's cohort fixed effected interacted the municipality group enrollment rate in 1950, child age by gender fixed effects, and child age by municipality group fixed effects. In specification 1, the instrument is a dummy for parent aged 4 to 7 in 1956 interacted with squared wind speed. In specification 2, the instruments are individual parent age indicators for ages 4 to 7 interacted with squared wind speed. RF≡Reduced Form, TSLS≡Two Stage Least Squares, OLS≡Ordinary Least Squares. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

TABLE 8 - THE EFFECT OF MATERNAL EDUCATION ON CHILDREN'S HUMAN CAPITAL: EXTENDED SAMPLE
(Sample: Children Aged 5-14 with Mothers Aged 1-14 in 1956)

		Coefficients			
	Mean	RF (Spec. 1)	TSLS (Spec. 1)	TSLS (Spec. 2)	OLS
Dependent Variable	(1)	(2)	(3)	(4)	(5)
A. Mothers and Children Aged 5-14					
Highest Grade Completed	9.660	-0.0501 ***			
		(0.0171)			
Child Enrolled in School	0.924	-0.0019 *	0.039	0.014	0.006 ***
		(0.0011)	(0.026)	(0.017)	(0.001)
Child Below Grade	0.219	0.0019	-0.039	-0.031	-0.024 ***
		(0.0015)	(0.033)	(0.025)	(0.001)
Child Can Read and Write	0.820	-0.0010	0.020	0.022	0.009 ***
		(0.0015)	(0.031)	(0.024)	(0.001)
Child Can Speak English	0.188	-0.0018	0.036	0.045 ***	0.018 ***
		(0.0014)	(0.027)	(0.021)	(0.001)
Observations	17566	17566	17566	17566	17566
B. Mothers and Daughters Aged 5-14					
Highest Grade Completed	9.653	-0.0469 *			
		(0.0246)			
Child Enrolled in School	0.928	-0.0031 ***	0.067	0.054	0.005 ***
		(0.0012)	(0.044)	(0.037)	(0.001)
Child Below Grade	0.187	0.0016	-0.034	-0.047	-0.021 ***
		(0.0019)	(0.042)	(0.038)	(0.001)
Child Can Read and Write	0.829	-0.0030	0.064	0.064	0.007 ***
		(0.0019)	(0.053)	(0.047)	(0.001)
Child Can Speak English	0.204	-0.0023	0.050	0.056	0.019 ***
		(0.0018)	(0.043)	(0.041)	(0.001)
Observations	8519	8519	8519	8519	8519
C. Mothers and Sons Aged 5-14					
Highest Grade Completed	9.666	-0.0571 ***			
		(0.0209)			
Child Enrolled in School	0.920	-0.0010	0.018	-0.007	0.007 ***
		(0.0016)	(0.029)	(0.016)	(0.001)
Child Below Grade	0.250	0.0028	-0.050	-0.031	-0.027 ***
		(0.0020)	(0.037)	(0.018)	(0.001)
Child Can Read and Write	0.811	0.0004	-0.008	-0.009	0.010 ***
		(0.0019)	(0.034)	(0.021)	(0.001)
Child Can Speak English	0.173	-0.0014	0.024	0.021	0.017 ***
		(0.0016)	(0.027)	(0.014)	(0.001)
Observations	9047	9047	9047	9047	9047

Notes: See notes to Table 7.

TABLE 9 - HURRICANE BETSY AND THE PROBABILITY OF APPEARING IN THE CHILD SAMPLE

	Dependent Variable:	
	Any Children (=1)	Any Children 5-14 (=1)
A. Women Aged 1-10 in 1956		
Mean	0.690	0.513
Age 4-7 in 1956 * Wind Speed ^{2} / 100	0.0025	0.0023
	(0.0015)	(0.0018)
R^2	0.06	0.13
Predicted impact at maximum (46 m/s)	0.05	0.05
Predicted impact at median (24 m/s)	0.01	0.01
Predicted impact at minimum (9 m/s)	0.00	0.00
P-value on joint significance (spec. 2)	0.000	0.227
Observations	11327	11327
B. Women Aged 1-14 in 1956		
Mean	0.722	0.570
Age 4-7 in 1956 * Wind Speed ^{2} / 100	0.0019	0.0022
	(0.0015)	(0.0018)
R^2	0.06	0.13
Predicted impact at maximum (46 m/s)	0.04	0.05
Predicted impact at median (24 m/s)	0.01	0.01
Predicted impact at minimum (9 m/s)	0.00	0.00
P-value on joint significance (spec. 2)	0.000	0.233
Observations	15373	15373

Notes: Robust standard errors are in parentheses. All regressions include municipality group fixed effects, cohort fixed effects, municipality group trends, an indicator for whether the individual has resided in the U.S. at some point over the past ten years, and cohort fixed effects interacted with the 1950 municipality group enrollment rate. Predicted impacts at maximum, median, and minimum wind speeds are calculated as the coefficient times squared wind speed divided by 100.

Figure 1: Puerto Rico, 1956 Hurricane Betsy
Experienced Wind Speed by Municipality

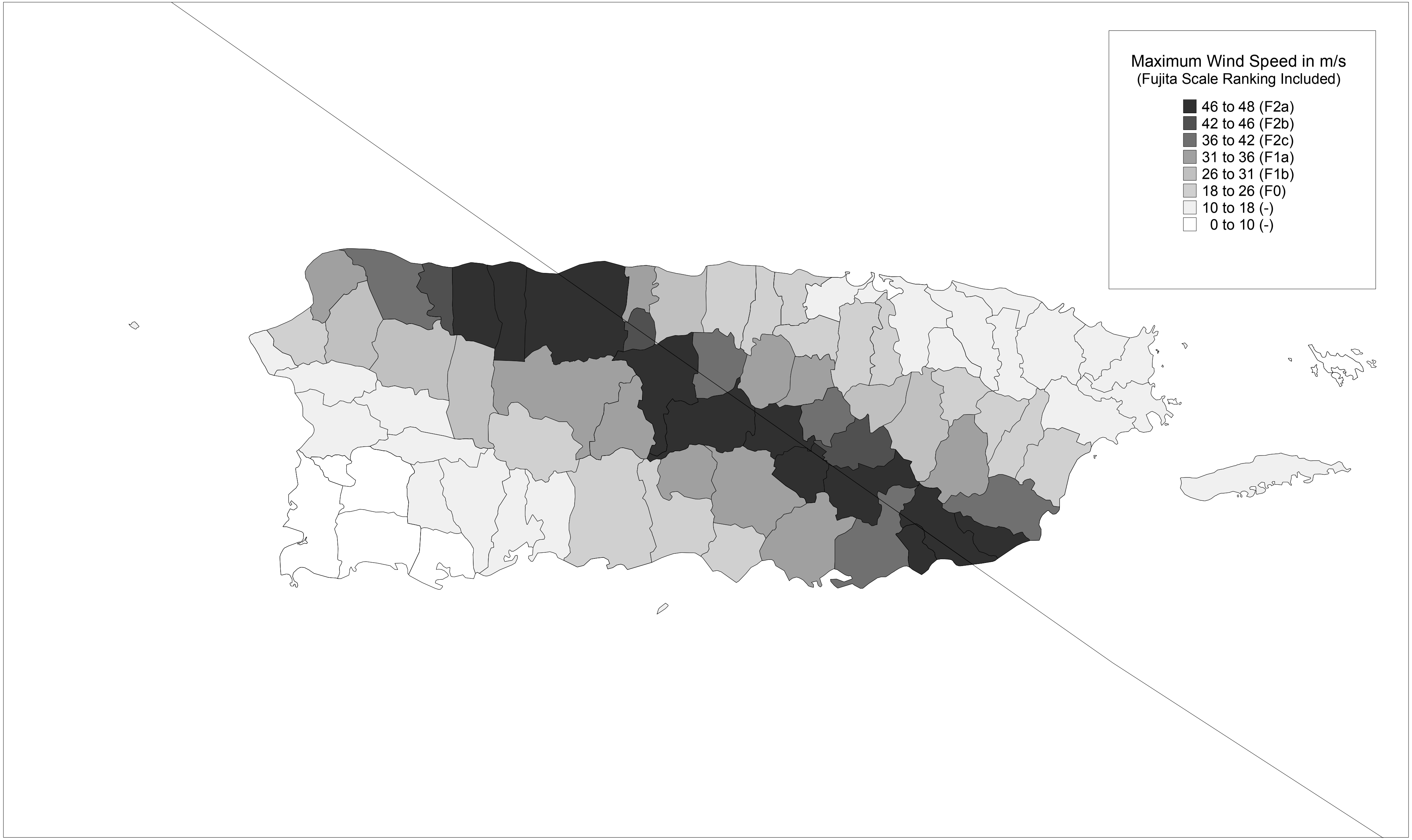


Figure 2: Puerto Rico, 1956 Hurricane Betsy
Percent of Homes Reported Destroyed or Damaged

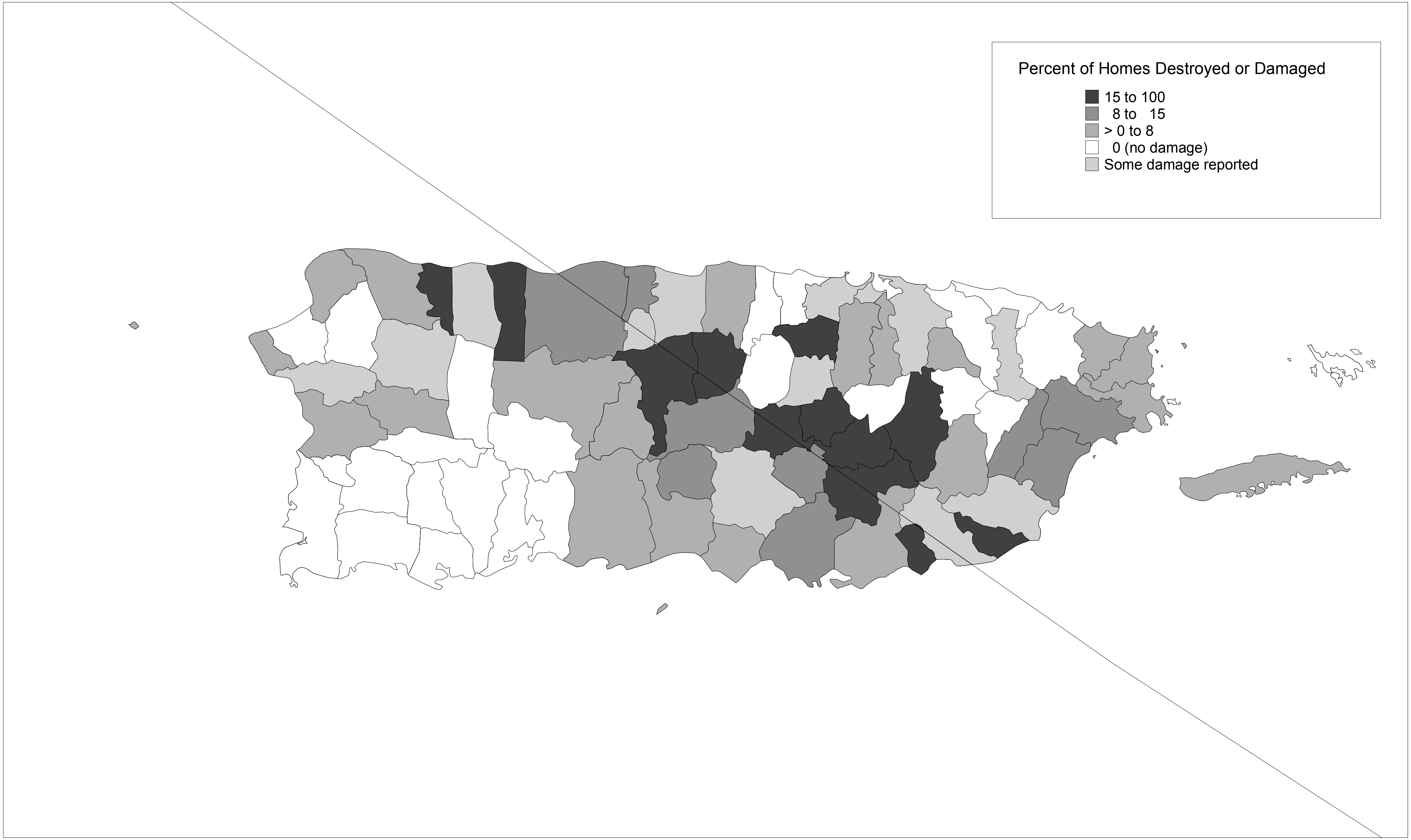
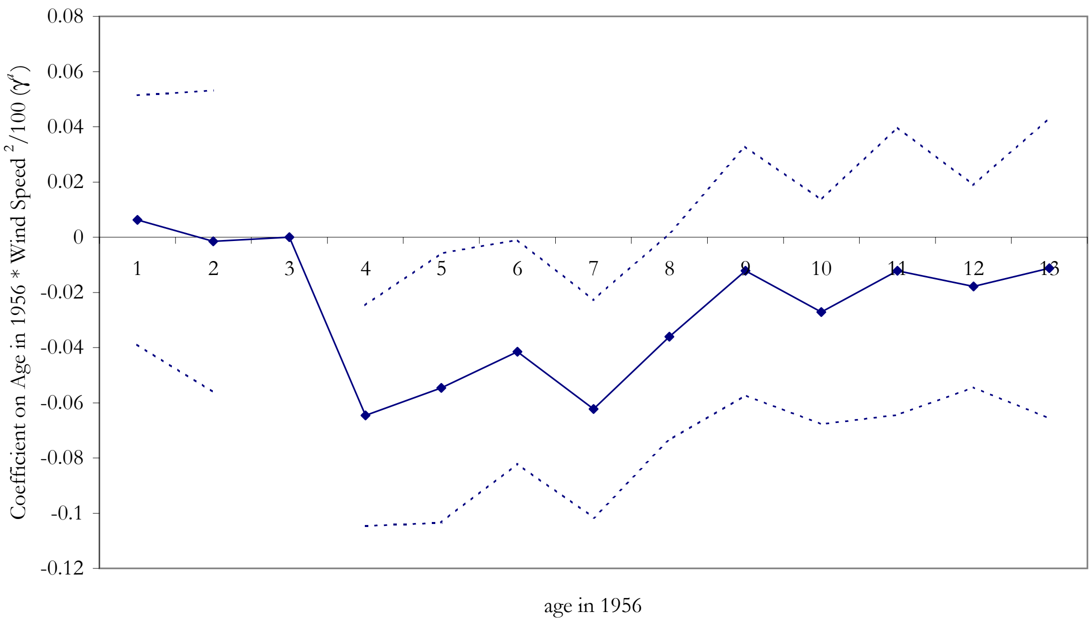
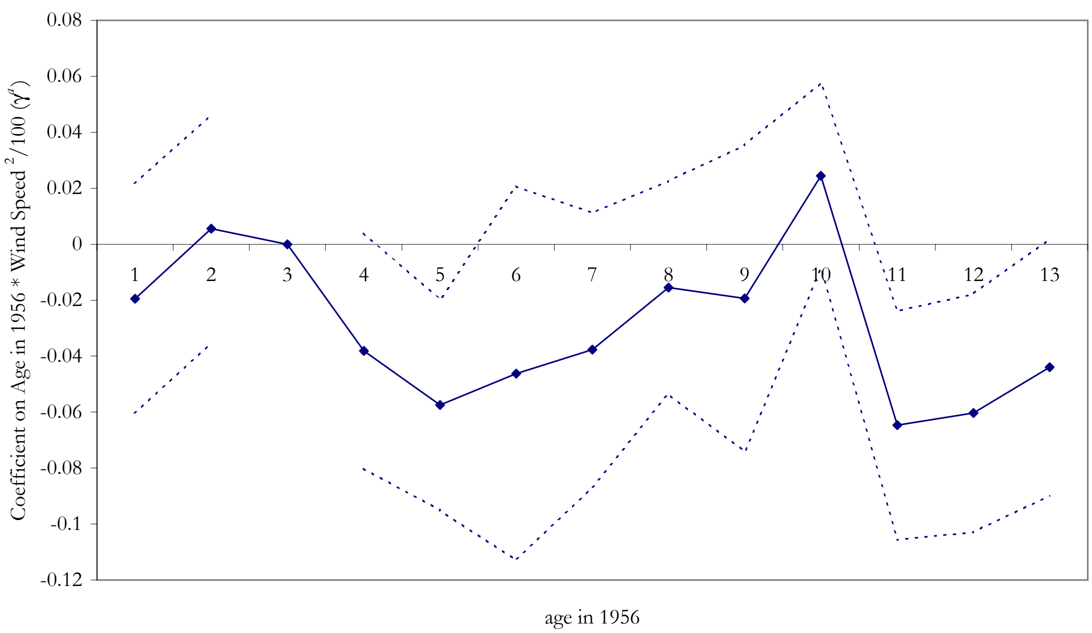


FIGURE 3 - THE REDUCED FORM EFFECT OF HURRICANE BETSY ON EDUCATIONAL ATTAINMENT IN 1980

A. Women



B. Men



Notes: The dependent variable is highest grade completed. The dotted lines connect bounds on the 90 percent confidence intervals on the coefficient estimates. Underlying standard errors are robust to clustering at the cohort/municipality group level.

FIGURE 4 - PREDICTED EFFECTS OF HURRICANE BETSY ON EDUCATIONAL ATTAINMENT IN 1980, BY WIND SPEED

A. Women

B. Men

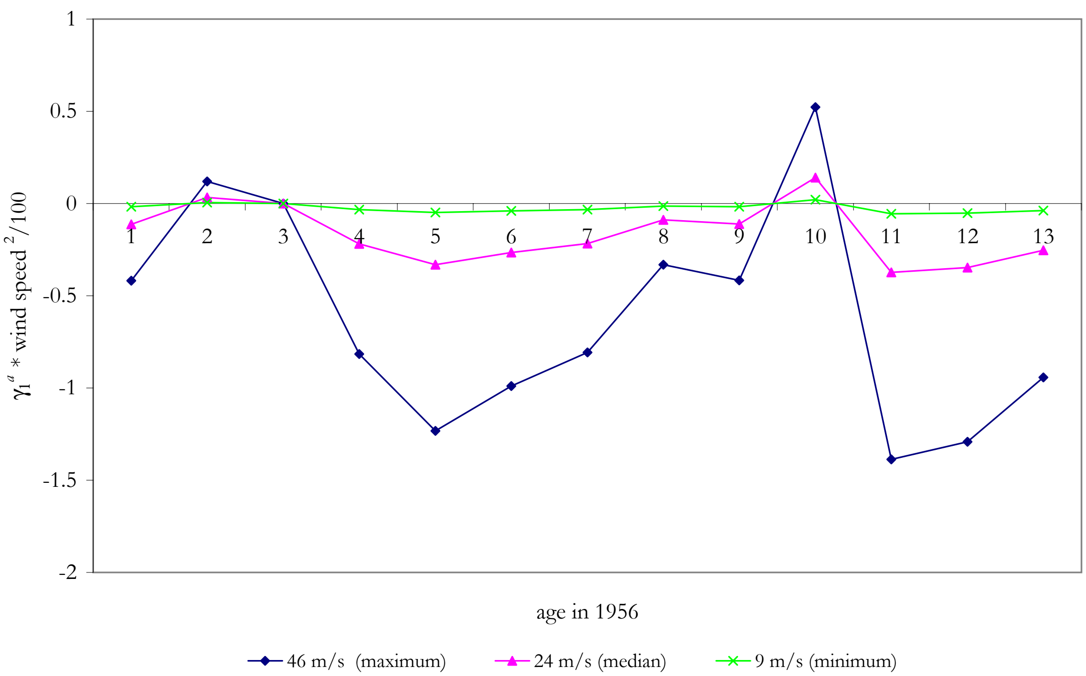
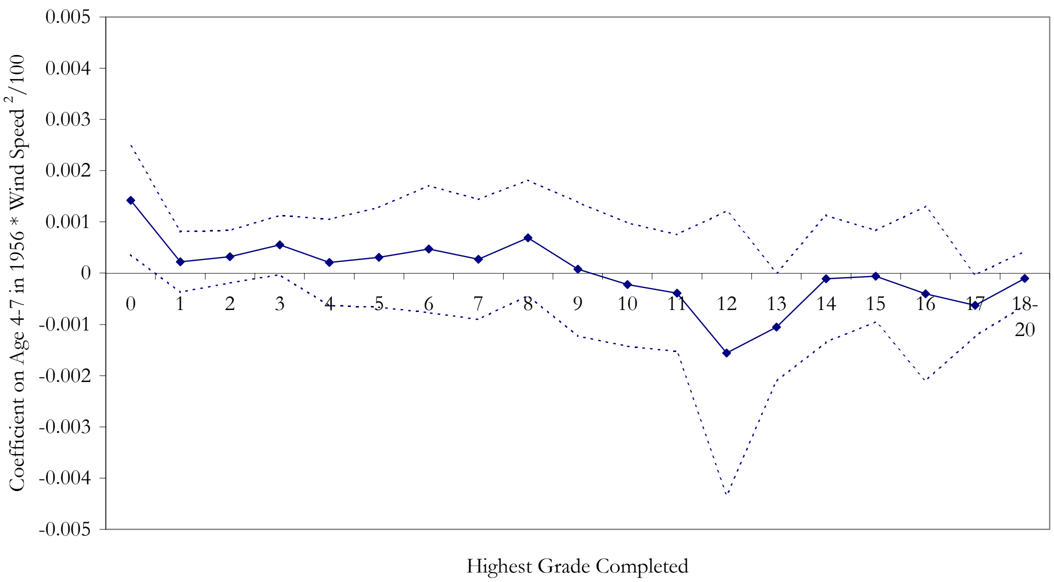
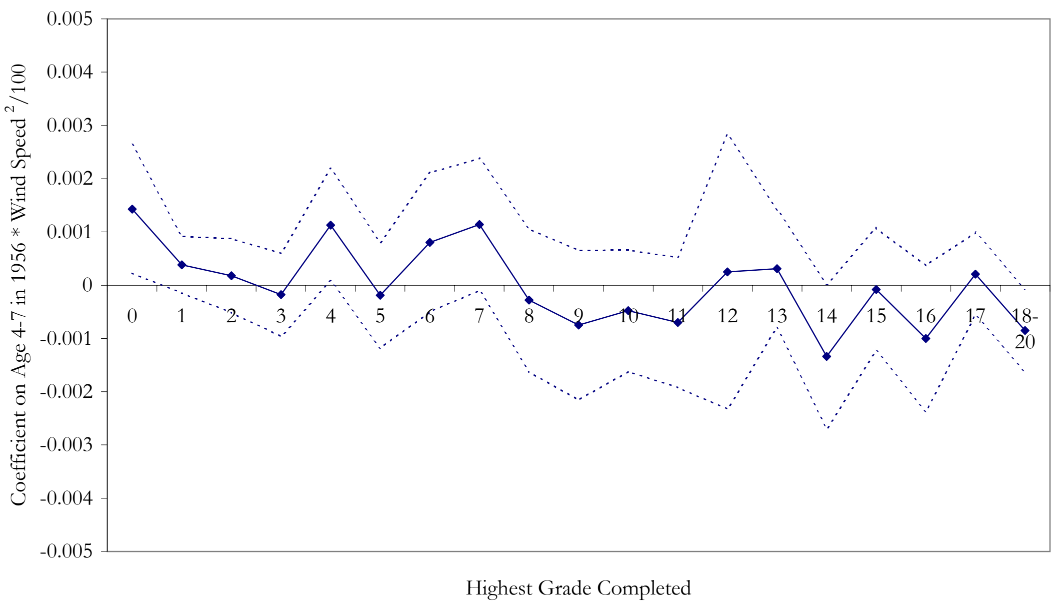


FIGURE 5 - REDUCED FORM EFFECTS OF HURRICANE BETSY BY LEVEL OF EDUCATION

A. Women



B. Men



Notes: Each point on the solid line is the coefficient from a separate regression where the dependent variable is an indicator for the level of education on the horizontal axis. The dotted lines connect bounds on 90 percent confidence intervals on the estimates. Underlying standard errors are robust to clustering at the cohort/municipality group level.