Online Appendix for "Macroeconomic Effects of 'Free' Secondary Schooling in the Developing World"

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A. Appendix Figures and Tables

Figure A.1: SHS Completion by Quartile of Test Score: Data vs Model

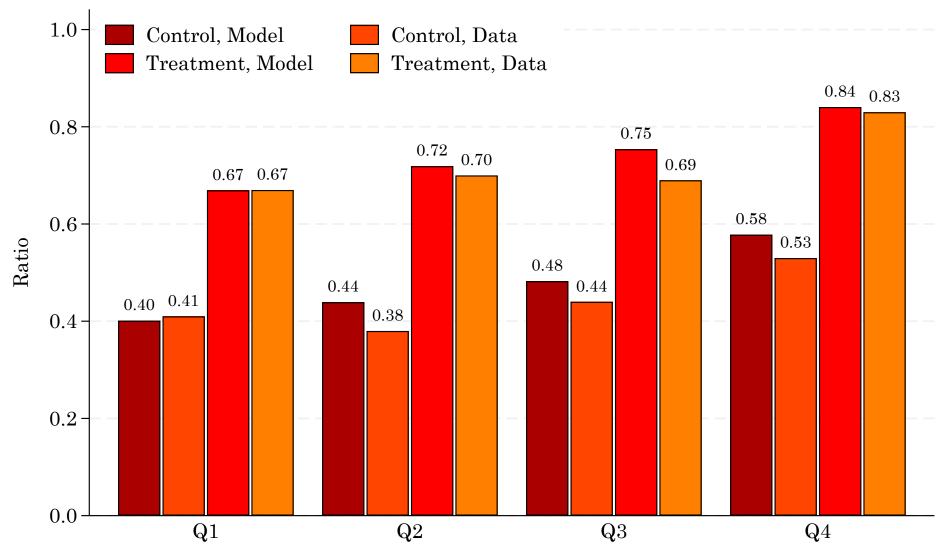
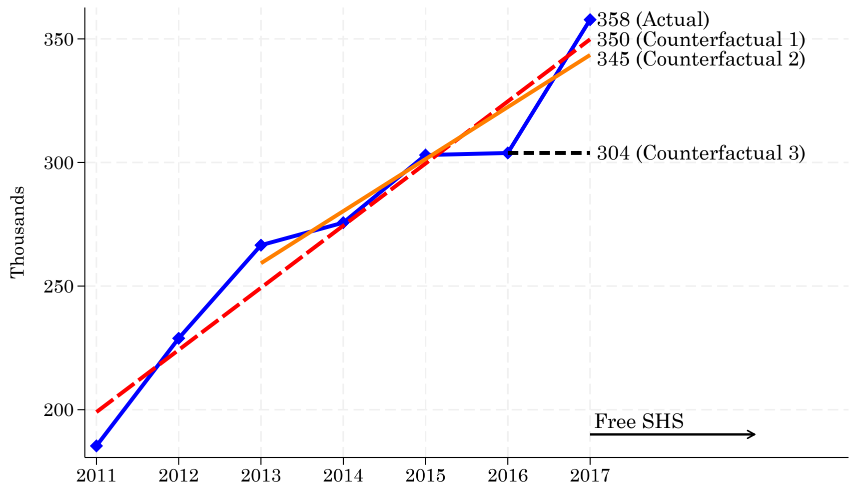


Figure A.2: Total SHS Enrollment in Ghana



Note: This figure displays the plots corresponding to the various SHS enrollment counterfactuals described in Table A.7. Counterfactual 1 refers to the best-fit line from 2011-2017, Counterfactual 2 refers to the best-fit line from 2013-2017, and Counterfactual 3 refers to the assumption that enrollment levels in 2017 would have been the same as those in 2016 regardless of policy.

Figure A.3: Compensating Variation of Secondary School to Children

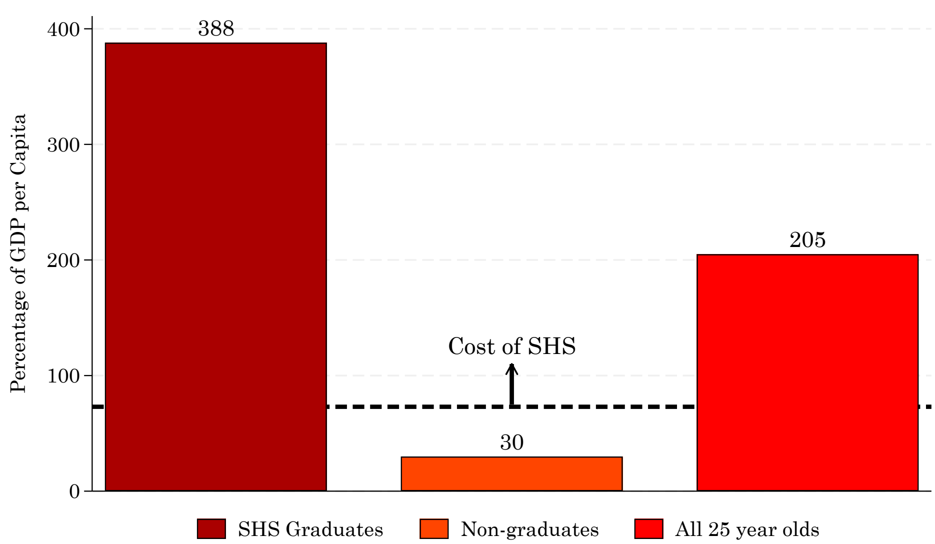


Table A.1: Free Secondary Schooling Policies in Developing Countries

Country	Year	Requirement
Benin	2007	Pass Brevet d'Etudes du Premier Cycle
Gambia	2015	Pass Basic Education Certificate Exam
Ghana	2017	Pass Basic Education Certificate Exam
Kenya	2008	Pass Certificate of Primary Education Exam
Malawi	2019	Pass Primary School Leaving Certificate Exam
Mauritius	2016	Pass General Certificate of Education Exam
Nepal	2018	Pass final district-level exam
Philippines	1988	Do not fail in two consecutive years
Rwanda	2012	Score $\geq$ 'High' on O-level Test
Sierra Leone	2018	Score $\geq$ 6 on Basic Education Certificate Exam
Tanzania	2015	Pass Standard 7 Exam
Uganda	2007	Score $\geq$ 28 in Primary School Leaving Exam
Zambia	2022	Pass Baccalaureate Exam

Note: This table reports the year that each country adopted a free secondary schooling policy and the merit requirement to attend secondary schooling.

Table A.2: Statistics from Figure 2 Economies

	Low Misalloc.	High Misalloc.
Aggregate SHS Attendance	39%	38%
SHS Wage Premium	130%	130%
Treatment Effect on Attend.	+11pp	+50pp
Treatment Effect on Wages	+2.4%	+28%
GDP gains from Free SHS	+0.4%	+12%

Note: This table displays various statistics calculated from the examples economies used to produce Figure 2 and the surrounding discussion.

Table A.3: Control Earnings from Duflo et al. (2025)

Year	Age	Earnings (DDK)	Ghanaian CPI (WB)	Real Earnings
2019	28-29	1458	278.5	524
2023	32-33	3193	610.0	523
Ratio		2.19	2.19	1.0

Note: This table displays nominal earnings in the control group from Duflo et al. (2025) as a function of age, as well as Ghanaian CPI and real earnings.

Table A.4: Employment Rates from 2016/2017 GLSS

	Employed (A)	In School/Training (B)	Neither (A) nor (B) (C)	Employment Rate (A/(A+C))
15-20 years	20.8	63.4	15.8	56.8
20-60 years	79.4	7.1	13.5	85.5
Ratio				0.66

Note: This table displays employment rates by age as computed in the 2016/2017 waves of the GLSS.

Table A.5: Labor Income Tax Schedule in Ghana

Income	Tax Rates
First 1,008 GHC (=up to 42% of GDP p.c.)	0%
Next 240 GHC (=up to 52% of GDP p.c.)	5%
Next 720 GHC (=up to 82% of GDP p.c.)	10%
Next 14,232 GHC (=up to 675% of GDP p.c.)	17.5%
Exceeding 16,200 GHC ($\geq$ 675% of GDP p.c.)	25%

Note: The table reports the marginal labor tax schedule in Ghana in 2011. It shows, by income in Ghanaian Cedis (GHC), the marginal tax rate assessed on labor income, and the corresponding ratio of GDP per capita in Ghana in 2011.

Table A.6: Duflo et al. (2025) Sample vs Nationally Representative Sample

	DDK Control Group	GLSS Rep. Sample
Total Years of Education	11.4	7.6
% Completed SHS	44%	28%
% Self Employed	25%	36%
% w/ Wage Job	35%	26%

Note: This table compares education levels, SHS completion rates, self employment rates, and rates of wage employment between the control group in (Duflo et al., 2025) and a comparable representative sample constructed from the Ghanaian Living Standards Survey. The experimental control group was surveyed in 2019 at an average age of around 28. We use the 2016/2017 waves of the GLSS and limit our sample to 25-30 year olds in order to construct a comparable group.

Table A.7: Actual and Counterfactual SHS Enrollment Increases, 2016 to 2017

	Number	Percent
	Increases in Enrollment	
Actual SHS Enrollment Increase	54,000	17.8
Counterfactual 1 (Trend Since 2011)	46,000	15.1
Counterfactual 2 (Trend Since 2013)	41,000	13.5
Counterfactual 3 (No Change)	0	0
	Increase due to 'Free SHS' (%)	
Counterfactual 1	8,000	2.6
Counterfactual 2	13,000	4.3
Counterfactual 3	54,000	17.8

Note: This table displays the numeric values corresponding to the various SHS enrollment counterfactuals displayed in Figure A.2.

B. Model Appendix

In this appendix we define the concepts of recursive competitive equilibrium and balanced growth path for our model. Letting X denote the vector of individual state variables $(\tau, a, z_p, s_p, \zeta_p, \delta_J, \delta_S, z_c, s_c, \tilde{z}_c, \zeta_c)$, a recursive competitive equilibrium is defined as follows.

Definition: A **recursive competitive equilibrium** consists of

1. A price system $w_S(f, P)$, $w_U(f, P)$
2. Household value functions $V(X, f, P)$ and policy functions $a'(X, f, P)$, $c(X, f, P)$, $s_c'(X, f, P)$
3. Perceived laws of motion $f' = F(f, P), P' = H(f, P)$

such that

a) V, a', c, s_c' solve the household's optimization problem given w_S, w_U, F, P.

b) For all f, P,

$$w_S(f, P) = (1-\alpha) A K^{\alpha} (N_J)^{\lambda-1} \left[(N_J)^{\lambda} + (N_S)^{\lambda}\right]^{\frac{1-\alpha}{\lambda}-1},$$

$$w_U(f, P) = (1-\alpha) A K^{\alpha} (N_S)^{\lambda-1} \left[(N_J)^{\lambda} + (N_S)^{\lambda}\right]^{\frac{1-\alpha}{\lambda}-1},$$

$$r^* = \alpha A K^{\alpha-1} \left[(N_J)^{\lambda} + (N_S)^{\lambda}\right]^{\frac{1-\alpha}{\lambda}}.$$

c) Markets clear:

$$N_J = \Big[\int_{6\leq\tau\leq 12, s_p=J} \zeta_p h(z_p, s_p) f(X) dX + \int_{9\leq\tau\leq 10, s_c'(X,f,P)=J} \zeta_c h(z_c, s_c') f(X) dX\Big] P,$$

$$N_S = \Big[\int_{6\leq\tau\leq 12, s_p=S} \zeta_p h(z_p, s_p) f(X) dX + \int_{\tau=10, s_c=S} \zeta_c h(z_c, s_c') f(X) dX\Big] P.$$

d) Perceived laws of motion for f and P coincide with those induced from household policy functions a', c, s_c'.

The balanced growth path is a particular type of recursive competitive equilibrium defined below.

Definition: A **balanced growth path** is a recursive competitive equilibrium that satisfies the following properties:

1) Aggregate population grows at a constant rate: $\frac{P'}{P} = \nu$ for some constant $\nu > 0$.

2) The distribution of X is stationary: $f' = f$.

3) The household value and policy functions do not depend on P.

Along the balanced growth path, aggregate population grows but the distribution of households across individual states remains stationary. Further, the household value and policy functions are independent of aggregate population, and thus household behavior remains the same over time conditional on the individual states.

Now we walk through the details of population growth within the model and discuss how model parameters translate to outcomes that are measured in data such as the aggregate population growth rate and the number of children per household. We start with the most general case that applies to any equilibrium whether it satisfies the properties of a balanced growth path or not. Later, we specialize to the case of the balanced growth path to provide more explicit formulas. By definition, the aggregate population growth rate is given by the formula

$$\text{Agg. Pop. Growth Rate} = \frac{\text{\# births} - \text{\# deaths}}{P} \tag{13}$$

Given the aggregate state variables of the economy, f and P, we have the following accounting equations for births and deaths

$$\text{\# births} = \big[\nu_J \int_{s_p=J,\tau=5} f(X)dX + \nu_S \int_{s_p=S,\tau=5} f(X)dX\big] P \tag{14}$$

$$\text{\# deaths} = \big[\int_{\tau=14} f(X)dX\big] P \tag{15}$$

In any given period, the aggregate population growth rate can be computed from state variables as

$$\nu - 1 = \nu_J \int_{s_p=J,\tau=5} f(X)dX + \nu_S \int_{s_p=S,\tau=5} f(X)dX - \int_{\tau=14} f(X)dX \tag{16}$$

Note that as written, $\nu - 1 > 0$ is the aggregate population growth rate such that $P' = \nu P$. To compare to data, it must be converted to an annual percentage growth rate.

Recall that the aggregate population growth rate is constant along the balanced growth path by definition. By leveraging this assumption we can calculate the aggregate population growth rate as a function of educational shares along the balanced growth path analytically. This calculation provides insight into the changes in population dynamics that can be expected due to changes in education. Such changes are important for our general equilibrium analysis.

With the aggregate population growth rate fixed at $\nu - 1$, we know that the ratio of the population of households of age x and households of age y must be given by:

$$\frac{\int_{\tau=x} f(X)dX}{\int_{\tau=y} f(X)dX} = \nu^{y-x} \tag{17}$$

From that fact that $\tau \in \{1, \cdots, 14\}$ and $\int f(X)dX = 1$ because f is a pdf, we can derive that along the balanced growth path with aggregate population growth rate $\nu - 1$ the following equations are true

$$\int_{\tau=14} f(X)dX = \frac{\nu - 1}{\nu^{14} - 1} \tag{18}$$

$$\int_{\tau=5} f(X)dX = \frac{(\nu - 1)\nu^9}{\nu^{14} - 1} \tag{19}$$

Finally, because household policy functions are invariant with respect to P and f is stationary along the balanced growth path, we have that the share of the adult population with a given level of education is the same for all ages. In particular, this implies that the education shares of the parents giving birth this period can be replaced by the aggregate education shares $\hat{J}, \hat{S}$.

$$\hat{J} \equiv \frac{\int_{s_p=J,\tau\geq 5} f(X)dX}{\int_{\tau\geq 5} f(X)dX} = \frac{\int_{s_p=J,\tau=5} f(X)dX}{\int_{\tau=5} f(X)dX} \tag{20}$$

$$\hat{S} \equiv \frac{\int_{s_p=S,\tau\geq 5} f(X)dX}{\int_{\tau\geq 5} f(X)dX} = \frac{\int_{s_p=S,\tau=5} f(X)dX}{\int_{\tau=5} f(X)dX} \tag{21}$$

Combining equations (18) to (21) with equation (16) yields the following equation which describes the aggregate population growth rate along the balanced growth path as an implicit function of the education shares of the population:

$$\nu - 1 = \left[\nu^9\left(\nu_J \hat{J} + \nu_S \hat{S}\right) - 1\right] \frac{\nu - 1}{\nu^{14} - 1} \tag{22}$$

which can be reduced to

$$\nu^5 = \nu_J \hat{J} + \nu_S \hat{S}. \tag{23}$$

One wrinkle not yet addressed is the fact that, as written, the balanced growth path of the model is not an attractor. That is, the model does not necessarily converge over time to the balanced growth path. To see why, consider a simplified model with two generations, each of whom do nothing other than live through their first period of life and, at the end of their second period of life, die and have ν children who become the new first generation. If the initial stocks of age 1 and age 2 agents are N_1 and N_2, the aggregate population growth rate will oscillate between $\frac{(\nu-1)N_2}{N_1+N_2}$ and $\frac{(\nu-1)N_1}{N_1+\nu N_2}$ indefinitely, never converging to a single constant rate, as there is no mechanism to close "gaps" in size between the initial stocks.

To address the computational issues arising from this fact, we assume that a negligibly small fraction of children leave their parents and have their own children one period earlier than the typical timing (that is, at age 20 rather than 25). This slight randomization in timing effectively mixes away any differences in the initial stocks of agents for each generation, ensuring that the model converges to the balanced growth path over time regardless of the initial state. In our computations, we assume the probability that any given child leaves early is 0.1 percent, small enough to ensure that this outcome has minimal impact on parents' decisions.

C. Intuition and Details on Model Identification

An important question is which of the targeted moments are most informative for each of the estimated parameter values. To help answer this question, the Jacobian matrix is presented in Appendix Table C.1. Here we summarize what we see as the main lessons from this matrix.

The population growth parameters ν_J and ν_S are, perhaps unsurprisingly, significant determinants of the aggregate population growth rate and the treatment effects on fertility. The variance and persistence parameters of the ability process, σ_v and ρ, naturally increase the variance of the permanent component of income and the intergenerational schooling correlation, but also have sizable effects on many other moments in equilibrium.

The effectiveness of schooling, η_S, and the intergenerational altruism parameter, b, govern the benefits of schooling and thus result in similar changes, notably a sizable increase in aggregate secondary attendance. The key difference is that η_S increases the treatment effect on human capital while b has a minimal effect, as it only impacts the parent's valuation of better schooling. Intuitively, the cost of schooling, Ψ_S, decreases school attendance, increases the treatment effect on schooling, and consequently increases (in absolute value) the treatment effect on fertility.

Finally, the savings wedge, χ, and the standard deviations of the test score noise and taste shocks, σ_ε and θ, all jointly impact secondary attendance in the top and bottom quartiles of the test score distribution as well as the difference in treatment effect between the quartiles. In fact this was the purpose of introducing these shocks into the model, and without them schooling completion and the treatment effect on schooling are always (counterfactually) much larger for those with higher test scores.

Table C.1: Elasticities of Moments to Parameters

	ν_J	ν_S	σ_υ	ρ	η_S	b	Ψ_S	σ_ε	θ	χ
Aggregate population growth	0.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TE on fertility	-12.0	12.8	-0.7	-1.3	0.8	-0.3	0.7	-0.1	0.0	0.1
Intergenerational school corr.	0.5	-0.1	0.1	1.6	-0.8	-0.5	0.6	-0.3	0.0	0.0
Var(permanent income)	-0.6	0.6	1.4	4.3	1.6	0.0	0.0	-0.2	0.0	0.0
TE on human capital	0.1	0.0	-0.1	-0.1	0.1	-0.1	0.2	0.0	0.0	0.0
TE on SHS completion	0.1	0.2	-0.7	-1.3	0.8	-0.3	0.7	-0.1	0.0	0.1
Aggregate SHS attendance	-1.0	0.6	0.5	1.1	1.2	0.6	-0.6	-0.3	0.0	0.0
SHS in top quartile	0.0	0.0	0.2	0.4	-0.1	0.0	0.0	-0.2	0.0	0.0
SHS in bot quartile	0.0	0.0	-0.3	-0.4	0.1	0.0	0.0	0.3	0.0	0.0
TE on SHS, Q4-Q1 difference	5.1	-2.3	2.6	6.8	-12.1	-0.6	-1.6	8.9	-0.6	-0.7

Note: This matrix represents the elasticities of each moment to each parameter. The entry in row r and column c represents the percentage change in model moment r resulting from a one-percent increase in model parameter c.

D. Welfare Analysis

In this section, we briefly discuss and quantify the impact of the free secondary school on welfare. Welfare is inherently hard to discuss in this setting due to the presence of endogenous fertility. Any policy that changes schooling attendance decisions also changes fertility, and the set of agents that exists in the post-policy balanced growth path is not the same as the set that would have existed had the policy never been implemented. In our case, free secondary school leads to higher attendance and higher fertility. Thus implementing the policy "creates" some individuals who would have otherwise never been born.

Rather than taking a stance on how to aggregate welfare across agents who may or may not exist depending on a policy change (as in Golosov, Jones, and Tertilt, 2007; De la Croix and Doepke, 2021), we simply report consumption-equivalent welfare separately for different groups of agents. In particular, we focus on parents with newborns at the time of policy implementation and their eventual children. Because these parents have already given birth, their fertility decisions are determined, and all agents in these two groups exist both with and without the policy, making traditional welfare comparisons possible. To give a sense of the longer run impacts of the policy, we also report the welfare gains for the grandchildren of these parents, restricting our analysis to the set of grandchildren who are always born regardless of policy.

For each of these groups, we compute lifetime utility from consumption, ignoring utility gained from altruism towards children (or grandchildren or great-grandchildren, etc.). We compute this value under both the free secondary schooling policy and the case of no policy change, and our measure of consumption-equivalent welfare reports the percentage increase in the consumption of all individuals (within the relevant group) required to raise the average utility level under no policy change to that achieved by the policy.

We are also interested in the redistributive component of the policy; that is, how much of the welfare gains accrue to poor households relative to rich ones. As in Fernández and Rogerson (1995), rich households in our model are more likely to go to school. Thus a free SHS policy risks being regressive. Unlike Fernández and Rogerson (1995), who model schooling as funded through proportional taxation, this effect is mitigated by the fact that our tax schedule is strongly progressive. Thus the redistributive nature of the policy is a quantitative question. In order to answer this question, we also report the change in welfare for parents and children in the

Table D.1: Welfare Change of Select Groups under Free Schooling

	Overall	Bottom 25 Pct	Top 25 Pct
Parents	1.7	3.4	-2.5
Children	4.5	18.5	-3.9
Grandchildren (always born)	3.9	-	-

Note: This table reports the average change in consumption-equivalent welfare for select groups of individuals under the free schooling policy.

top and bottom 25 percent of the (pre-policy) income distribution.

The first two rows of Table D.1 report our welfare measure for parents (those with newborn children at the time of policy implementation) and their children. Welfare for parents increases on average by 1.7 percent of consumption. This is somewhat surprising as, due to higher school attendance and the loss of children's wages, the policy actually reduces income in this group. Instead, the welfare gains come entirely from redistribution. The poorest 25 percent of parents gain 3.4 percent of consumption while the richest lose 2.5 percent. Despite concerns that wealthy parents are more likely to send their children to secondary school and thus are more likely to be beneficiaries of the policy, the tax schedule is sufficiently progressive that the policy acts redistributively overall.

The gains for children are larger and positive at 4.5 percent. As was the case for parents, the policy is highly redistributive. The children who would have ended up in the top 75 percent of the income distribution absent the policy lose 3.9 percent, slightly more than the parents, due to higher taxes. The (pre-policy) poorest 25 percent of children, however, make substantial gains of 18.5 percent. While a small portion of these gains occur broadly within this group due to higher unskilled wages, the majority are accrued by the small number of misallocated children who make substantial income gains. The third row of Table D.1 list welfare gains for the grandchildren of the parents described in the first row, limited to those grandchildren who are always born regardless of whether the free schooling policy is implemented or not. They gain 3.9 percent.

Improving School Quality: Table D.2 lists the changes in consumption-equivalent welfare under improved schooling quality for the same groups of individuals as the discussion of welfare under the baseline policy in Section D. For parents, the gains in welfare are similar to those under the free schooling policy (1.4 percent vs 1.7 per-

Table D.2: Welfare Change of Select Groups under Improved Schooling Quality

	Overall	Bottom 25 Pct	Top 25 Pct
Parents	1.4	1.1	2.3
Children	7.5	3.9	14.1
Grandchildren (always born)	6.8	-	-

Note: This table reports the average change in consumption-equivalent welfare for select groups of individuals when schooling quality is improved.

cent), but children and grandchildren benefit substantially more under improved schooling quality. Children's welfare increases by 7.5 percent (vs 4.5 percent baseline) and grandchildren's increases by 6.8 percent (vs 3.9 percent).

The distributional implications of improved quality, however, are substantially different from free schooling. While the poorest children do benefit by 3.9 percent of consumption, this is substantially lower than the 18.5 percent gains from free schooling. Additionally, the largest gains accrue to the richest children whose welfare increased by 14.1 percent compared to -3.9 percent from free schooling. The reason for this substantial switch is twofold. First, children born to richer parents are more likely to attend school, and thus are more like to reap the benefits of improved schooling quality. Second, the policy is highly cost effective and pays for itself in the long run, resulting in a reduction in taxes — a benefit that mostly accrues to the richest.