Aggregate and Distributional Effects of 'Free' Secondary Schooling in the Developing World

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Abstract

This paper analyzes the aggregate and distributional effects of publicly funded secondary schooling in the developing world. To do so, we build a general equilibrium model of human capital accumulation by overlapping generations of heterogeneous households. Households face borrowing constraints that can lead to misallocation of talent of high-ability children from low-income households in equilibrium. We estimate the model to match a randomized controlled trial that provided scholarships for free secondary education to a random set of low-income, high-ability children in Ghana. We then simulate the effects of scaling up to a nationwide policy of taxpayer-financed secondary schooling in general equilibrium. The model predicts modest gains in GDP and welfare from free schooling, and in particular less than from policies focused on improving school quality costing the same amount. We conclude that free secondary school policies are largely redistributive in nature, and that low secondary school enrollment rates in the developing world may be largely an efficient response to low education quality and high opportunity cost of attending secondary school.

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1. Introduction

It has been said that talent is universal but opportunity is not. This saying seems like it could hardly apply better than to the millions of school-aged children throughout the developing world who are not actually enrolled in school. While enrollment rates for primary education have seen dramatic increases in low-income countries in recent years, secondary education rates remain low. Moreover, recent evidence confirms that a main reason many young people do not attend secondary schooling is their parents' lack of resources plus credit constraints that prevent them from borrowing (e.g. Brudevold-Newman, 2017; Duflo, Dupas, and Kremer, 2021). Keeping bright young people out of secondary school may lead to a significant misallocation of talent in the education system, reducing aggregate productivity and income levels (Hsieh, Hurst, Jones, and Klenow, 2019). More generally, the low rates of secondary schooling in the developing world are seen as one of the key proximate causes of low average income levels (e.g. Hall and Jones, 1999; Caselli, 2005).

In the last decade, numerous developing countries have adopted "free" secondary schooling policies aimed at reducing misallocation of talent in education and raising average schooling levels. Most of these free secondary schooling policies have replaced private tuition payments with publicly funded secondary education, but only for students with sufficiently high scores on national exams. This merit-based component of free schooling policies serves to keep secondary enrollment rates at manageable levels while also ensuring that enrollment is expanded primarily for the most talented students. Free schooling policies are generally viewed as a success by policy makers in developing countries, at least in part because they have been followed by clear increases in secondary school enrollments (Center for Global Development, 2022).

In this paper, we analyze the macroeconomic effects of free secondary schooling policies, focusing on both their aggregate and distributional consequences. To our knowledge, ours is the first macroeconomic analysis of free schooling policies in the developing world, though we build on several recent microeconomic studies of subsidized secondary education. Our analysis is based on a general-equilibrium overlapping generations (OLG) model of human capital accumulation through schooling. In the model, parents choose their children's education level and face credit constraints that prevent borrowing against future income. Learning ability is passed down stochastically from parent to child. Parents base the educational choice for their children on income, assets, and the child's ability as well as the child's performance on a secondary-school qualifying exam, which is modeled as a noisy signal of ability. Population growth is endogenous and depends on the child's education, with lower fertility for the more educated. High and low skilled workers are imperfect substitutes in production, and their relative wages in equilibrium depend on the relative supply of the high-skilled (consistent with the evidence of Khanna, 2022). Capital complements both labor types in production, and increases endogenously in response to higher marginal products of labor. Misallocation of talent arises in the model when children with high learning ability complete less schooling than they otherwise would have because of their parents' low asset levels.

We discipline the model (in large part) using experimental evidence from a long-term study that offered secondary school scholarships to a randomly selected set of high-ability children from poor families in Ghana (Duflo, Dupas, and Kremer, 2021). Those getting offered the scholarships were about 25 percent more likely to finish secondary school than a control group four years hence. Scholarship winners performed about 0.2 standard deviation higher tests of literacy and mathematics, which is comparable to the effects found in other successful studies of merit-based educational subsidies in developing countries. Earnings for scholarship winners were higher, though imprecisely estimated, and fertility rates were significantly lower than in a control group. Our estimated model does well at matching these and other non-targeted moments. In disciplining our model to experimental data, we build on a growing body of research in macroeconomic development that uses field experiments in order to guide general-equilibrium policy counterfactuals (e.g. Kaboski and Townsend, 2011; Buera, Kaboski, and Shin, 2019; Brooks and Donovan, 2020; Lagakos, Mobarak, and Waugh, 2020; Buera, Kaboski, and Townsend, Forthcoming).

We use the model to simulate the long-run effects of free secondary schooling policies in general equilibrium. The model predicts an increase in the number of secondary school graduates by around 10 percent. The policy has surprisingly modest effects on GDP per capita, which increases by 0.2 percent in the long run, and on average welfare, which rises by around 2 percent in consumption equivalents. The policy is not budget neutral, and pays for only about one sixth of its cost in the long run. While adult wages do rise substantially for those treated by the policy, these gains are offset in large part by lost wages during schooling years, signaling an important role for opportunity cost of schooling in holding back secondary school completion. We show that the welfare gains largely accrue to the poorest quartile of households, who see the largest increases in secondary schooling completion and relative wages, but pay little of the tax increases needed to finance the greater public expenditures.

As a frame of reference, we compare the effects of free secondary schooling to a economy wide improvement in schooling quality, which could represent pay-for-performance incentives for teachers (Muralidharan and Sundararaman, 2011; Duflo, Hanna, and Ryan, 2012; Mbiti, Muralidharan, Romero, Schipper, Manda, and Rajani, 2019), additional teachers in the classroom (Banerjee, Cole, Duflo, and Linden, 2007) or other interventions that bolster student academic performance. We find that school quality improvements are substantially more effective at raising average income and welfare levels than free secondary schooling. A nationwide school quality improvement improving test scores by a 0.1 standard deviations – a conservative value relative to the micro studies above – leads to a GDP increase of 4 percent and average welfare by around 5 percent. This time the largest winners in welfare terms are the top quartile of the income distribution, who have the highest rates of secondary school enrollment to begin with. Yet even the bottom quartile gains more under the school quality improvement policy than the free schooling one. The main factor accounting for why free schooling policies perform so much worse than policies aimed at raising education quality is that free schooling ends up the affecting just 3 percent of new secondary graduates, compared to the 33 percent of inframarginal students already attending school plus new attendees affected by the schooling quality improvements.

We conclude that free secondary schooling policies can be interpreted as largely redistributionary in nature, at least at current schooling quality levels. While a nontrivial number of students are misallocated under a system of privately funded secondary education, our estimated model implies that the majority of those not attending secondary schooling would have low potential returns to education and high opportunity cost from lost work years. This suggest that low secondary school enrollment rates are largely an efficient response to the low quality of secondary education in developing countries. This implication is broadly in line with the conclusions of the macro development literature emphasizing low schooling quality, rather than low years of average schooling per se, in depressing income levels in poor countries (Hanushek and Woessmann, 2007; Schoellman, 2012).

Our paper builds on a long literature focused on how human capital investments shape the income distribution (Galor and Zeira, 1993; Bénabou, 2002). Celik (2015) shows that misallocating the talent of those with high ability in innovating can reduce growth. Our quantitative exercises are related to those in the literature on credit constraints in education, such as the seminal work of Lochner and Monge-Naranjo (2011), though we don't focus on relaxing credit constraints per se because it is less policy relevant for secondary education in the developing world. Our paper is perhaps most closely related to the studies by Abbott, Gallipoli, Meghir, and Violante (2019) and Daruich (2020), both of whom study expansions in publicly funded education in the

United States. Both studies reach fairly positive conclusions about the effects of publicly funded education, unlike our study, which highlights differences in school quality between rich and poor economies. As in the paper by Daruich (2020), we discipline our model using experimental evidence from a randomized controlled trial.[1]

2. Free Secondary Schooling in the Developing World

Cross-country data on school enrollment show that developing countries mainly lag behind richer countries when it comes to secondary schooling enrollment. Figure 1 plots primary and secondary school net enrollment rate against GDP per capita in 2019 using data from the World Bank's World Development Indicators. Net enrollment rates are defined as the share of students of official school age enrolled in primary (secondary) school education to the population of the age group corresponding to primary (secondary education). Each blue circle plots the net enrollment rate in primary schools against 2019 GDP per capita with the blue line representing the best linear fit. Similarly, each red $'x'$ plots secondary school net enrollment rates against 2019 GDP per capita while the red line represent the line of best fit.

Figure 1 shows that while primary enrollment rates are higher in richer countries than poorer ones, the differences are not too large overall. In the poorest countries in the world, around 80 percent of children of primary school age are enrolled in school, compared to nearly every child in richer countries. For secondary schooling, the differences are much more stark. In the poorest countries, around 30 percent of children of secondary school age are enrolled in school. In the richest countries, enrollment rates are again not too far from one hundred percent.

One salient difference between rich and poor countries in terms of education policy is that richer countries are much more likely to publicly finance secondary education. It is not surprising then that many developing countries have recently considered implementing free schooling policies, in which the government finances school fees for at least some secondary-age students (Center for Global Development, 2022). One main rationale for publicly funded schooling is to help raise average schooling levels, which is thought to be a key proximate determinant of GDP per capita. A second rationale is to make secondary education more accessible to poorer households, consistent with

[1] Our analysis abstracts from several potentially important factors that are worth mentioning explicitly. Education expansions have been shown to reduce crime (e.g. Lochner and Moretti, 2004), create more informed voters, or raise the wages of others through externalities more generally (e.g. Lucas, Jr., 1988; Acemoglu and Angrist, 2000; Ciccone and Peri, 2006). We abstract from these channels largely because we do not have any new evidence to offer about them. Moreover, we conjecture that given our low estimated effects of free schooling policies on GDP and average wages, adding an external effect of human capital on the wages of others would be unlikely to have much additional impact.

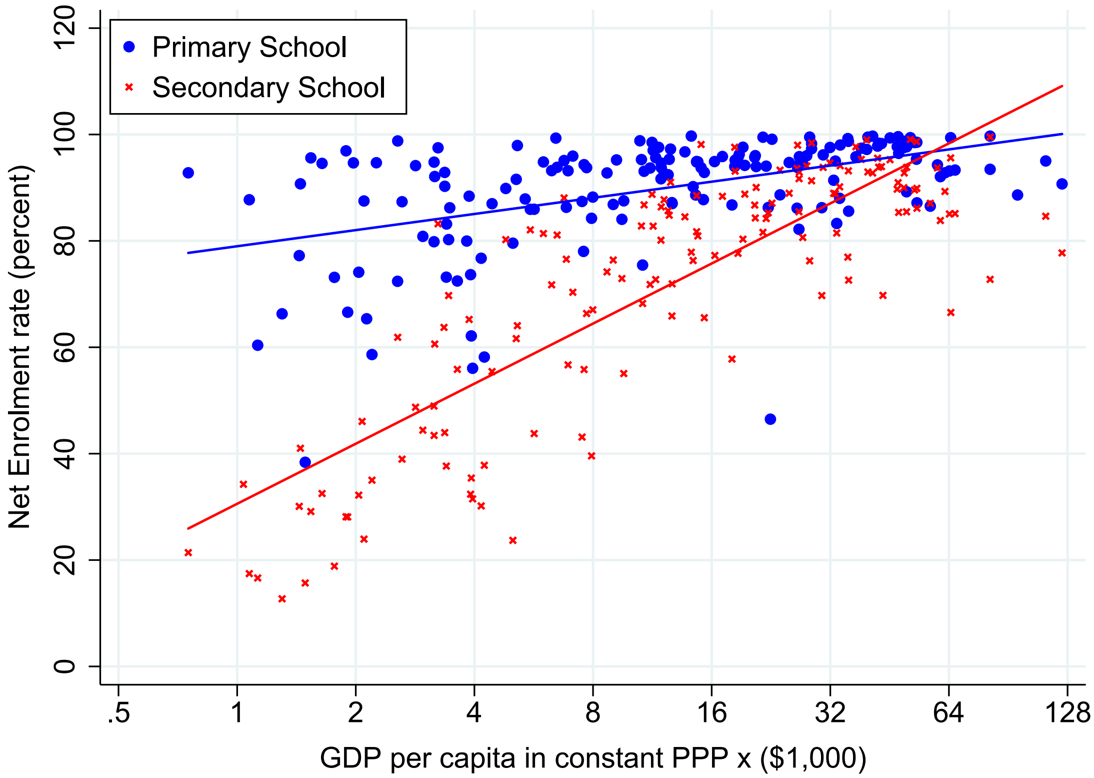


Figure 1: Primary and Secondary School Enrollment Rates

redistribution motives. These two objectives are not necessarily in contrast with one another, since raising average years of schooling is likely to require expanding schooling access to poorer households previously unable to afford the costs of secondary school.

Table 1 lists some developing countries that have adopted free schooling policies in recent years. An interesting, and little studied, feature of each of these policies is a merit requirement, usually coming in the form of an eligibility exam. As the Table shows, all but one of these countries enacting free secondary schooling require that students pass an ability test of some kind. The only country in Table 1 offering secondary schooling to more or less every child of secondary school age is the Philippines, who requires only that students do not fail two consecutive years. The merit requirements likely serve two basic purposes. First, they allow governments with an additional lever to control the inflow of new secondary school enrollees each year. Second, they focus the new secondary school enrollment on the most able students, which are most likely to be the ones misallocated to begin with.

Table 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 ≥ 6 on Basic Education Certificate Exam
Tanzania	2015	Pass Standard 7 Exam
Uganda	2007	Score ≥ 28 in Primary School Leaving Exam
Zambia	2022	Pass Baccalaureate Exam

Note: Information sources provided for each country in Appendix B.

Experimental Study of Duflo, Dupas and Kremer (2021). Recently, several microeconomic studies have documented the impacts of merit-based scholarship programs in different parts of the developing world. The experiment of Duflo, Dupas, and Kremer (2021) is the first study to conduct a long-run evaluation of such a scholarship program. Their setting is Ghana, where the education system in Ghana consists of primary school and junior high school (JHS) until age 14 or 15, followed by secondary school, which lasts 4 years. At the end of JHS, students take a Basic Education Certification Examination (BECE) which serves as an entry exam for senior high school (SHS). Roughly 70 percent of students take the test and about 60 percent of test-takers pass, implying that 42 percent of Ghanian youth of secondary school age are eligible to attend. Until 2017, Ghanaians wishing to attend secondary school were required to pay tuition and school fees amounting to roughly 20 percent of GDP per capita on average; afterwards, schooling was publicly funded for those passing the BECE.

Duflo et al. (2021) identified 2,064 students who had passed the BECE exam in 2008, were assigned to a SHS location within their own district, but had not enrolled by October 2008. Almost all students cited financial difficulties as the main reason that they had not enrolled. Of these students, one-third were randomly selected to receive a four-year scholarship covering all tuition, school fees, and exam fees. Scholarship funds are paid directly to the school, removing the possibility that recipients used the funds on non-educational expenditures. In total, the average scholarship was equal to roughly 80 percent of GDP per capita.

Students who receive a scholarship were about 25 percent more likely to enroll in SHS relative to the control group. Treatment effects on schooling completion are roughly equally large in the top and bottom quartiles of the initial test score distribution. Note that many students in the control group do eventually manage to enroll; however, their enrollment still remains lower than the treated group. By 2019, 71.2 percent of the treatment group had completed SHS compared to 44.5 percent of the control group.

Two distinct measures show improvements in human capital from the treatment. The first is the effect on scores on math and reading tests, and these were around 0.2 standard deviations higher in the treatment group than in the control group. This effect size is very similar to the effects on test scores estimated in several previous studies providing merit-based scholarships for secondary school students in Colombia (Angrist, Bettinger, and Kremer, 2006) and Kenya (Kremer, Miguel, and Thorton, 2009).

The second measure of human capital is wage earnings. On the one hand this is arguably the most direct measure of human capital one could attempt to measure. On the other hand, in this setting many of the workers had not yet found jobs, in part because some of the study participants were still attending (or had only recently graduated from) college. There was also a nationwide public hiring freeze during this period due to an IMF intervention, and the COVID-19 pandemic, which negatively impacted the job market. These aggregate factors cloud the interpretation of wage effects found in this study, similar to the argument of Rosenzweig and Udry (2020) on how aggregate shocks make it harder to interpret the results of RCTs. The estimated wage effects overall were around 3 percent, with a very wide confidence interval. For this reason we choose to target the effects on test scores in our model as our measure of the human capital impacts of secondary schooling subsidies.

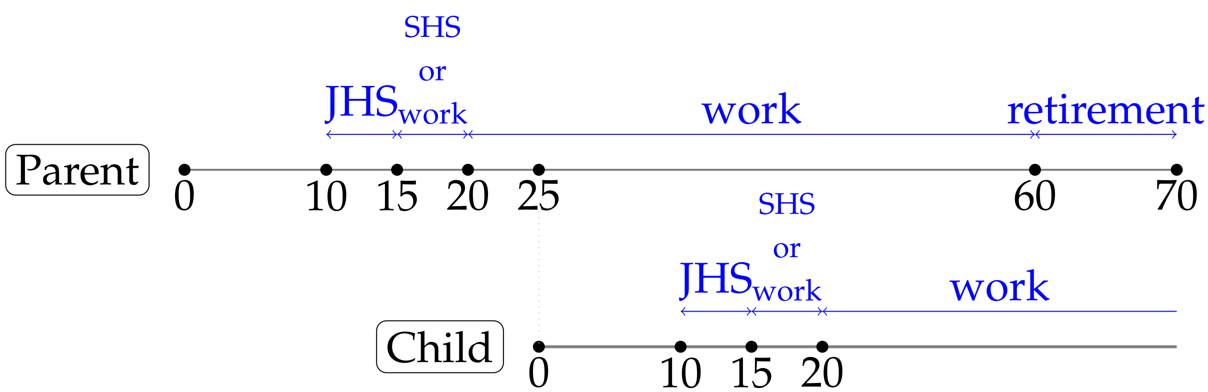
The scholarship lead to negative and fairly precisely estimated effects of secondary schooling on fertility. Students who receive the scholarship have, on average, 0.104 fewer children than students in the control group after 12 years. The persistence of the reduction in fertility even multiple years after the completion of secondary school suggests that this reduction is a fundamental reduction in fertility, rather than just the effect of parents delaying having children due to being in school. This effect operates mostly through a reduction in unplanned, out-of-wedlock pregnancies strengthening the case that this reduction is permanent. We target this effect in our model estimation, as we explain in the following section.

3. Overlapping Generations Model of Schooling

In this section we present out model, which we construct in order to be able to simulate the affects of free secondary schooling policies in general equilibrium. Secondary school slots are rationed in the model through entrance tests and require parents school fees, consistent with the evidence above. Overlapping generations of households are heterogeneous in their parental human capital, child ability and savings and face borrowing constraints in education decisions. Population growth is endogenous and depends on the educational outcomes of the younger generation. We abstract from labor supply decisions and endogenous retirement choices due to the high average employment rates and hours worked in the developing world, and the relatively short retirement periods that prevail there.

3.1. Environment

Time is discrete and goes from 0 to infinity, and there is a single consumption good. The economy is populated by a large number of overlapping generations of agents, whose timeline of events is as shown in the graphic below.



Agents live for 14 periods, where each period corresponds to 5 years. Let $\tau \in \{1, 2, \ldots, 14\}$ denote the period of life. From $\tau = 1$ to 5 (i.e., age 0–24), agents live with their parents. In $\tau = 3$ (i.e., age 10–14), all agents attend JHS, while in $\tau = 4$ (i.e., age 15–19), agents either SHS or work. In $\tau = 5$, all agents work with either JHS or SHS education. At the beginning of $\tau = 6$ (i.e., when turning age 25), agents leave their parents and form new households. All agents work from age 20 to 60, at which point they retire, and die at age 70. This is roughly the average life expectancy in Ghana, for example, whose features we will use to parameterize our model in the following section.

Each new household consists of a parent aged 25 and new born children, where the number of children, denoted as $1 + \nu_{s_p}$, depends on the parent's schooling level s_p. All household decisions are made by parents, who derive flow utility $U(c) = \log(c)$ from household consumption $c \geq 0$ and discount the future with $\beta \in (0,1)$. Parents are imperfectly altruistic toward children and therefore derive utility also from children's well-being. No borrowing is possible, but one can save at an exogenous interest rate r.

We assume that parents make educational decisions directly for their children. This is consistent with evidence that parents in low-income countries predominantly take an "authoritarian" approach to parenting, dictating decisions directly rather than trying to reach an agreement with children (Doepke and Zilibotti, 2017). In Section X to follow we present evidence that our estimated model does not give rise to a substantial disagreement between the education choices that parents make and children would have made.

Agents are heterogeneous in innate ability $z \in Z = \{z^1, z^2, \ldots, z^N\}$. The ability within a household follows a first-order Markov chain which mimics an AR(1) process

$$\log z_c = \rho \log z_p + \epsilon,\ \rho \in (0,1). \tag{1}$$

Here, z_p and z_c denotes the parent and children's ability,[2] respectively, and ϵ is a zero mean i.i.d. (independently and identically distributed) random variable. Thus, ability is transmitted within each household but only imperfectly, and it is identical across siblings. Following the evidence in e.g. Cunha and Heckman (2007), we interpret ability to be a function of inherited capabilities and parental inputs.

Parents make schooling decisions for their children when children turn age 15, after observing the children's ability and test score as well as the realizations of schooling taste shocks. More precisely, parents enjoy random utility δ_s from providing children schooling level $s \in S = \{J, S\}$ (Junior High/Primary, Secondary), where δ_s follows a standard Gumbel distribution with scale parameter θ. Parents must forgo a period of children's income to send their children to SHS, and further, providing children final schooling level $s \in S$ requires goods costs Ψ_s. These goods costs represent school fees and satisfy $\Psi_S > \Psi_J = 0$, where the equality reflects the free primary education that prevails in most developing countries. To capture the fact that one must pass an entrance test to enter secondary schooling in most developing countries, we set a

[2]Throughout, variables with superscript p and c pertain to parents and children, respectively.

threshold test score for entering SHS. One's test score $\tilde{z}$ is related to ability as

$$\tilde{z} = z + \varepsilon, \tag{2}$$

where the noise ε follows a normal distribution with mean zero and standard deviation σ_ε. The human capital of an agent with ability z and schooling level s is given by

$$h(z,s) = \begin{cases} 1 & \text{if } s = J, \\ z\eta_S & \text{if } s = S, \end{cases} \tag{3}$$

where $\eta_S > 0$. Thus, innate ability affects human capital only for those with SHS education, who will be hired for jobs that require relatively complex tasks.

Markets are competitive and the aggregate production function, operated by a representative profit-maximizing firm, is given by:

$$Y = AK^\alpha \left[(N_J)^\lambda + (N_S)^\lambda \right]^{\frac{1-\alpha}{\lambda}}, \ \alpha, \lambda \in (0,1). \tag{4}$$

Here, A is aggregate productivity, K is physical capital, and N_s is aggregate efficiency units of labor of agents with schooling level s. The firm rents physical capital from households or foreign investors at the international market rate r^*. Due to savings frictions, however, the return to physical capital for households is lower, at $r = r^* - \chi < r^*$. This lower return to capital helps us match the low savings rates among households in low-income economies (as in Donovan, 2021).

The labor income y of an agent who works in that period equals the product of three terms. The first term is the wage rate per efficiency units of unskilled ($s = J$) or skilled ($s \in S$) labor, denoted as w^U or w^S, respectively. The second term, ζ, represents idiosyncratic shocks to labor productivity. The third term is human capital $h(z,s)$, given by (3). For example, the labor income of an agent who graduated from SHS and works in that period is given by

$$y(z,S,\zeta) = w^S \zeta h(z,S) = w^S \zeta z \eta_S. \tag{5}$$

3.2. Parents' Problems

Parents make consumption and saving decisions in each period, and additionally, schooling decisions when their children reach the age for secondary school. We discuss below the parents' problems in the key periods in the life-cycle and relegate to Appendix the description of their problems in other periods. In addition to individual state variables described below, the parent's problems depend on the probability density function(pdf) f describing the distribution of households across individual states and the aggregate population level P.

In $\tau = 9$, parents observe the realizations of the schooling taste shocks (δ_J, δ_S), children's ability and test score $(z_c, \tilde{z}_c)$, and their own and children's labor productivity (ζ_p, ζ_c). Then, if $\tilde{z}_c$ weakly exceeds the threshold test score $\bar{z}$, parents have an option to send children to SHS. The value function of such parents with ability z_p, schooling level s_p, and assets a is given by

$$\begin{aligned} V_9(a, z_p, s_p, \zeta_p, \delta_J, \delta_S, z_c, \zeta_c; f, P | \tilde{z}_c \geq \bar{z}) = \max_{c \geq 0, a' \geq 0, s'_c \in \{J, S\}} & \log(c) + \delta_J \mathbf{I}\left(s'_c = J\right) + \delta_S \mathbf{I}\left(s'_c = S\right) \\ & + \beta \mathrm{E}\left[V_{10}(a', z_p, s_p, \zeta'_p, \delta'_S, \delta'_C, z_c, s'_c, \zeta'_c; f', P')\right], \end{aligned}$$

where the maximization is subject to the flow budget constraint

$$\begin{aligned} a' + c + \left(1 + \nu_{s_p}\right) \mathbf{I}\left(s'_c = S\right) \Psi_S = & \; y_p(z_p, s_p, \zeta_p) + (1 + r)a \\ & + \left(1 + \nu_{s_p}\right)\left(1 - \mathbf{I}\left(s'_c = S\right)\right) y_c(z_c, J, \zeta_c) - T(z_p, s_p, \zeta_p, z_c, J, s'_c, \zeta_c), \end{aligned} \tag{6}$$

and the perceived laws of motion for the aggregate state variables f and P, given by $f' = F(f, P)$ and $P' = G(f, P)$, respectively. Here, the prime denotes values of variables in the next period, and $\mathbf{I}\left(s'_c = S\right)$ is a variable that equals 1 if sending children to SHS and equals 0 otherwise. Further, $y_p(z_p, s_p, \zeta_p)$ represents the labor income of parent, while $y_c(z_c, J, \zeta_c)$ denotes the labor income of children who work with JHS education. Finally, T is total amount of taxes paid by the household, which depends on the parent and children's labor income, and is therefore a function of $(z_p, s_p, \zeta_p, z_c, J, s'_c, \zeta_c)$.[3] We suppress the dependence of y_p, y_c, and T on f and P except where it is necessary to make that dependence explicit.

In $\tau = 10$, parents live with children who work with either JHS or SHS education. The value function of such parents is expressed as

$$\begin{aligned} V_{10}(a, z_p, s_p, \zeta_p, z_c, s_c, \zeta_c; f, P) = \max_{c \geq 0, a' \geq 0} & \log(c) + \beta \mathrm{E}\left[V_{11}(a', z_p, s_p, \zeta'_p; f', P')\right] \\ & + \beta b \left(1 + \nu_{s_p}\right) \mathrm{E}\left[V_6(0, z_c, s'_c, \zeta'_c; f', P')\right] \end{aligned} \tag{7}$$

[3] Note that T depends on both the children's current schooling level s_c $(= J)$ and next period's schooling level s'_c. This is because the labor income depends on educational attainment, and only the children who do not go to school $(s'_c = s_c)$ earns the labor income in the current period.

subject to

$$a' + c = y_p(z_p, s_p, \zeta_p) + (1+r)a \\ + \left(1+\nu_{s_p}\right) y_c(z_c, s_c, \zeta_c) - T(z_p, s_p, \zeta_p, z_c, s_c, s_c', \zeta_c), \tag{8}$$

$f' = F(f, P)$, $P' = G(f, P)$, and $s_c' = s_c$. Here, $y_c(z_c, s_c, \zeta_c)$ is the labor income of children who work with schooling level s_c. On the right-hand side (RHS) of (7), $V_{11}(a', z_p, s_p, \zeta_p'; f', P')$ denotes the parent's value function in the following period, which no longer depends on the ability and schooling of children who become independent from parents. The last term on the RHS of (7) denotes utility that imperfectly altruistic parents derive from their children's well-being, where $b > 0$ is the altruism parameter and $V_6(0, z_c, s_c', \zeta_c'; f', P')$ is the value function of children who form new households with zero amount of assets.

3.3. Recursive Competitive Equilibrium and the Balanced Growth Path

In this section, 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 $f' = F(f, P), P' = G(f, P)$

such that

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

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:

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

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

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 remain stationary. Further, the household value and policy functions are independent of aggregate population, and thus the household behavior remains the same over time conditional on the individual state variables.

In our quantitative analysis, we first compute the balanced growth path, which is straightforward to do since there is no need to track the evolution of the distribution of X over time. We then compute the transition dynamics by calculating the sequences of population growth rates and prices that converge to the balanced growth path.

4. Parameterization

A small number of model parameters are chosen directly, either as normalizations or to match values from the literature. These are summarized in Table 2. In particular, aggregate productivity A is normalized to 1 and the mean of the intergenerational ability process μ is chosen so that average ability is normalized to 1. We set the share of capital α to 0.33, a standard value in the literature. The discount factor is chosen to be 0.96^5, consistent with typical values in the literature, adjusted for the fact that our model period corresponds to 5 years. Similarly, the international market interest rate r^* is chosen to generate a (depreciation-inclusive) user cost of capital equal to 10 percent per year. Finally, we choose the parameter governing the substitutability of skills λ to be 0.75, generating an elasticity of substitute of 4 consistent with the long-run estimates of Bils, Kaymak, and Wu (2020) based on cross-country school attainment and wage data.

We estimate the remaining parameters of the model using the Simulated Method of Moments (SMM). Like the Generalized Method of Moments (GMM), SMM chooses parameters to minimize the deviation between a chosen set of data moments and their model counterparts. Unlike GMM, SMM does not require closed-form expressions for the value of the moments in the model and instead constructs the moments through simulation. For our model, there are 11 free parameters to estimate which we estimate using 11 moments.

Table 2: Directly Chosen Parameters

Description	Parameter	Value	(Source)
Agg. Productivity	A	1	(normalization)
Mean of $\log z$	μ	set s.t. $E[z] = 1$	(normalization)
Skill Substitutability	λ	0.75	Bils, Kaymak, and Wu, 2020
Share of Capital	α	0.33	Standard value
Discount Factor	β	0.96^5	Standard value
International Market Rate	r^*	0.10^5	Standard value

Note: The table reports the values of directly chosen parameters in the model.

Our chosen set of moments fall into two broad categories. The first is a set of aggregate moments. Some of these are taken from existing work, such as the intergenerational correlation of schooling taken from Azomahou and Yitbarek (2016). Others are taken from common data sources such as the World Bank. All together, there are four such aggregate moments. These are typical moments in models of human capital and income dispersion, and their calculation is similarly standard. We find the balanced growth path distribution of households (discussed in section 3.3) in the model and use this distribution to calculate these moments.

The remaining seven moments are taken from an experiment performed by Duflo et al. (2021). This experiment randomly offered scholarships that covered all secondary school tuition and fees to a high ability, low income subset of Ghanaian JHS graduates. This exogenous variation in the cost of education allows credible estimation of the causal impact of education on earnings, fertility, and other outcomes which can be used to discipline model parameters such as the human capital gains from schooling. Relative to previous analysis, this methodological novelty allows us to construct a general equilibrium model of education that is based on well-identified causal microeconomic estimates of the effect of education. Section 4.1 below provides details on the implementation of this approach, including a brief description of the experiment and details on how experimental moments are constructed within the model.

4.1. The DDK Experiment from the Perspective of the Model

Using the experimental evidence of DDK described in Section 2 to discipline our model via SMM requires a method to simulate the experiment and its results within the model. In this subsection, we describe our approach to this problem.

First, we treat the experiment as occurring in partial equilibrium. Duflo et al. (2021) select 2,064 students from 5 regions of Ghana with a combined population of over 10 million. It is implausible that the experiment had any significant general equilibrium effects. In the context of the model, we implement this notion by performing the experiment on a measure 0 subset of households; any changes in behavior of these households has no impact on equilibrium outcomes.

We mimic the sample selection process of Duflo et al. (2021) to select "smart kids from poor families." To match the requirement that students in the sample have passed the BECE exam, we choose a test score cutoff at the 58th percentile. This matches the 42 percent passing rate measured in the data. From the households with passing students, we then chose a cutoff on parental income such that 47.5 percent of children from households below the cutoff finish secondary school (with no treatment). This matches the eventual SHS completion rate of the control group in the experiment. In the model, the experimental sample is a measure 0 subset of households with children above the test score cutoff and income below the income cutoff. We choose our sample to be representative of the distribution of households along the balanced growth path of the model.

For the households in our sample, we treat the experiment as unanticipated. Households also have perfect foresight and know that the experiment ends after a single generation (i.e. the children who receive a scholarship do not expect that their eventual children will also receive scholarships). Households selected into the control group solve their optimization problem as usual. Households selected into treatment experience an exogenous reduction in the goods cost of secondary school Ψ_S to 0 for the current period and resolve their optimization problem subject to this change. We can then construct simulated equivalents of the experimental moments by comparing the outcomes between the treatment and control households within the model.

4.2. Parameters Estimated from Experiment

While all moments in the model are jointly determined, there is a rough correspondence between moments and parameters. In this and the following section, we summarize this intuitive mapping. Below, we provide some quantitative demonstrations of how certain model moments pin down certain (important) model parameters. Here we focus on the parameters that are largely determined by the experimental moments and highlight how the use of an experiment enhances our macroeconomic analysis. In the next section, we focus on aggregate moments. The estimated parameters are summarized in Table 4 and the resulting moments, their value in the data, and their source are summarized in Table 3.

The two main outcomes from the experiment are the differences in fertility and human capital (measured through earnings and test scores) between the treatment and control groups. The experimental effects on fertility are easy to interpret: DDK observe a decline in fertility for treated individuals which, together with the aggregate population growth rate, helps pin down the fertility parameters ν_J and ν_S. More precisely, the treatment effect on fertility determines the relative fertility between secondary- and primary- educated households, $\frac{\nu_S}{\nu_J}$, while the aggregate population growth rate pins down the level of fertility.

Interpretation of the human capital effects of the treatment is more complicated. Ideally, we would like to directly observe wage gains of treated individuals relative to the control groups, interpret any differences in earnings as differences in human capital, and pick the human capital parameter η_S to match these gains; however, a few experimental details prevent such an exercise. First, DDK find a statistical significant increase in tertiary enrollment as a result of treatment suggesting that many of the highest-return individuals may be out of the labor force at the time of follow-up and thus missed in earnings calculations. Second, the cohort selected for treatment faced a particularly harsh labor market including a government hiring freeze. As with many

Table 3: Targeted Moments and Model Predictions

Moment	Model	Data	Source
Aggregate Population Growth	2.24%	2.22%	World Bank
Intergenerational Schooling Corr.	0.34	0.45	Azomahou & Yitbarek (2016)
Var(Permanent Component of Income)	0.222	0.224	Lagakos and Waugh (2013)
Var(Transitory Component of Income)	0.100	0.077	Lagakos and Waugh (2013)
Avg. SHS Compl. Rate	0.301	0.338	Duflo et al. (2021)
Treatment Effect on Wages	0.067	0.076	Duflo et al. (2021) (imputed)
Treatment Effect on Fertility	-0.116	-0.108	Duflo et al. (2021)
Top Quart. SHS Compl. (Control)	0.65	0.53	Duflo et al. (2021)
Bottom Quart. SHS Compl. (Control)	0.35	0.41	Duflo et al. (2021)
Treatment Effect on SHS Compl.	0.21	0.27	Duflo et al. (2021)
TE SHS Compl. Top - Bottom Quart.	0.03	0.04	Duflo et al. (2021)

Note: The table reports the moments targeted using simulated method of moments and their sources. See Section 4 for more on the rationale for each moment.

developing countries, the government is a primary source of high-income jobs for educated individuals in Ghana, suggesting that earnings for SHS graduates may be lower than typical. Finally, the treatment effect on earnings itself is imprecisely estimated, with the 95 percent confidence interval containing wage gains anywhere between -10 percent to +15 percent.

For all these reasons, we choose to use the treatment effect on test scores of 0.16 standard deviations as the experimental moment disciplining the human capital parameter η_S. It is precisely estimated, statistically significant, and a direct measure of human capital gains. Although these is no direct analogue in the model, we convert this increase in test scores to an increase in wages which we refer to as the "imputed treatment effect on wages", which we then choose η_S to match. In particular, we assume that a 0.16 standard deviation increase in test scores for the treatment group relative to the control group corresponds to a 0.16 standard deviation increase in wages for the treatment group. In our quantitative model, this is equivalent to wage gains of 7.6 percent. This is substantially higher than DDK's point estimate of 2.5 percent, suggesting that this may be an optimistic interpretation of their results aimed at giving free SHS policy the largest chance at generating large aggregate gains.

With the human capital gains from SHS pinned down, the average SHS completion rate and the treatment effect on SHS completion jointly help pin down the intergenerational discount factor b and the goods cost of schooling Ψ_S. The intuition is straightforward; with the gains from SHS fixed, the average level of SHS completion is determined by comparing the benefits of attendance (governed by b describing how much the parent cares about their child's eventual wage gains) to the cost Ψ_S, while the treatment effect is determined by how this cost-benefit comparison changes when Ψ_S is set to 0.

The remaining three parameters pinned down by experimental moments are the standard deviation of noise in the SHS entrance exam σ_ε, the Gumbel scale parameter of the taste shock for schooling θ and the rate-of-return wedge faced by households χ. These three parameters all impact the distribution of SHS completion with respect to ability and thus are estimated to match SHS completion in the top and bottom test score quartiles of the control group as well as the difference in the treatment effect on SHS completion between these two quartiles. Because households are only selected into the control group if their child passes the SHS entrance exam, the test score noise largely determines SHS completion in the bottom score quartile where the fraction of children who are low ability (and thus have low returns to SHS attendance) but passed the test due to idiosyncratic noise are a large determinant of eventual SHS completion rates (conditional on other model parameters). On the other hand, in the top quartile where average ability is high enough that all students pass and selection into the control group is a negligible force, the SHS completion rate is strongly impacted by the variance of the taste shocks (again conditional on other model parameters). Finally, the rate of return wedge χ determines the extent to which credit constraints are binding and thus determines the extent to which a scholarship to SHS impacts children born to wealthy parent and poor parents differentially (where test scores are correlated with child ability and thus serve as a proxy for parent ability and income).

4.3. Parameters Estimated from Aggregate Data

The remaining parameters correspond to moments constructed from aggregate data. As mentioned in the previous section, the aggregate population growth rate (taken from the World Bank World Development Indicators) pins down the level of the fertility in the model. To estimate the intergenerational persistence parameter of the learning ability process ρ, we match a correlation coefficient between parent and child years of schooling of 0.45 as measured in Azomahou and Yitbarek (2016). The estimated value for ρ is 0.79, implying a high degree of intergenerational persistence. This is broadly consistent with the recent conclusions of Lee and Seshadri (2019) that parental traits – summarized by ability in our model – explain a substantial amount of the vari-

Table 4: Parameters and Estimated Values

Description	Parameter	Value
Fertility of Primary School Graduates	ν_J	1.07
Fertility of Secondary School Graduates	ν_S	0.185
Gains from Secondary School	η_S	1.98
Goods cost of Secondary School	Ψ_S	1.5
Intergenerational Altruism Factor	b	2.26
Std. Dev. of Exam Score Noise	σ_ε	0.92
Gumbel Scale Parameter of Taste Shock	θ	0.42
Savings Wedge	χ	0.09
Persistence of Ability Process	ρ	0.79
Std. Dev. of Ability Process	σ	0.36
Std. Dev. of Idiosyncratic Income Shock	σ_ζ	0.316

Note: The table reports the parameters of the model and their estimated values. See Section 4 for more on the rationale for each moment.

ation in children's income levels.

The final two parameters govern the distribution of income in the model. The first is the variance of the shock in the AR(1) process governing intergenerational transmission of learning ability, denoted σ_z. The second, σ_ζ, is the variance of the idiosyncratic income shock that households face each period. Intuitively, the variance of the ability process generates income differences that are permanent (at least with respect to the lifespan of an individual) while the idiosyncratic shocks generate transitory differences. Following this intuition, these two parameters are largely pinned down by the variance of the permanent component of wages and transitory component of wages estimated by Lagakos and Waugh (2013). In particular, we target the variances estimated for non-agricultural workers which are 0.077 for the transitory component and 0.224 for the permanent component. In the model, these moments are constructed following Lagakos and Waugh (2013). Namely, the permanent component is measured by calculating $Cov(\log(w_{i,t}), \log(w_{i,t-1}))$ for a panel of households taken from the balanced growth path of the model, and the transitory component is measured by subtracting the permanent component of variance from total variance.

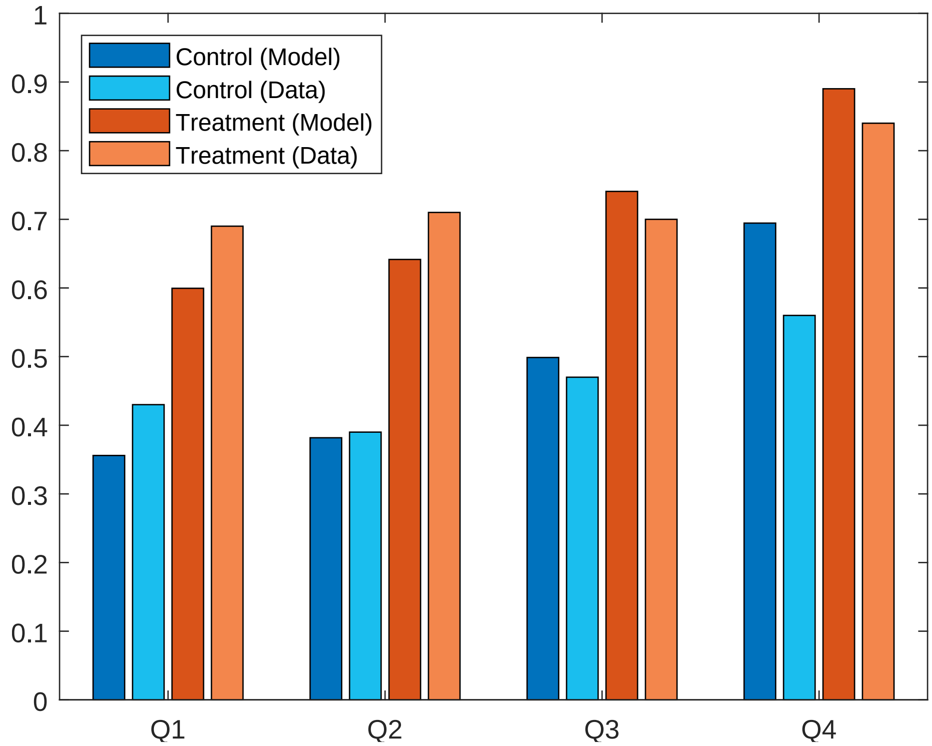


Figure 2: SHS Completion by Quartile of Test Score: Data vs Model

5. Simulating the Effects of Free Secondary School

Using the estimated model, we simulate the effects of a national free secondary schooling policy. We assume that households do not anticipate the policy and that the economy is growing along the balanced growth path at the time of implementation. The policy does not change the entrance exam score cutoff required to attend secondary school but does allow students who pass the entrance exam to attend secondary school for free. That is, the policy reduces the parameter summarizing the goods cost of secondary schooling Ψ_S to 0.

Of course, such a policy is not truly free and must be funded by the government. We require that the government pay for the policy by raising taxes on all households proportionally. Before the policy, each household paid taxes according to the tax function $T(z_p, s_p, z_c, s_c)$ which takes the ability and schooling levels (i.e. income) of the parent and child as arguments. The post-policy tax function takes the form $(1+\tau)T(z_p, s_p, z_c, s_c)$ where τ is the proportional increase in taxes. Taking this approach allows higher taxes to distort households' educational decision while minimizing the change in redistribution from changes in taxes which would otherwise make welfare effects difficult to interpret.

Table 5: G.E. Effects of Free Secondary Schooling

Variable	Benchmark	Free Schooling
Secondary School Completion	30.1%	33.1%
Population Growth Rate	2.39%	2.33%
Adult Earnings		+0.7%
Child Earnings		-1.7%
GDP per capita		+0.2%
Taxes per capita		+1.2%
Unskilled wage		+1.2%
Skilled wage		-1.2%
Gini Coefficient	0.294	0.282
Intergenerational Schooling Corr.	0.336	0.307

Note: This table reports the long-run general-equilibrium effects of free secondary schooling relative to the estimated benchmark economy.

We choose τ so that per period tax revenue along the post-policy balanced growth path is equal to per period tax revenue along the pre-policy balanced growth path plus the additional cost of the subsidy. In other words, we assume that after implementing the policy, the government must raise the amount of tax revenue that it was raising before as well as the additional cost of the subsidy.

5.1. Quantitative Results

The general equilibrium effects of a free secondary schooling policy funded by a proportional increase in taxation are summarized in Table 5. The number of secondary schooling graduates increase by about 10 percent, from 30.1 percent of the population to 33.1 percent. This increase is small relative to the changes in secondary school completion in the experiment. This difference stems from the fact that the experimental sample is selected from relatively high ability students who have passed the qualifying exam but did not immediately enroll in SHS. The group is small in the overall economy and thus large gains to SHS completion in the experiment translate to small gains in overall SHS completion. Fertility falls due to the schooling expansion, but this leads to a negligible decline in the population growth rates, largely because the increase in secondary schooling is small.

Adult earnings increase by about 0.7 percent from the policy, stemming larger from

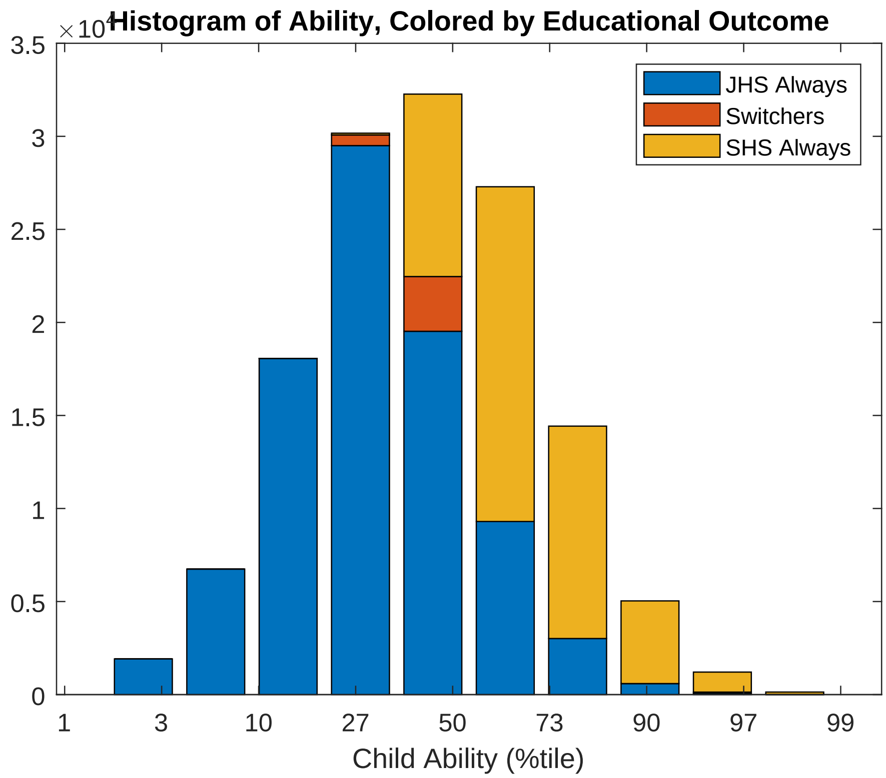


Figure 3: Ability of the Educated Before and After Policy

the higher wages for the 3 percent of the population now receiving secondary education. This is offset in part by a 1.7 percent drop in the child earnings, representing the opportunity cost of the newly educated workers. Secondary-school aged children represent a smaller fraction of the population than the adults, so the net impact on wage earnings is positive.

Figure 3 compares the distribution of ability for the secondary educated before and after the policy. As can be seen from the figure, the very top of the ability distribution remains roughly the same. The highest ability students receive education with or without the policy, mostly due to the fact that the highest ability students are almost always born into families who earn enough to pay for schooling. Instead, the policy primarily operates by allowing students with more modest, although still large, returns to education to attend school. The majority of these marginal students more than double their wages by attending secondary school. A small number of marginal students even triple their earnings.

The increase in GDP per capita from free schooling is modest, at about 0.2 percent in the long-run. The long-run cost of the policy is 1.2 percent of GDP per capita, implying the program pays for only about one sixth of its cost. Relative wages of the

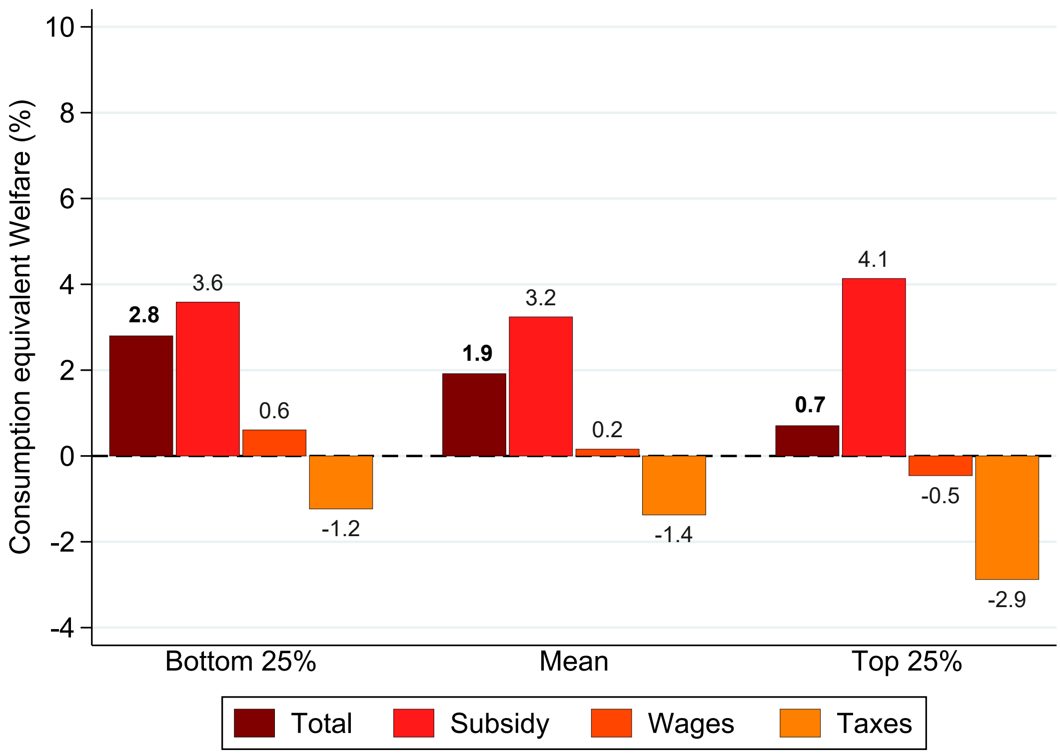


Figure 4: Welfare Effects of Free Schooling by Parental Income

unskilled rise by 1.2 percent while wages of the skilled fall by about the same amount, point to clear distributional impacts of free schooling policies. Our predictions here are similar at least qualitatively to those of Khanna (2022), who finds substantial declines in the relative wages of skilled workers after an education expansion in India. His wage effects are larger than ours quantitatively, though his study focuses on the short run, where elasticities of substitution between low and high skilled workers are likely smaller.

Consumption equivalent welfare calculations are performed by asking a household how much per period consumption they would be willing to give up to be indifferent between having the free schooling policy and the higher consumption. We compute the welfare equivalents along the full transition path for every individual that is alive at the time of the policy change. The distribution of welfare gains is show in Figure 4. The darkest (leftmost) bars on the graph report the average welfare gain for the bottom quartile of the income distribution, the mean welfare change, and the average welfare gain for the richest quartile. The average individual gains 1.9 percent in consumption equivalents, compared to 2.8 for the poorest quartile and 0.7 percent for the richest quartile. Thus, the policy mostly helps the poorest households.

To get some insights into the sources of the welfare gains, the remaining bars of Figures 4 decompose the gains into the pure effects of the schooling subsidy, the effects of G.E. wage adjustments, and the tax adjustment channels. We compute the pure effects of the subsidy by offering the same free schooling but without requiring that it be funded, and restricting relative wages to be the same as in the estimated model. Similarly, the effects of G.E. wage adjustments represent the wage changes by themself without any free schooling or taxes to pay for it. The pure effects of taxes simulate the impacts of the tax increases by themselves, holding wages fixed and without actually using the tax increases to pay for free schooling.

The education subsidy by itself (red bars) results in large wage gains for all income groups. The largest gains (4.1 percent) accrue to the top quartile of the income distribution, since they have somewhat higher ability children on average and are more likely to have children attend secondary schooling. the poorest quartile gain only somewhat less (3.6 percent). Wage effects by themselves (orange bars) have somewhat modest effects, causing around 0.6 percent welfare gains for the poorest group and 0.5 percent welfare losses for the richest group. The tax increases by themselves (yellow bars)are bad news for everyone, causing welfare losses of 1.2 percent for the poorest households and 2.9 percent for the richest quartile, who pay most of the tax increases.

Finally, the Gini coefficient drops slightly as a result of the policy, indicating that overall inequality in the economy decreases. This is a result of the fact that a large portion of inequality within the model is across education groups, determined mostly by parents income, rather than within education groups, determined mostly by ability. The correlation between parents' and children's years of schooling drop substantially from 0.336 down to 0.307, indicating a modest reduction in inequality across generations. Taken together, these two statistics point to an important redistributionary effect of the policy, which is the clear message from the weflare analysis as well.

5.2. Could the Model Have Predicted Larger Effects?

The estimated model implies fairly small impacts of free schooling on GDP, with somewhat larger (but still modest) impacts on average welfare. In this section we explore whether this conclusion was pre-determined by a modeling choice, or a function of the estimation and targeted moments. In this subsection we address this issue by computing the GDP and welfare gains from free schooling – and model fit – after changing certain specific parameters starting from the estimated parameter values. The goal of this exercise is to illustrate how the model can predict larger gains from free schooling policies, but at the cost of missing out on the targeted moments.

Table 6: Welfare Effects of Free Schooling, Alternative Parameter Choices

	GDP Gain (%)	Welfare Gain (%, Avg)	T.E. SHS Grad. (%)	T.E. Wages (%)	T.E. SHS Q4 - Q1 (%)
Data	-	-	27	8	4
Estimated model	0.2	2	21	7	3
+ Schooling quality $\times 2.5$	1.1	8	9	2	-11
+ Schooling cost $\times 3.5$	7.9	24	44	26	-19
+ Savings wedge $\times 2$	10.5	22	50	38	-17

Note: This table reports the gains in GDP and average welfare from free secondary schooling under alternative parameter choices. The last three columns report moments of the data and model (the treatment effect on SHS graduation, the treatment effect on wages, and the treatment effect on SHS for the top quartile of test scores minus the bottom) under the benchmark calibration and three alternative parameter choices. The first of these increases η_S by a factor 2.5 and keeps all other parameter values the same as in the estimated model. The second also increases ψ_S by a factor 3.5, in addition to the factor 2.5 increase in η_S, and keeps all other parameter values the same as in the main estimation. The last one additionally increases the savings wedge, χ, by a factor 2.

Table 6 reports the model's predictions for free schooling after increasing the benefits from schooling and also the cost. The first row reports three empirical moments that are targeted in the estimation: the secondary school completion rate, the treatment effect of the experiment on wages, and the difference in the treatment effect on secondary schooling between the highest quartile of the test score distribution and lowest quartile. The second row reproduces the estimated model's predictions for the effects of free schooling on GDP and average welfare, plus the three moments.

The third row of Table 6 reports what happens when we increase the benefit of schooling, captured by η_S, by a factor 2.5, keeping all other parameters equal. In this case the GDP gain is around five times as large, at 1.1 percent, and the average welfare gains increase to 8 percent in consumption equivalents. The treatment effect on schooling is too low now, at only 9 percent, and the treatment effect on secondary schooling is now counterfactually 11 percentage points higher for the students with the lowest quartile of test scores. These counterfactual predictions stem from the fact that when η_S is higher, more of the higher ability children in this version of the model are already going to secondary school before schooling is made free.

The fourth row of Table 6 presents the model's predictions for free schooling when the cost of schooling, ψ_S, is multiplied by 3.5 (in addition to the higher productivity η_S, as before). In this case the GDP gains are now larger, at 7.9 percent. The welfare gains are also now much larger, at 24 percent. Note that this case has a SHS completion rate of 32 percent which is similar to the data and only somewhat higher than in the benchmark calibration. In other words, this model, with both higher cost and benefits of schooling, has a reasonable prediction for secondary school enrollments. Intuitively, this model predicts much higher GDP and welfare gains from free schooling due to credit constraints proving much more binding for students who have a larger potential gain from schooling than before.

Unfortunately, this model does not make accurate predictions for the treatment effects on wages, which are far too high, at 26 percent. Nor does it make accurate predictions for the treatment effect on SHS completion, which is 44 percent compared to 27 percent in the data. This model also gets wrong the difference between the treatment effect on schooling for those with the highest quartile of test scores and the lowest quartile of test scores. In the data the treatment effect on schooling completion for kids with the highest test scores is 4 percentage points larger than the treatment effect on schooling for kids with the lowest test scores. In this model, the differences is -19 percentage points. In other words, this model counterfactually predicts that most of the experiment's effect on schooling happened for kids with the lowest test scores, whereas in fact kids with high and low test scores witness similar increases in schooling completion.

The final row of the table presents the model's predictions when the savings wedge χ is doubled. This puts even more households up against credit constraints, since it makes it even harder to save. This model predicts a 10.5 percent increase in GDP from free schooling, accompanied by a 22 percent increase in average. The large positive effects of free schooling in this version of the model stem from getting a large number of very credit constrained people into high quality schooling, that leads to substantial increases in average wages for all of them. Yet this model's predictions for treatment effects on SHS graduation are about twice as high as actually observed (50 percent versus 27 percent in the data), and the treatment effects on wages are about five times as high as in the data (38 percent versus 8 percent). Again, the selection on which students complete secondary schooling (by test score) are counterfactually negative.

The upshot of this subsection is that the model is able to deliver much larger impacts of free schooling on GDP and welfare with only a simple set of changes to parameter values. These changes substantially reduce the model's fit to the data however. This suggests that that the conclusion of low GDP and welfare impacts of free schooling is not an artifact of the model structure per se, but a feature of the model once estimated to the targeted moments in question.

6. Aggregate Effects of Alternative Policies

Are there any alternative policy levers that governments in low income countries can pull to bolster their education systems and raise their average income levels? Or do they all lead to small changes in GDP per capita by virtue of being small? In this section we use the estimated model to simulate alternative policies in order to address these questions. Doing so also helps shed light on why the model predicts such modest impacts from free secondary schooling.

Table 7: Aggregate Effects of Alternative Policies

	GDP Gain (%)	Welfare Gain (%, Avg)	SHS Increase (%)
Free Secondary School	0.2	1.9	3.0
Free Secondary School + Lower Cutoff	0.0	4.8	6.4
Universal Basic Income (costing same amount)	0.0	0.5	0.0
Ban Labor of Children	-20.6	-18.8	6.0
Raise Schooling Quality	4.1	4.6	3.1

Note: This table reports the gains in GDP, the gains in C.E. welfare and the increase in the SHS graduation rate for Free Secondary Schooling and several alternative policies (described in the text).

Table 7 summarizes the aggregate effects of these alternative policy counterfactuals. The first row reproduces three key aggregate statistics from the free schooling policy counterfactual from the previous section: the gains in GDP and average welfare and the increase in secondary schooling completion. The second row reports some key outputs from an alternative simulation where free secondary schooling is offered alongside a reduction in the test score cutoff allowing 62 percent of students to pass, up from 42 percent in the current system. This policy leads to no change in GDP per capita, but a more substantial 4.8 percent increase in average welfare. The increase in secondary graduates is roughly twice what it was under the baseline policy, at 6.4 percent, providing education for more households (with more marginal abilities).

The third row simulates a simple universal basic income policy costing the same amount as the free schooling policy in the main experiment. We simulate universal basic income by simply increasing the tax rates proportionally, as before, but now simply redistributing the proceeds to all households. The result is no change in GDP (at least to one decimal place) and a 0.5 percent increase in average welfare. The welfare gains here stem purely from transferring consumption from those with low marginal utility of consumption to high marginal utility of consumption. Secondary high school completion rates are basically unchanged. The upshot of this policy simulation is to highlight how pure redistribution is a substantial force for raising average welfare in our estimated model, accounting for around one quarter of the welfare gains we predict from the free secondary schooling policy.

The fourth row of Table 7 shows what happens when we ban labor supply by children, meaning that the household's only income can come from the parent. This is not a realistic policy in the sense that these are 15 to 25 year olds in our model, and this age range forms a key part of the workforce in developing countries. No county to our knowledge has proposed a ban on labor for this age group. Nevertheless, it is informative to consider the hypothetical effects of a child labor ban since it shows how important income from children is in the model. When child labor is banned, GDP is 20.6 percent lower, and welfare is 18.8 percent lower. This includes the losses of those aged 15 to 20, which is the schooling period, as well as the last period the children are at home, when they are aged 20 to 25. Secondary schooling rises a lot though, by 6 percentage points, signaling that a substantial fraction of the households eligible for secondary schooling are not currently attending due to the high opportunity cost, rather than not having enough income.

The last row of Table 7 summarizes the effects of improving schooling quality in such a way that average test scores rise by 0.1 standard deviations (relative to the benchmark estimation). This effect is conservative relative to the average effect size estimated in a number of different randomized interventions aimed at improving schooling quality in the developing world (many of which find effects of around 0.2 standard deviations or higher). One such intervention is to offer financial incentives to teachers based on the test scores of their students. Muralidharan and Sundararaman (2011) and Duflo et al. (2012) found that this raised test scores in India for example, while Mbiti et al. (2019) found effects of a similar size for teacher incentives plus block grants for schools in Kenya. Another successful schooling quality intervention is to increase the numbers of teachers in the classroom, as in the studies of Banerjee et al. (2007) and Muralidharan and Sundararaman (2013) in India.

Our model implies larger effects on GDP and welfare of improving schooling quality through large scale interventions raising schooling quality[4] GDP rises by 4.1 percent and welfare increases by 4.6 under such an invention. Even though this policy has no provisions aimed at expanding secondary enrollment directly, improved schooling

[4]For this intervention, we take the fiscal cost of the policy from Mbiti et al. (2019) who write "In Combination schools, we estimate that the cost of increasing test scores by 0.1σ per student was US \$5.78."

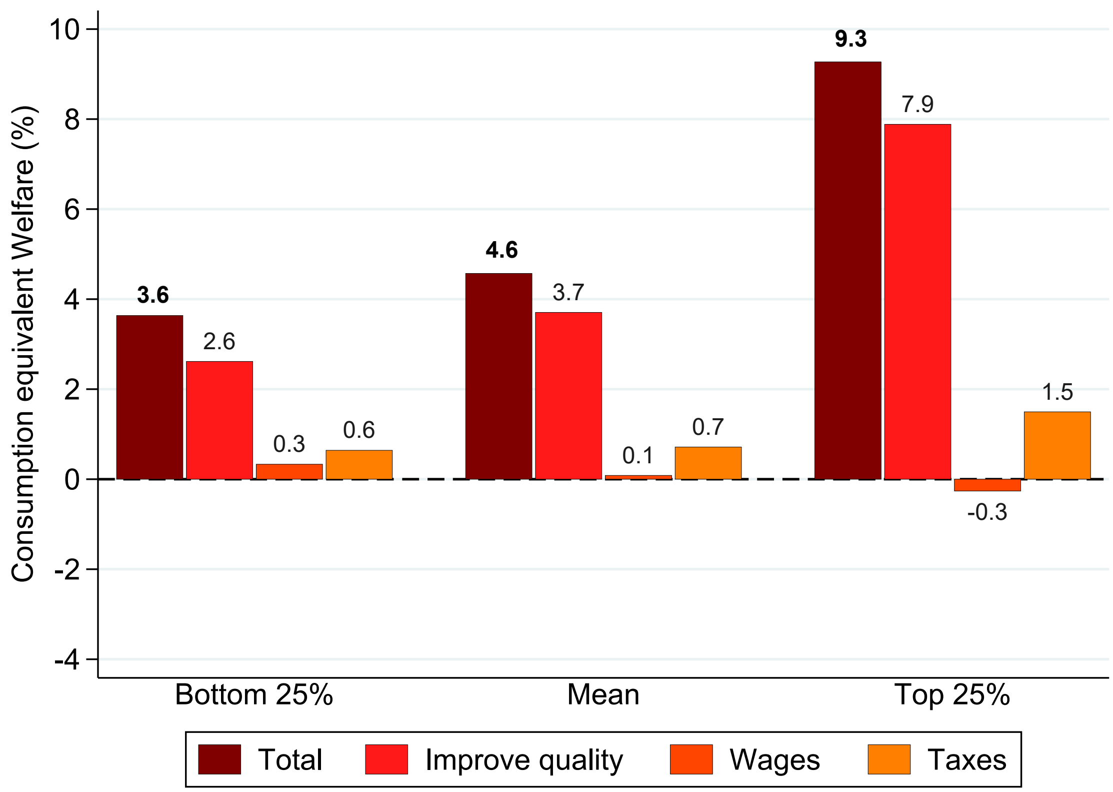


Figure 5: Welfare Effects of Improving School Quality by Parental Income

quality raises school enrollments by 3.1 percent, almost exactly the same increase as in the free schooling policy. The implication is that many students were not attending secondary schooling to begin with because they felt the returns were not high enough to justify the costs (including opportunity cost).

Figure 5 plots the welfare gains from improving school quality across the income distribution. The dark bars show that welfare gains are higher everywhere under schooling quality improvements than under free secondary school. The largest welfare gains are for the richest quartile of the Ghanaian income distribution, since this group is most likely to have kids in secondary school already. The remaining bars break down the welfare gains into the pure effects of schooling quality improvements, relative wage effects and taxes. One can see that the pure gains from quality improvements drive the welfare gains for each income group. Wage effects are modest, and tax effects are even positive now. The reason is that this policy raises human capital enough so that tax rates can be lowered and still have enough funds to cover the cost of the schooling quality improvements. In other words, schooling quality improvements with similar costs and benefits to the micro studies cited above pay for themselves in the long run, unlike free secondary schooling.

7. Conclusions

One of the main reasons income per capita is low in the developing world is that human capital levels are so low (Hendricks and Schoellman, 2018). One of the main obvious potential paths these countries can take to raise human capital is to raise attendance levels in secondary school. Making secondary schooling free for students, and funding the costs through higher taxes, is a natural policy to consider. Not surprisingly, many developing countries have pursued exactly these policies in recent years.

In this paper we analyze the aggregate and distributional effects of free secondary schooling policies in the developing world, looking through the lens of an OLG model of human capital accumulation with credit constraints. We focus on the case of Ghana, for which we can draw on recent experimental evidence on the outcomes of students randomly assigned to receive free secondary schooling, leading to higher secondary school completion rates and higher average test scores (Duflo et al., 2021). Ghana is also a country that has recently adopted free secondary schooling, and the policy is viewed as a success there and in other developing countries (Center for Global Development, 2022).

Our conclusions are less optimistic. When we simulate the general equilibrium effects of free secondary school in our model, we find that it would have next to no impact on GDP per capita and increase welfare by only around 2 percent. The reason for these modest aggregate effects is that when estimated to match the experimental data, our model implies that most students eligible for secondary school but not attending choose not to attend due to low potential returns and high opportunity costs. The model implies that some students are misallocated, but credit constraints are not the main reason secondary enrollment rates are not higher.

We conclude that free secondary education policies are mostly redistributive in nature, rather than a path to economic growth, at least the current low levels of schooling quality. Our model predicts that spending the same amount on improving schooling quality would lead to substantially higher increase in GDP per capita and welfare across the income distribution. Improving schooling quality would also expand schooling enrollments by around the same amount as free schooling policies. Our analysis suggests that the best way for poor countries to raise aggregate human capital is to focus on improving the quality of their current schooling systems rather than by giving away a mediocre education to more young people.

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Appendix (for Online Publication)

A. Background on Free Secondary Schooling Policies

BENIN: Education in Benin was declared free in 2007 after an Educational Forum. After that, the government of Benin enrolled a free education program that eliminate fees at all levels of education. For students to access free secondary education, they need to first write and obtain a passing grade (aggregate 10) in the Primary School Certificate examinations to enter into a 4-year Junior High School. After the four years of Junior High School, students who want to further pursue Senior High School need to pass the Brevet d'Etudes du Premier Cycle (BEPC) which is the equivalent of the O-level. For more information kindly visit the below links: link 1, link 2, and link 3.

GAMBIA: The government of Gambia with support from development partners such as the World Bank and the Global Partnership for Education introduced a progressive free education policy aimed at eliminating school fees at public primary and secondary schools by 2015. The policy started in 2013 where all forms of school fees were abolished at the primary school level through a grant scheme known as the School Improvement Grant (SIP). The policy aims at abolishing school fees at the lower and upper secondary levels in 2014. In Gambia, students who aspire to pursue upper secondary education are required to write and pass the Gambia Basic Education Certificate Examinations. In contrast, students are automatically promoted to lower secondary school from primary school without taking any examinations. Check the below links for more: link 1 and link 2

GHANA: The government of Ghana started implementing a Free Senior High School policy in 2017. The government absorbed almost all associated cost in secondary education including tuition and boarding fees for boarding students and tuition fees for day students, feeding fees, uniforms, and some core text books. To gain admission into a Senior High School in Ghana, students have to obtain an aggregate pass in 6 subjects in the Basic Education Certificate Examination at the end of Junior High School (Grade 9) before posted into a publicly funded Senior High School. The posting of students is administered by the Computerized School Selection and Placement System (CSPSS). For more information kindly click here.

KENYA: Kenya's Free Secondary Schooling Education Program began in 2008. The program adopts a cost sharing approach whereby the Kenyan government waives tuition fees for secondary school students while parents carter for boarding fees, uniforms, and other ancillary cost. Students have to pass 'well' in the Kenya Certificate of Primary Education Examination before gaining entry into a secondary school. More information can be found clicking these links link 1, link 2, and link 3.

MALAWI: Malawi abolished secondary school fees in 2019. This means that tuition fees, general purpose fund, and the textbook fund have all been absorbed by the government of Malawi. For admission into secondary schools in Malawi, pupils have to write and pass the Primary School Leaving Certificate examinations. Click the below links for more: link 1 and link 2.

MAURITIUS: Mauritius have been implementing a comprehensively free secondary education since 1977. This means that all direct school fees and administrative expenses are subsidized by the government. Secondary school education comprises the lower and upper secondary and starts from grade 7 through to grade 13. Upper secondary is further divided into grades 10 & 11 and grades 12 & 13. Following the education reforms in 2016, students were automatically transitioned into lower secondary as part of the new nine-year basic education cycle. After basic education, students are moved to the first phase of upper secondary (grades 10 & 11). Upon the completion of phase 1 of upper secondary, students write the General Certificate of Education (GCE) 'O' level examinations after which successful candidates go on to pursue the second phase of upper secondary (i.e. grades 12 & 13). For more check the below links: link 1 and link 2.

NAMIBIA: The government of Namibia declared free secondary school in 2016. The free secondary policy removed all tuition and examination fees and parental contributions to the school development fund. Secondary school education in divided into Junior and Senior secondary schools. Pupils are promoted to Junior Secondary without writing any examination. However, to gain access to Senior Secondary school, students are required to pass junior secondary school examinations. For more, please check these links: link 1 link 2, link 3, and link 4.

NEPAL: The government of Nepal operationalized the constitutional provision of "free educational up to the secondary level" for every citizen when the federal parliament passed into law the "Act Relating to Compulsory and Free Education" in 2018. The Act explained "free education" to mean education free of all charges of any kind from a school or educational institutions. Specifically, the Act provides that all educational liabilities including fees, textbooks, and other educational materials shall be borne by the state. To be admitted into a secondary school, students have to sit and pass the final district-level examination at the end of grade 8. For more check these website links: link 1 and link 2

PHILIPPINES: Philippines started a free secondary education program in 1988/89 school year when the *"Free Public Secondary Education Act of 1988"* was passed. The Act waived tuition fees and other costs supportive of instruction. Although the Act states that only qualified citizen are eligible for the free secondary education, no qualification criteria was proposed. However, students are prevented from enjoying the free education program if they fail in two consecutive school years. More can be found here.

RWANDA: Rwanda initiated a free Nine Year Basic Education in 2008 which was free up-to only the lower secondary level. However, in 2012, the government expanded the program to cover up-to the upper secondary schools. Only tuition fee is waived under the program while parents cover the other cost of education. To gain access to lower secondary education, grade averages from the Primary School Leaving examinations are used. On the other hand, students are required to score 'high' grades in the O level examinations to gain admission into the upper secondary schools. For more information, kindly click link 1, link 2, and link 3.

SIERRA LEONE: The government of Sierra Leone commenced a Free Quality School Education in 2018 which waived admission, tuition, and examination fees charged from primary school to secondary school levels. The program also distribute some core text books free of charge to students. Entry into secondary schools in Sierra Leone requires students to score Unit/Grade 6 at the Basic Education Certificate Examination. More information can be found at link 1, link 2, and link 3.

SEYCHELLES: Seychelles have been implementing a free secondary education program since 1981. The policy covers tuition-fees and books, however, students must buy their own school uniforms. Students write the national attainment test at the end of primary school to determine admission into secondary schools. More can be found at link 1 link 2, and link 3.

TANZANIA: Tanzania embarked on Free Education Policy for Secondary Education in 2015 to eliminate tuition and most fees associated with secondary education. However, it is the duty of parents to provide school uniforms and other scholastic materials such as exercise books, test books, etc. As regards to admission requirements into secondary schools, students are expected to obtain a passing score in the Standard 7 examinations organized after primary school. More information can be found here.

UGANDA: The government of Uganda have been providing a free secondary education since 2007 known as the Universal Secondary Education. Under the program, students who successfully gain admission into secondary schools are exempted from paying tuition and other related fees. Also, school some core text books are provided free of charge. Other secondary education related cost such as the provision of uniforms, feed, accommodation, medical care, and other school materials are borne by parents/guardians. Students are required to score an aggregate score of 28 in the Primary School Leaving examination to qualify for admission into a secondary school. More information can be found here: link 1 and link 2.

ZAMBIA: The government Zambia began a free education in January 2022 by replacing tuition-fees with a compensatory grant. In addition to the elimination of tuition-fees, Parent Teacher Association and examination fees were also abolished in all government schools. This means that school uniforms, shoes, and other educational materials are to be provided by parents. However, a separate funding arrangement was put in place support children from extremely poor families to buy school uniforms and shoes. Students have to pass the end of Primary School and Baccalaureate examinations to gain access to the lower and upper secondary school levels respectively. Kindly find more by clicking: link 1, link 2 and link 3.

B. Aggregate Population Dynamics

This section of the appendix walks through the details of population growth within the model and discusses 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. To save on notation, we follow the quantitative section of the paper and assume that college attendance is zero.

By definition, the aggregate population growth rate is given by the formula

$$\text{Agg. Pop. Growth Rate} = \frac{\text{\# births} - \text{\# deaths}}{P} \tag{9}$$

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

$$\text{\# births} = \big[\nu_J \int_{s_p=J,\tau=5} f(X)dX + \nu_S \int_{s_p=S,\tau=5} f(X)dX\big]P \tag{10}$$

$$\text{\# deaths} = \big[\int_{\tau=14} f(X)dX\big]P \tag{11}$$

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

$$\nu - 1 = \nu_J \int_{s_p=J,\tau=5} f(X)dX + \nu_S \int_{s_p=S,\tau=5} f(X)dX - \int_{\tau=14} f(X)dX \tag{12}$$

Note that as written, $\nu > 1$ 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.

The previous discussion described the aggregate population growth rate in a manner consistent with recursive competitive equilibrium (i.e. as a function of state variables). Here we describe the growth rate from the perspective of the balanced growth path.

Recall that the aggregate population growth rate ν 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 BGP 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 ν, we know that the ratio of the population of households of age x and households of age y must be given by (WLOG let $x < y$)

$$\frac{\int_{\tau=x} f(X)dX}{\int_{\tau=y} f(X)dX} = \nu^{y-x} \tag{13}$$

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 ν the following equations are true

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

$$\int_{\tau=5} f(X)dX = \frac{(\nu - 1)\nu^9}{\nu^{14} - 1} \tag{15}$$

Finally, because household policy functions are invariant with respect to P and f is stationary along the BGP, 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 $\hat{J}, \hat{S}$.

$$\hat{J} \equiv \frac{\int_{s_p=J,\tau\geq 5} f(X)dX}{\int_{\tau\geq 5} f(X)dX} = \frac{\int_{s_p=J,\tau=5} f(X)dX}{\int_{\tau=5} f(X)dX} \tag{16}$$

$$\hat{S} \equiv \frac{\int_{s_p=S,\tau\geq 5} f(X)dX}{\int_{\tau\geq 5} f(X)dX} = \frac{\int_{s_p=S,\tau=5} f(X)dX}{\int_{\tau=5} f(X)dX} \tag{17}$$

Combining equations 14-17 with equation 12 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:

$$\nu - 1 = \left[\nu^9\left(\nu_J \hat{J} + \nu_S \hat{S}\right) - 1\right] \frac{\nu - 1}{\nu^{14} - 1} \tag{18}$$

which can be reduced to

$$\nu^5 = \nu_J \hat{J} + \nu_S \hat{S} \tag{19}$$

Appendix Tables and Figures

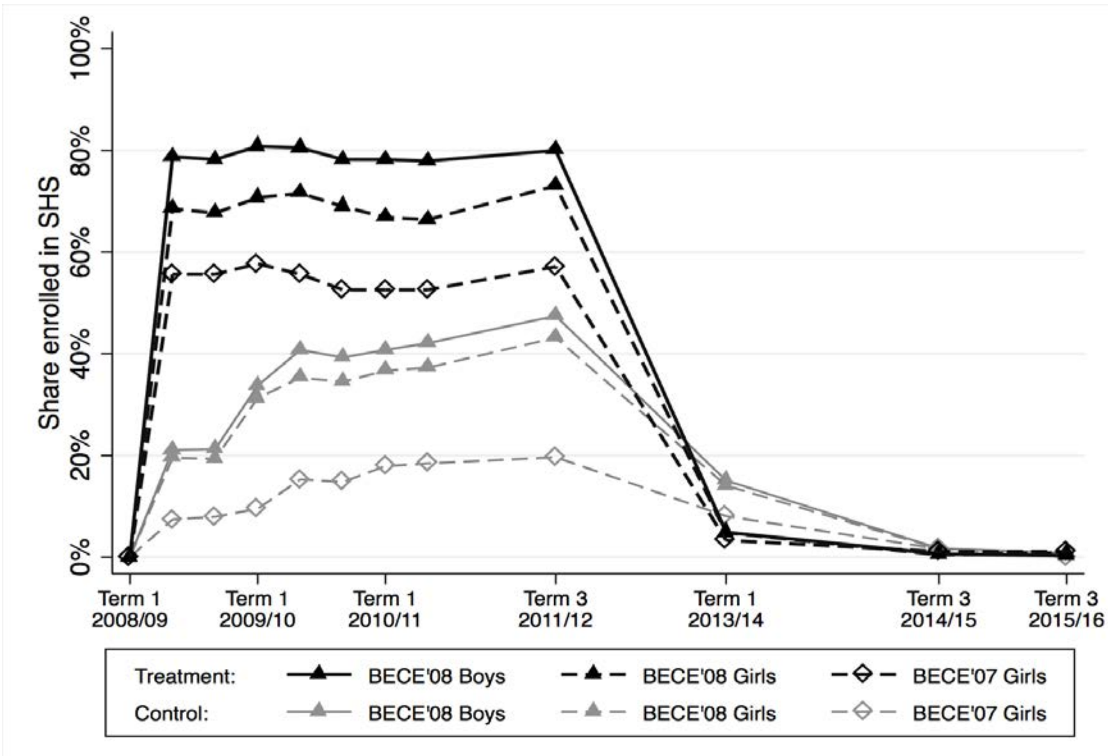

Figure C.1: School Attendance in the DDK Experiment

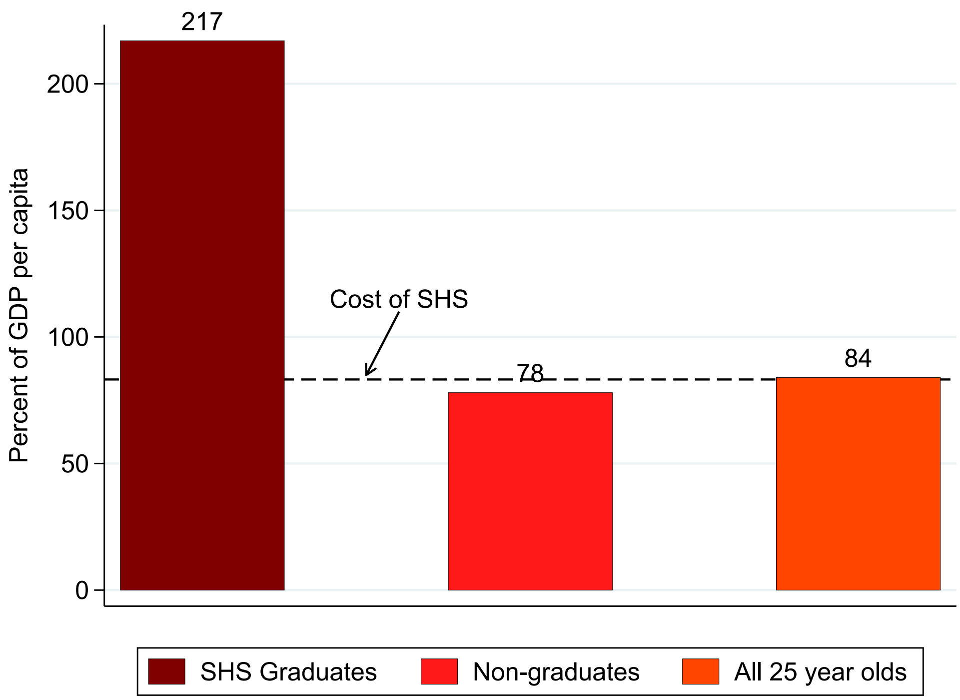

Figure C.2: Equivalent Variation of Secondary School to Children

Table C.1: 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 2018. 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 2018.