Online Resource 1

Diverging Mobility Trajectories: Grandparent Effects on Educational Attainment in One- and Two-Parent Families in the United States

Xi Song

Table S1 Additive Model Estimates for Direct Effects of Grandparents' Education on Grandchildren's Education based on Mixed-Effects Models with Random Intercepts (Regular) and Marginal Structural Models (MSM)

	Full Sample		African Americans		Whites	
	Regular	MSM	Regular	MSM	Regular	MSM
Grandparents, generation 1						
Years of schooling (A_1)	0.015	0.056***	0.020	0.039*	0.008	0.055***
	(0.013)	(0.012)	(0.018)	(0.018)	(0.019)	(0.017)
Family structure (M_1) (ref: two-parent)						
One-parent, divorced	-0.210**	-0.337***	-0.007	-0.090	-0.408**	-0.574***
	(0.081)	(0.090)	(0.109)	(0.123)	(0.118)	(0.124)
One-parent, unmarried	0.239†	0.077	0.291†	0.186	0.268	0.022
	(0.140)	(0.154)	(0.162)	(0.177)	(0.276)	(0.287)
Disability	-0.223**	-	-0.067	-	-0.347***	-
	(0.075)		(0.099)		(0.107)	
Occupational status (socioeconomic index)	0.003	-	0.001	-	0.002	-
	(0.002)		(0.005)		(0.003)	
Own home	0.067	-	0.106	-	0.039	-
	(0.084)		(0.106)		(0.133)	
Average family income during G2's childhood	$4.57*10^{-6}$***	-	$3.45*10^{-6}$	-	$3.66*10^{-6}$**	-
	($1.27*10^{-6}$)		($2.98*10^{-6}$)		($1.40*10^{-6}$)	
Parents, generation 2						
Years of schooling (A_2)	0.256***	0.304***	0.198***	0.239***	0.296***	0.361***
	(0.017)	(0.018)	(0.025)	(0.027)	(0.024)	(0.024)
Family structure (M_2) (ref: two-parent)						
One-parent, divorced	-0.477***	-0.501***	-0.517***	-0.657***	-0.334***	-0.344***
	(0.068)	(0.074)	(0.114)	(0.111)	(0.087)	(0.100)
One-parent, unmarried	-0.498***	-0.547***	-0.450***	-0.614***	-0.500***	-0.591***
	(0.079)	(0.087)	(0.103)	(0.105)	(0.155)	(0.165)
Disability	-0.171**	-	-0.107	-	-0.188*	-
	(0.057)		(0.083)		(0.080)	
Occupational status (socioeconomic index)	0.009***	-	0.004	-	0.010***	-
	(0.002)		(0.004)		(0.003)	
Own home	0.288***	-	0.197	-	0.282*	-
	(0.079)		(0.100)		(0.143)	
Average family income during G2's childhood	$-3.46*10^{-7}$†	-	$7.05*10^{-6}$**	-	$-4.06*10^{-7}$*	-
	($1.94*10^{-7}$)		($2.11*10^{-6}$)		($1.96*10^{-7}$)	
Grandchildren, generation 3						
African Americans	0.019	-0.222**	-	-	-	-
	(0.086)	(0.084)				
Female	0.670***	0.675***	0.871***	0.876***	0.497***	0.507***
	(0.051)	(0.053)	(0.075)	(0.078)	(0.069)	(0.073)

Table S1. (Cont.)

Age group (ref: 25-34)						
35-44	-0.088*	-0.089	-0.045	-0.056	-0.115	-0.117
	(0.059)	(0.067)	(0.087)	(0.096)	(0.080)	(0.093)
45-54	0.002	0.018	0.028	0.004	-0.051	0.035*
	(0.111)	(0.119)	(0.143)	(0.149)	(0.179)	(0.186)
55-65	0.442*	0.531**	0.459*	0.497*	0.387	0.496*
	(0.177)	(0.191)	(0.222)	(0.238)	(0.298)	(0.248)
Religion (ref: Catholic)						
Jewish	0.255	0.620*	-0.100	0.136	0.259	0.545†
	(0.276)	(0.291)	(0.848)	(0.453)	(0.295)	(0.311)
Protestant	0.010	-0.068	0.251	0.144	-0.030	-0.110
	(0.095)	(0.100)	(0.199)	(0.216)	(0.110)	(0.111)
Others	-0.116	-0.228	0.335	0.217	-0.190	-0.306
	(0.154)	(0.172)	(0.288)	(0.311)	(0.183)	(0.199)
Region (ref: Northeast)						
North central	0.124	0.117	-0.110	-0.159	0.228†	0.219
	(0.113)	(0.125)	(0.221)	(0.254)	(0.133)	(0.136)
South	-0.086	-0.104	0.018	-0.066	-0.176	-0.171
	(0.108)	(0.119)	(0.200)	(0.225)	(0.131)	(0.140)
West	-0.135	-0.140	-0.112	-0.219	-0.151	-0.124
	(0.126)	(0.135)	(0.260)	(0.270)	(0.144)	(0.151)
Intercept	8.726***	8.645***	8.845***	9.118***	8.519***	8.005***
	(0.274)	(0.300)	(0.455)	(0.531)	(0.372)	(0.363)
Number of family lineages	1,485	1,485	586	586	899	899
Number of observations	5,357	5,357	2,525	2,525	2,832	2,832

Data sources: Multigenerational linked data from Panel Study of Income Dynamics, 1968-2013.
Notes: Figures in parentheses are robust standard errors from 20 imputed samples. $p\dagger < .1$, $p* < .05$, $p** < .01$, $p*** < .001$ (two-tailed tests). The final marginal structural models do not include the covariates, including grandparents' and parents' disability status, occupational status, family income, and homeownership, because they are used to construct the inverse probability weights and do not bias our estimates of exposure variables, namely grandparents' education, after the weighting.

Table S2 Interactive Model Estimates for Direct Effects of Grandparents' Education on Grandchildren's Education by Family Structures across Generations based on Mixed-Effects Models with Random Intercepts (Regular) and Marginal Structural Models (MSM)

	Full Sample		African Americans		Whites	
	Regular	MSM	Regular	MSM	Regular	MSM
Grandparents, generation 1						
Years of schooling (A_1)	0.049**	0.089***	0.095***	0.121***	0.028	0.075**
	(0.018)	(0.019)	(0.030)	(0.033)	(0.024)	(0.024)
Family structure in G1 (M_1) (ref: two-parent)						
One-parent, divorced	1.190**	1.608**	0.496	1.161	1.224†	1.318†
	(0.453)	(0.521)	(0.637)	(0.789)	(0.714)	(0.770)
One-parent, unmarried	0.205	0.758	-0.524	0.194	0.520	0.467
	(0.817)	(0.942)	(0.993)	(1.178)	(1.482)	(1.246)
A_1 × Family structure in G1 (M_1) (ref: two-parent)						
One-parent, divorced	-0.031	-0.050†	-0.034	-0.058	-0.021	-0.026
	(0.028)	(0.030)	(0.036)	(0.042)	(0.043)	(0.047)
One-parent, unmarried	0.033	0.021	0.023	0.016	0.020	0.010
	(0.042)	(0.047)	(0.053)	(0.061)	(0.068)	(0.073)
A_1× Family structure in G2 (M_2) (ref: two-parent)						
One-parent, divorced	-0.027	-0.026	-0.085*	-0.082*	-0.020	-0.023
	(0.022)	(0.024)	(0.036)	(0.042)	(0.029)	(0.035)
One-parent, unmarried	-0.088***	-0.096***	-0.109***	-0.115***	-0.124**	-0.131*
	(0.024)	(0.028)	(0.033)	(0.036)	(0.048)	(0.057)
Disability	-0.219**	-	-0.079	-	-0.343***	-
	(0.075)		(0.100)		(0.107)	
Occupational status (socioeconomic index)	0.002	-	0.001	-	0.002	-
	(0.002)		(0.005)		(0.003)	
Own home	0.071	-	0.114	-	0.048	-
	(0.084)		(0.106)		(0.134)	
Average family income during G2's childhood	$3.95*10^{-6}$**	-	$2.88*10^{-6}$	-	$3.46*10^{-6}$*	-
	$(1.27*10^{-6})$		$(2.98*10^{-6})$		$(1.41*10^{-6})$	
Parents, generation 2						
Years of schooling (A_2)	0.276***	0.347***	0.183***	0.264***	0.304***	0.388***
	(0.024)	(0.026)	(0.041)	(0.043)	(0.030)	(0.033)
Family structure in G2 (M_2) (ref: two-parent)						
One-parent, divorced	-0.618	-0.316	-0.701	-0.463	-0.343	0.011
	(0.410)	(0.477)	(0.700)	(0.872)	(0.525)	(0.608)
One-parent, unmarried	0.995*	1.398*	0.772	0.965	0.436	0.949
	(0.464)	(0.561)	(0.622)	(0.749)	(0.868)	(1.044)
A_2 × Family structure in G1 (M_1) (ref: two-parent)						
One-parent, divorced	-0.081*	-0.106**	-0.012	-0.052	-0.102†	-0.114*
	(0.035)	(0.041)	(0.050)	(0.061)	(0.052)	(0.054)

Table S2. (Cont.)

One-parent, unmarried	-0.018	-0.062	0.049	-0.010	-0.033	-0.040
	(0.059)	(0.066)	(0.070)	(0.080)	(0.114)	(0.086)
$A_2\times$ Family structure in G2 (M_2) (ref: two-parent)						
One-parent, divorced	0.034	0.009	0.078	0.047	0.018	-0.007
	(0.033)	(0.037)	(0.053)	(0.064)	(0.043)	(0.046)
One-parent, unmarried	-0.050	-0.080†	-0.015	-0.040	0.029	-0.011
	(0.037)	(0.046)	(0.048)	(0.056)	(0.075)	(0.093)
Disability	-0.172**	-	-0.110	-	-0.177*	-
	(0.057)		(0.083)		(0.080)	
Occupational status (socioeconomic index)	0.009***	-	0.005	-	0.010***	-
	(0.002)		(0.004)		(0.003)	
Own home	0.312***	-	0.211*	-	0.311*	-
	(0.079)		(0.100)		(0.143)	
Average family income during G2's childhood	$-3.06*10^{-7}$	-	$6.83*10^{-6}$***	-	$-3.75*10^{-7}$†	-
	($1.94*10^{-7}$)		($2.13*10^{-6}$)		($2.00*10^{-7}$)	
Grandchildren, generation 3						
African Americans	0.038	-0.183*	-	-	-	-
	(0.086)	(0.085)				
Female	0.667***	0.667***	0.863***	0.878***	0.503***	0.505***
	(0.051)	(0.053)	(0.075)	(0.078)	(0.069)	(0.073)
Age group (ref: 25-34)						
35-44	-0.093	-0.105	-0.057	-0.074	-0.112	-0.121
	(0.059)	(0.067)	(0.087)	(0.097)	(0.080)	(0.093)
45-54	-0.006	-0.003	0.019	-0.003	-0.031	0.039
	(0.111)	(0.120)	(0.143)	(0.150)	(0.180)	(0.188)
55-65	0.447*	0.497**	0.446*	0.467*	0.439	0.525*
	(0.177)	(0.184)	(0.222)	(0.236)	(0.300)	(0.245)
Religion (ref: Catholic)						
Jewish	0.263	0.532†	-0.134	0.033	0.294	0.517†
	(0.276)	(0.289)	(0.848)	(0.405)	(0.297)	(0.309)
Protestant	0.006	-0.051	0.254	0.188	-0.029	-0.100
	(0.095)	(0.098)	(0.200)	(0.212)	(0.111)	(0.111)
Others	-0.130	-0.225	0.332	0.248	-0.229	-0.336†
	(0.154)	(0.171)	(0.290)	(0.321)	(0.184)	(0.198)
Region (ref: Northeast)						
North central	0.110	0.088	-0.150	-0.185	0.222†	0.200
	(0.113)	(0.121)	(0.221)	(0.249)	(0.134)	(0.134)
South	-0.098	-0.119	-0.017	-0.085	-0.173	-0.182
	(0.108)	(0.115)	(0.200)	(0.221)	(0.132)	(0.138)
West	-0.112	-0.128	-0.126	-0.209	-0.108	-0.096
	(0.126)	(0.131)	(0.260)	(0.266)	(0.146)	(0.149)
Intercept	8.148***	7.696***	8.365***	7.997***	8.132***	7.392***
	(0.348)	(0.375)	(0.624)	(0.717)	(0.451)	(0.460)
Number of families	1,485	1,485	586	586	899	899
Number of observations	5,357	5,357	2,525	2,525	2,832	2,832

Data sources: Multigenerational linked data from Panel Study of Income Dynamics, 1968-2013.
Notes: Figures in parentheses are robust standard errors. p† < .1, p* < .05, p** < .01, p*** < .001 (two-tailed tests).

Table S3 Additive Model Estimates for Direct Effects of Grandparents' Education on Grandchildren's Education based on Marginal Structural Models (MSM) of Mixed-Effects Models with Random Intercepts

	African Americans				Whites			
	Paternal grandparent	Maternal grandparent	Grandfather	Grandmother	Paternal grandparent	Maternal grandparent	Grandfather	Grandmother
Grandparents, generation 1								
Years of schooling (A_1)	0.032	0.036†	0.030	0.042*	0.067**	0.049*	0.069***	0.053**
	(0.031)	(0.020)	(0.019)	(0.019)	(0.025)	(0.023)	(0.017)	(0.018)
Family structure (M_1) (ref: two-parent)								
One-parent, divorced	-0.010	-0.085	-0.165	-0.124	-0.565**	-0.646***	-0.685**	-0.554***
	(0.221)	(0.129)	(0.222)	(0.122)	(0.217)	(0.151)	(0.163)	(0.125)
One-parent, unmarried	-0.166	0.362†	0.462	0.157	0.201	-0.051	-0.219	0.024
	(0.300)	(0.191)	(0.290)	(0.178)	(0.374)	(0.340)	(0.447)	(0.306)
Parents, generation 2								
Years of schooling (A_2)	0.258***	0.256***	0.286***	0.240***	0.389***	0.386***	0.362***	0.374***
	(0.045)	(0.032)	(0.039)	(0.028)	(0.034)	(0.031)	(0.027)	(0.023)
Family structure (M_2) (ref: two-parent)								
One-parent, divorced	-0.660**	-0.617***	-0.612***	-0.658***	-0.567***	-0.170	-0.446***	-0.337***
	(0.204)	(0.134)	(0.143)	(0.115)	(0.163)	(0.122)	(0.108)	(0.102)
One-parent, unmarried	-0.958***	-0.489***	-0.657***	-0.589***	-1.083**	-0.476**	-0.519**	-0.711***
	(0.211)	(0.129)	(0.134)	(0.106)	(0.394)	(0.181)	(0.198)	(0.159)
Number of family lineages	228	529	355	574	491	653	732	878
Number of observations	628	1,961	1,408	2,433	1,248	1,672	2,281	2,754

Data sources: Multigenerational linked data from Panel Study of Income Dynamics, 1968-2013.
Notes: Figures in parentheses are standard errors from 20 imputed samples. p† < .1, p* < .05, p** < .01, p*** < .001 (two-tailed tests). Coefficients of control variables including grandparents' and parents' disability status, occupational status, family income, and homeownership as well as parents' age groups, sex, region, and religion, are not presented in the table.

Table S4 Interactive Model Estimates for Direct Effects of Grandparents' Education on Grandchildren's Education based on Marginal Structural Models (MSM) of Mixed-Effects Models with Random Intercepts

	African Americans				Whites			
	Paternal grandparent	Maternal grandparent	Grandfather	Grandmother	Paternal grandparent	Maternal grandparent	Grandfather	Grandmother
Grandparents, generation 1								
Years of schooling (A_1)	0.063	0.136***	0.069*	0.112**	0.072*	0.086**	0.073***	0.079**
	(0.051)	(0.040)	(0.029)	(0.036)	(0.030)	(0.033)	(0.020)	(0.025)
A_1 × Family structure in G1 (M_1) (ref: two-parent)								
One-parent, divorced	-0.052	-0.060	-0.093†	-0.039	-0.015	-0.067	0.018	-0.007
	(0.068)	(0.045)	(0.055)	(0.044)	(0.089)	(0.060)	(0.033)	(0.050)
One-parent, unmarried	0.003	0.000	-0.073	0.076	-0.083†	0.101	-0.104†	-0.044
	(0.065)	(0.070)	(0.074)	(0.071)	(0.048)	(0.084)	(0.056)	(0.057)
A_1× Family structure in G2 (M_2) (ref: two-parent)								
One-parent, divorced	-0.002	-0.102*	-0.040	-0.086†	0.008	-0.041	-0.003	-0.058
	(0.093)	(0.047)	(0.040)	(0.045)	(0.049)	(0.043)	(0.051)	(0.038)
One-parent, unmarried	-0.018	-0.126**	-0.040	-0.114**	-0.160	-0.150*	0.018	-0.097†
	(0.066)	(0.045)	(0.039)	(0.039)	(0.123)	(0.062)	(0.131)	(0.053)
Number of family lineages	228	529	355	574	491	653	732	878
Number of observations	628	1,961	1,408	2,433	1,248	1,672	2,281	2,754

Data sources: Multigenerational linked data from Panel Study of Income Dynamics, 1968-2013.
Notes: Figures in parentheses are standard errors from 20 imputed samples. p† < .1, p* < .05, p** < .01, p*** < .001 (two-tailed tests). Coefficients of control variables including grandparents' and parents' disability status, occupational status, family income, and homeownership as well as parents' age groups, sex, region, and religion, are not presented in the table.

Table S5 Interactive Model Estimates for Direct Effects of Grandparents' Education on Grandchildren's Education by Family Structures across Generations based on Marginal Structural Models (MSM)

	Full Sample		African Americans		Whites	
	Model 1	Model2	Model 3	Model 4	Model 5	Model 6
Grandparents, generation 1						
Years of schooling (A_1)	0.100***	0.099***	0.112**	0.116**	0.080***	0.073**
	(0.020)	(0.020)	(0.037)	(0.038)	(0.025)	(0.025)
A_1 × Family structure in G1 (M_1) (reference: two-parent)						
One-parent, divorced	-0.055†	-0.055†	-0.068	-0.068	-0.027	-0.027
	(0.032)	(0.032)	(0.043)	(0.043)	(0.050)	(0.050)
One-parent, unmarried	0.018	0.017	0.017	0.017	0.007	0.010
	(0.050)	(0.050)	(0.063)	(0.064)	(0.077)	(0.078)
A_1× Family structure in G2 (M_2) (reference: two-parent)						
One-parent, divorced	-0.029	-0.028	-0.080†	-0.086*	-0.027	-0.012
	(0.026)	(0.027)	(0.043)	(0.044)	(0.037)	(0.038)
One-parent, unmarried	-0.108***	-0.104***	-0.123***	-0.128***	-0.130*	-0.101†
	(0.029)	(0.030)	(0.037)	(0.037)	(0.061)	(0.061)
Number of missing grandparents (reference: two)						
One	1.424†	1.407†	1.130	1.498	0.623	1.054
	(0.825)	(0.817)	(1.027)	(1.005)	(1.195)	(1.122)
Three	-0.052	-0.124	-0.225	-0.161	-0.063	-0.307
	(0.273)	(0.286)	(0.395)	(0.414)	(0.434)	(0.449)
A_1× # missing grandparents						
One missing grandparent	-0.131*	-0.127†	-0.087	-0.138	-0.080	-0.102
	(0.066)	(0.065)	(0.096)	(0.093)	(0.090)	(0.084)
Three missing grandparent	0.001	0.002	0.021	0.023	0.004	0.007
	(0.025)	(0.025)	(0.039)	(0.039)	(0.039)	(0.039)
Family structure in G2 (M_2) × # missing grandparents						
One-parent, divorced, one missing grandparent	--	-0.349 (0.407)	--	-0.174 (0.703)	--	-0.311 (0.499)
One-parent, divorced, three missing grandparent	--	0.187 (0.591)	--	0.687 (0.640)	--	-2.054* (0.984)
One-parent, unmarried, one missing grandparent	--	-0.031 (0.172)	--	-0.281 (0.243)	--	0.366 (0.249)
One-parent, unmarried, three missing grandparent	--	0.198 (0.172)	--	-0.020 (0.212)	--	0.571 (0.363)
Number of family lineages	1,485	1,485	586	586	899	899
Number of observations	5,357	5,357	2,525	2,525	2,832	2,832

Data sources: Multigenerational linked data from Panel Study of Income Dynamics, 1968-2013.
Notes: Figures in parentheses are robust standard errors. p† < .1, p* < .05, p** < .01, p*** < .001 (two-tailed tests). Coefficients of main effects of parents' family structure and education as well as interactions between

parents' education and family structure in G1 and G2 are omitted from the table. Coefficients of control variables including grandparents' and parents' disability status, occupational status, family income, and homeownership as well as grandchildren's age groups, sex, region, and religion are not presented in the table. Individuals need to have at least one grandparent information available to be included into the analysis. Because of the sampling design of the PSID, most grandchildren have either paternal or maternal grandparents unavailable, namely two missing grandparents.

SENSITIVITY ANALYSIS

The causal interpretation for results presented in Tables 4 and 5 rests on the assumption that unobserved confounding variables that affect education and family structure across generations (i.e., $W_{(t)}$ in Figure 1) do not correlate. This assumption may be invalid because unmeasured factors, such as a genetic component of education-enhancing traits of grandparents and parents, may sort individuals into different educational groups. Such a selection mechanism may lead to spurious or overestimated effects of grandparents' education on grandchildren's education. By simulating a range of correlations between the unobserved variables ($W_{(t)}$) and education ($A_{(t)}$) across generations (shown in Figure S1), the sensitivity analysis assesses the extent to which the causal effect of grandparents' education is robust to the selection bias caused by the intergenerational transmission of unobserved variables. Figure S1 shows the new hypothetical causal diagram with the revised assumptions about unobserved variables. Note that the sensitivity analysis shows only one among many possible scenarios of relationships among the unobserved variables.

The sensitivity analysis follows two steps. In the first step, I assume a single variable $W_{(t)}$ that is a combination of all the omitted variables and thus captures selection bias from any source. I simulate plausible values for the association between $W_{(t)}$ and $A_{(t)}$ (i.e., θ) and between $W_{(t)}$ and $W_{(t-1)}$ (i.e., π), both of which range from 0 (no correlation) to 1 (perfect correlation). Given that all variables are standardized, the parameter θ can be roughly interpreted as the intergenerational correlation in the unobserved variables. The parameter π refers to the correlation between education (or family structure) and the unobserved variables in each generation, which reflects the magnitude of the selection bias. According to the causal mediation principles (Pearl 2014), we do not need to assume the effect of unobserved variables $U_{(t)}$ on covariates $L_{(t)}$ because these variables are not directly associated with the exposure variables $A_{(t)}$, mediators $M_{(t)}$, or the outcome variable Y, and biases caused by these variables are already addressed in the marginal structural models based on inverse probability weights. In the second step, I estimate grandparent effects by treating the simulated unobserved variables as time-varying covariates and include them into the weighted mixed-effect models. Lastly, I compare the bias-corrected estimates of grandparent effects with the original ones.

Figure S2 displays adjusted average grandparent effects, based on a range of selected values of θ and π in the sensitivity analysis. When the parameter π is equal to 0, that is, no intergenerational transmission of the unobserved variables, the estimated grandparent effects simply replicate previous estimates shown in Table S9. To speed up the simulation, I rely on data with complete cases rather than data with missing-data imputation. Despite a wide range of possible combinations between values of θ and π, Figure S2 only presents results from scenarios when $\theta = \pi$. Results from the sensitivity analysis based on other possible values of θ and π are available upon request.

In general, the estimated grandparent effects decline with the increase of θ or π. The horizontal line refer to the scenario under which the average grandparent effect are zero. The shaded areas refer to 95% confidence intervals of the estimates. Estimates that fall below this line indicate that we need to reconsider the causal interpretation for influences of grandparents'

education on grandchildren's education because of potential selection mechanisms caused by the unobserved variables.

The results suggest that for African Americans, we would expect to see a positive causal effect of grandparents' education on grandchildren's education as long as the intergenerational correlation of the unobserved variables and the correlation between education and the unobserved variables are both below roughly 0.9. For whites, the causal effect of grandparents persists even if the unobserved variable W_1 and grandparents' education A_1 are perfectly correlated. Therefore, the sensitivity analysis indicates that if there is any intergenerational transmission of the unobserved variables, the magnitude would have to be unreasonably large to alter our inferences about the causal effects of grandparents' education on grandchildren's education. The interpretation of the grandparent effect is subject to revision if future research reveals a stronger intergenerational transmission of the unobserved variables.

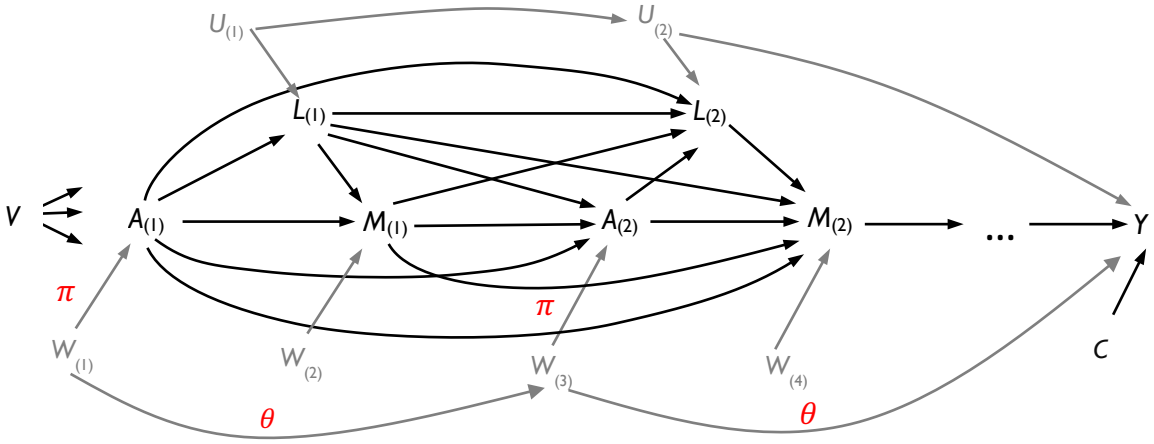

Fig. S1. A Hypothetical Causal Framework of Multigenerational Social Mobility with Unmeasured Time-Varying Variables

Notes: $A_{(1)}$ = G1's educational attainment, $M_{(1)}$ = family structure in G1 during G2' childhood, $L_{(1)}$ = socioeconomic characteristics, such as family income, occupational status, home ownership, and disability status in G1 during G2' childhood, $A_{(2)}$ = G2' education, $M_{(2)}$ = family structure in G2 during G3's childhood, U, W = unmeasured variables, Y = G3's educational attainment. C = exogenous variables that influence Y, such as gender and age group. V = family invariant variables, such as race. Relationships among variables are encoded in the directed acyclic graph (DAG) above. For the sake of simplicity, the graph omits all the arrows pointing from $A_{(t)}$, $L_{(t)}$, $M_{(t)}$, and $W_{(t)}$ to Y. While not explicitly shown in the graph, the strength of grandparent's direct effect, i.e., the arrow pointing from $A_{(1)}$ to Y, may vary by the values of $M_{(1)}$ and $M_{(2)}$ according to the research hypothesis of this study. Unlike Figure 1, this graph assumes that the errors of $W_{(t)}$ are correlated with each other as well as with Y. The correlations of these standarized variables are represented by π and θ.

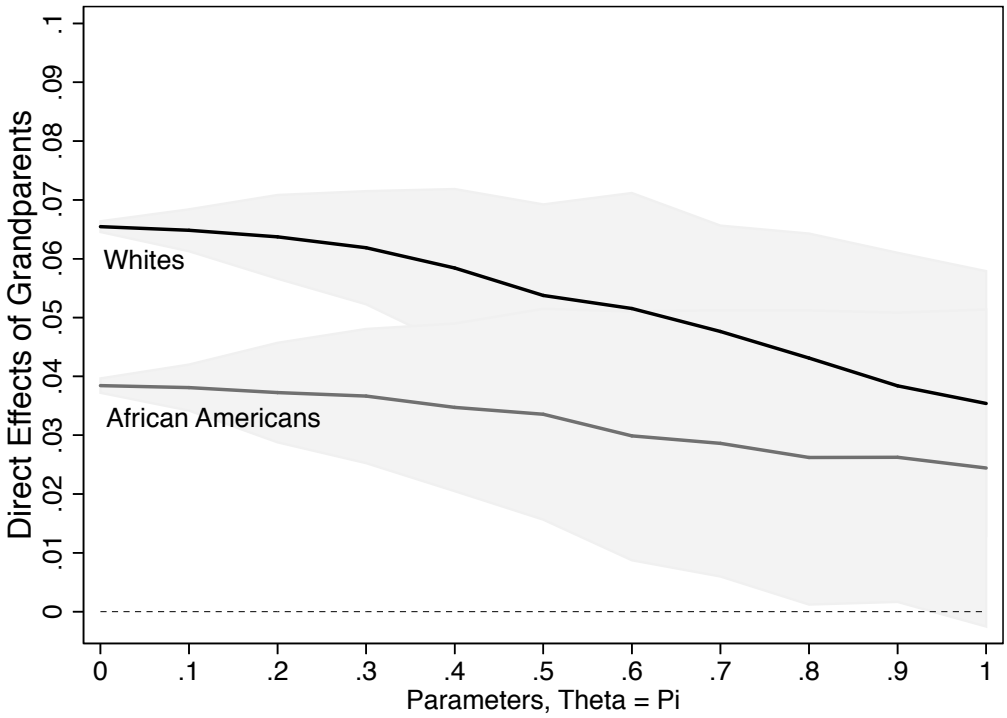

Fig. S2. Sensitivity Analyses for Effects of Grandparents' Education on Grandchildren's Education under Various Assumptions about Strengths of Unobserved Variables W

Notes: The parameter π can be roughly interpreted as the selection bias, or the correlation between W and A. The parameter θ refers to the intergenerational correlation between $W_{(t)}$ and $W_{(t+1)}$. Specifically, I assume that the unobserved variable $W_1 = \pi * A_1^* + \epsilon_1$ and $W_3 = \theta * W_1^* + \pi * A_2^* + \pi * Y^* + \epsilon_2$, where W^*, A^*, and Y^* are standardized variables of W, A, and Y. The values of $\theta, \pi \in [0,1]$. For the sake of simplicity, this figure shows only results from the sensitivity analysis when θ=π. The bias-corrected estimates for each value of the parameters are based on point estimates from 200 simulated samples. The horizontal line refers to the scenario under which the average grandparent effect is zero. The shaded areas refer to 95% confidence intervals. To speed up the computation, the sensitivity results are based on data with complete cases rather than data with missing-data imputation.