Human Capital and Structural Transformation*

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Abstract: This paper argues that public education policies, which affect schooling years and education quality, are important to understand sectoral employment. We build a multi-sector general equilibrium heterogeneous-agent life-cycle model, which features both education investment, in terms of schooling years and expenditure, and sectoral employment choices. Disciplining the stock of human capital using schooling years and return of education data, we perform counterfactual experiments and show that eliminating public education policies would increase agricultural employment by 35% while endowing a developing country with U.S. public education policies would reduce the agricultural employment by 21% and the cross-country income difference by 29%.

JEL codes: E24, I25, J24, O11, O41

Keywords: Education Quality, Education Policies, Sectoral Labor Allocation, Cross-Country Productivity Differences

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1 Introduction

Structural transformation is a distinctive feature of economic growth that occurs when a sustained period of rising income is accompanied with reallocation of economic activities from agricultural to nonagricultural sector. The literature has emphasized two channels to explain the pattern: the increase in income that reduces the relative demand for food and a relative technological progress in the agricultural sector that relaxes the constraint of subsistence requirement. Both of these channels reduce the demand for agricultural workers and make the agricultural sector shrinks over time.

In this paper, we argue that human capital is also an important to determine the structural transformation. As shown in Figure 1 (left panel), economies with larger stock of human capital are also the ones with smaller agricultural sector in terms of employment share.[1] Why does human capital important for structural transformation? Since human capital is relatively more valuable in the nonagricultural sector, people who accumulate more human capital choose to work in the non-agriculture. Thus, on top of other exogenous income and productivity effects, human capital plays important role in understanding structural transformation.

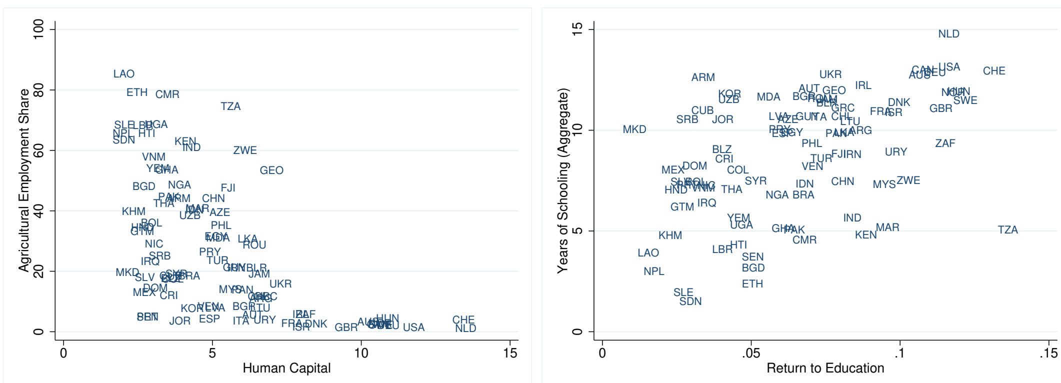

Figure 1: Sectoral Allocation, Years of Schooling and Return to Schooling

We emphasize both quantity and quality of education. Quantity of education refers to the years of schooling while the quality of education means how much human capital can be imparted per year of schooling, which can be inferred from the Mincer return (see, e.g., Hendricks, 2002; Schoellman, 2012). It can be seen from Figure 1 (right panel) that although years of schooling and return to education are positively and significantly correlated, their relation is not tight ($R^2 = 0.22$). For countries with very similar years of schooling, their return to education can be very different. For example, while both average workers in Italy and UK had 11 years of schooling in year 2005, the return to education was 10.8% in UK but 6.8% in Italy.[2] Therefore, it is important to treat years

[1] The calculation of human capital (H) follows Schoellman (2012) and assumes the following functional form $H = \exp[(SQ)^{0.5}/0.5]$. The data of years of schooling (S) is from Gollin, Lagakos and Waugh (2014) and the return to education (Q) is from Schoellman (2012). The current work use the method proposed in Hendricks (2002) and Schoellman (2012) to use the immigrants' earning in the U.S. to assess the education quality in their original countries. There are other works that directly estimate the human capital stock using the international testing score (for example, Hanushek and Kimko, 2000; Hanushek, Ruhose and Woessmann, 2017; Lee and Lee, 2022).

[2] The agricultural employment share in UK was 1.5% while that in Italy was 3.7%.

of schooling and return to education as two related but separate dimensions of human capital.

We also investigate how human capital accumulation varies systemically across countries by looking into the public education systems. We consider two types of education policies: years of government subsidized schooling and government expenditure on public education, both of which are important to determine human capital through their effects on years of schooling (quantity of education) and return to schooling (quality of education). A better education system decreases the marginal cost and increases the marginal benefit of education, and encourages individuals to accumulate more human capital. This also has implication for sectoral labor productivity and employment share.[3] In particular, our Mincer regression indicates that additional year of schooling increases one's productivity, especially in the nonagricultural sector. We take this as evidence that human capital is relatively more valuable outside of the agricultural sector, and people with larger stock of human capital will work in non-agriculture.

With the evidence mentioned, we develop a life-cycle model with human capital and sectoral employment decisions, embedded into a multi-sector general equilibrium framework. Our modeling of human capital accumulation built upon Córdoba and Ripoll (2013) but we differ from their work in two distinct aspects. First, we build human capital accumulation in a multi-sector general equilibrium setting. This setup not only allows our model to have prediction on the sectoral employment share, but generates endogenous sectoral productivity difference based on the composition of workers with different human capital. Second, relatedly, we add multi-dimension of household heterogeneity into the model, including endowments of wealth and abilities. Such heterogeneity makes different households in the same country choose different education investment and sectoral employment.

Human capital accumulation depends on both the duration of schooling and education investment (in terms of consumption goods) during the schooling period. Individuals' human capital decisions crucially depend on government education policies, which include both government education subsidy per pupil and its duration. The education subsidy lowers individuals' marginal cost and increases ones marginal benefit of education investment, and thus induces more human capital investment. Such effect is strengthen by the increase in duration of subsidy. As households acquire larger stock of human capital, they are more likely to self-select themselves into the nonagricultural sector. As a result, the model is able to generate the fact that economies with better education policies having more years of schooling and smaller agricultural sector.

To study the quantitative implications of our model, we first calibrate it to year 2000 U.S. data. Among the untargeted moments, the model is able to generate sectoral years of schooling distributions that match the data well. The model is able to explain more than half of the decrease in agricultural employment share and almost all increase in years of schooling in the last century, after we assume some of the model parameters (e.g. productivity, public schooling expenditure, life expectancy, etc.) to change according to data. The counterfactual analysis shows that education policies, like the duration of government subsidized schooling and government public education

[3] It is less controversial that education augments the nonagricultural sector production efficiency. In the agricultural sector, Goldin and Katz (2010) show that people with more years of schooling earns higher income, but smaller Mincer return compared to the nonagricultural sector.

expenditure, explain 45% of structural transformation and 54% of years of schooling difference in the last century. General equilibrium effect attenuates the effect of education policies through price effect.

Then we recalibrate the same set of parameters to cross-country data and test the model prediction on cross-country differences in agricultural employment share and human capital. The model produces some variables that have clear data counterparts: sectoral years of schooling and return to education. So, we discipline and test our model using two different dataset. The first dataset, used for calibration, is the agricultural and nonagricultural years of schooling documented in Gollin, Lagakos and Waugh (2014). The second dataset, used to test model fit, is from Schoellman (2012) who uses immigrants' return to education to derive quality of education across countries.[4] The calibrated model is able to generate some additional cross-country data features.

The counterfactual exercise shows that developing countries, like Bangladesh, would experience 13% reduction in human capital stock and 35% increase in agricultural employment share if the public education policies are removed. If, however, Bangladesh is endowed with the public education policies in the U.S. and assume that the years of schooling remains unchanged (but the quality of education increased for each additional year of schooling), the agricultural employment share would reduced by 21%, induced by 23% increase in human capital.

Related Literature. We build on the Roy (1951) model of self-selection based on comparative advantage. The framework is similar to that of Lagakos and Waugh (2013) and Porzio, Rossi and Santangelo (2022), that individuals with heterogeneous human capital choose their sector of employment. Porzio, Rossi and Santangelo (2022) argue that human capital is valued higher outside of the agricultural sector, higher human capital individuals will self-select to nonagricultural sector. In their framework, however, human capital is not chosen by individuals. Hence, their models are silent about the endogenous change of human capital distribution due to the change in education policies. Our contribution is to endogenize the process of human capital accumulation, link it education policies and economic environment, and quantify the impact of human capital accumulation on both sectoral labor allocation and productivity. Moreover, we take into account both quantity and quality dimensions of education in determining structural transformation. To our best knowledge, we are the first to quantify the effects of both quantity and quality of education on structural transformation.[5]

Our work is also related to the literature on human capital accumulation. Our model is similar to the ones in Córdoba and Ripoll (2013) and Manuelli and Seshadri (2014). The current paper follows Córdoba and Ripoll (2013) in modeling human capital accumulation, and both papers consider how different education policies, income level and economy-wide efficiency affect individuals'

[4]We do not use return to education data derived from the country's own census or survey data like in ones in Psacharopoulos (1985, 1994). This is because the return to education not only depends on the quality of education, but also the total human capital stock. In places with lower education attainment, secondary school completion is considered high education and individuals with such degree earn premium wage. For example, some of the less developed countries documented in Bils and Klenow (2000) had higher return to education when compared to the U.S. So, as argued in Schoellman (2012), it is desirable to control for the stock of human capital.

[5]Cheung (forthcoming) uses a two-sector model to quantify the effect of education policies on quantity-quality trade-off made by parents. However, he focuses on the decline in fertility rate and is also silent about international comparison in agricultural employment share.

human capital investment. In order to study structural transformation, we add multi-sectoral production sides and allow individuals with heterogeneous endowments to have different human capital investment and self-select themselves into different sectors. In additional, our work complements the human capital literature by incorporating both quality and quantity of education into a life-cycle model to account for the quality-adjusted human capital stock.

To our best knowledge, Caselli and Coleman (2001) is the seminal paper studying the effect of education on sectoral allocation of labor. The current work is different from theirs in the way human capital is used. In Caselli and Coleman (2001), education only serves as a prerequisite for individuals who wish to join the nonagricultural sector, but does not augment individuals' production efficiency. However, the current work treats human capital as a productive input. Thus, align with Manuelli and Seshadri (2014), different (sectoral) stock of human capital affects (sectoral) productivity in the economy. This allows us to use the measured sectoral human capital stock to understand sectoral labor allocation and productivity.

Finally, our model speaks to a large literature of structural transformation (see Herrendorf, Rogerson and Valentinyi, 2014, for literature review). The current work is mostly related to Acemoglu and Guerrieri (2008) that built on the insight of Rybczynski (1955) and develop a model in which endogenous changes in the supply of different inputs may lead to structural transformation if sectors vary by their factor intensity. Our contribution is to build a model that endogenizes the formation of human capital, and link it to structural transformation.

The subsequent discussion will be organized as follows. Section 2 discusses the empirical evidence. Section 3 presents a model with education and sectoral employment choice. Section 4 is to calibrate the model and establish the credibility of the model. Section 5 presents some counterfactual exercise. Section 6 concludes.

2 Stylized Facts

In this section, we show that education policies, namely, years of compulsory education and government education expenditure, are important to both the quantity (years of schooling) and quality (return to education) dimensions of education. We then show that higher quantity and quality dimensions of education increase labor productivity, especially in the nonagricultural sector, and reduce agricultural employment share.

Fact 1. Education policies affect positively both the quantity and quality of education The education policies, namely, years of compulsory education and government education expenditure, varies largely across different countries. For example, in the year 2005, the compulsory education in Bangladesh is 5 years and government spent 2.11% of GDP on education; in the U.S., however, the numbers were 12 years and 4.94%, respectively.

Not only does the difference in education policies have implication on years of schooling, but such difference also affects quality of education measured by return to education (Schoellman, 2012). In economies with better education policies, i.e., government provides longer years of compulsory

Figure 2: Education Policies on Quality and Quantity of Education

education and a larger amount of public education expenditure, the economies are likely to have more years of schooling. This is not very surprising because the improvement of the education policies reduces the marginal cost of education, and thus leads to an increase in schooling in general.

In addition, more human capital is imparted per year of schooling in countries with better education policies, which is associated with higher Mincer coefficient (i.e. higher wage income per an addition year of schooling). This increases the marginal benefit of education. Two lower panels in Figure 2 shows that the return to education positively correlated with education policies.

Fact 2. Nonagricultural sector is more human-capital-intensive and nonagricultural productivity is more responsive to the quantity and quality of education

The nonagricultural sector uses human capital more intensively when compared to the agricultural sector, which has been well documented by different scholars (see, e.g. Goldin and Katz, 2010; Porzio, Rossi and Santangelo, 2022). Figure A.1 uses data in Gollin, Lagakos and Waugh (2014) to replicate the cross-country result. It show that years of schooling in the nonagricultural sector is higher than that in the agricultural sector for all countries in the sample.

Sectoral labor productivity provides information on sectoral efficiency unit of labor per worker.

We decompose sectoral labor productivity in the following way:

$$\frac{Y_i/Y}{N_i/N} = \frac{Y_i}{N_i} \times \frac{N}{Y} \iff \frac{Y_i}{N_i} = \frac{Y_i/Y}{N_i/N} \times \frac{Y}{N}$$

where Y_i/N_i is sectoral labor productivity, Y/N is GDP per worker, Y_i/Y is sectoral value added share and N_i/N is sectoral employment share. By using the data from the World Bank and Gollin, Lagakos and Waugh (2014), we construct a measure for sectoral labor productivity Y_i/N_i.

Figure 3: Residual Sectoral Productivity and Education Policies

Nonagricultural labor productivity is more responsive to the increase in quality and quantity of education. A simple regression analysis shows that an additional year of schooling is associated with a 0.36-unit increase in agricultural productivity and 0.64-unit increase in nonagricultural productivity. At the same time, a 1 percentage point increase in Mincer coefficient from Schoellman (2012) is associated with a 0.42-unit increase in agricultural productivity and 0.66-unit increase in nonagricultural productivity. Together with Fact 1, we can conclude that public education policies have positive effect on the efficiency unit of labor in each sector, and the effect tends to be larger in the nonagricultural sector.

Fact 3. The quantity and quality of education negatively associated with agricultural

employment share

From Fact 2, we learn that higher quantity and quality of education are associated with higher sectoral labor productivity. The increase in labor productivity eases the subsistence food requirement and leads to labor reallocation from the agricultural to nonagricultural sector.

Moreover, since human capital is relatively more valuable in the nonagricultural sector, people who accumulate larger stock of human capital tend to work in nonagricultural sector. As shown in Figure 4, economies with higher quantity and better quality of education are also the ones with smaller agricultural employment share.

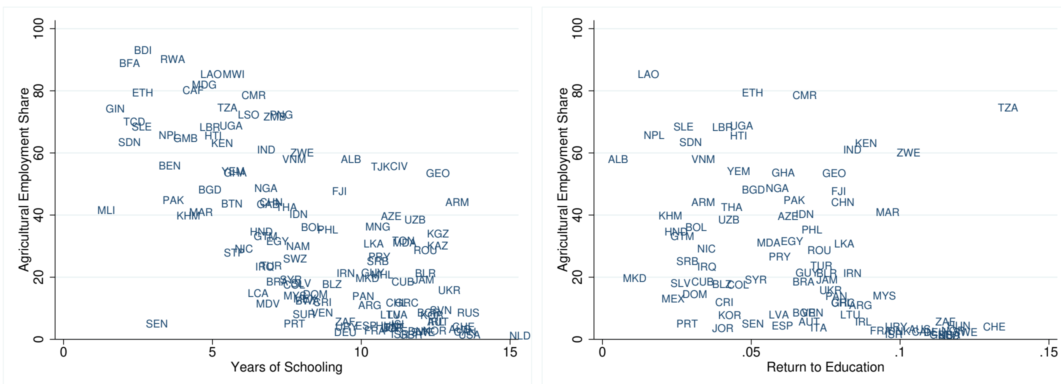

Figure 4: Sectoral Allocation, Years of Schooling and Return to Schooling

2.1 Summary

In this section, we show that the reason behind the negative correlation observed in Figure 4 can be understood in two dimensions. First, better education policies induce more years of schooling and better education quality. As the nonagricultural sector values human capital higher, increase in human capital leads to relative expansion in nonagricultural sector and relative decline in agricultural sector. This effect is also strengthened by the fact that larger human capital stock also implies richer countries that demand relatively less agricultural goods.

Second, countries with better education policies also have higher sectoral productivity, and such effect is stronger in the nonagricultural sector. This is also partly due to the fact that the nonagricultural sector is more human capital intensive. Hence, education policies can also explain part of the agricultural productivity gap.

3 Model

In this section, we present a life-cycle model with human capital and sectoral employment decisions, embedded into a general equilibrium economy. The modeling of human capital accumulation is built upon Córdoba and Ripoll (2013). We add the multi-sector production side and heterogeneity of individuals to allow individuals to choose sectoral employment following Roy (1951) model.

Financial constraints and education policies play important roles in determining the individuals' human capital investment decisions, and thereby their sectoral employment decisions.

3.1 Household and Endowment

Time is continuous and individuals differ in their endowment in initial wealth b, ability ψ and agricultural productivity l. We assume that each individual randomly draw $\{b, \psi, l\}$ from $G(b, \psi, l)$. Although l only affects individuals through its effect on efficiency of agricultural production, ψ affects both (nonagricultural) production efficiency and human capital accumulation process. Different from Córdoba and Ripoll (2013), we abstract from any intergenerational choices to simplify the problem and to focus on sectoral allocation of human capital rather than intergenerational mobility.

We assume that an individual start to derive utility at age 6 when she begins to go to school. An individual chooses a series of consumption and education investment, $\{c(\tau), e_p(\tau)\}_{\tau \in [6,T]}$, between age 6 and terminal age T. The individual also chooses the age s when she discontinues schooling and starts to work. So, the utility maximization problem of an individual with endowment $\{b, \psi, l\}$ and working in sector i is given by:

$$V_i(b; \psi, l) = \max_{c(\tau), e_p(\tau), s, \kappa(s)} \int_6^T e^{-\rho(\tau-6)} u(c(\tau)) d\tau \tag{1}$$

s.t.

$$\int_6^s e^{-r(\tau-6)} [c(\tau) + e_p(\tau)] d\tau + e^{-r(s-6)} \kappa(s) \leq b \tag{2}$$

$$\int_s^T e^{-r(\tau-6)} c(\tau) d\tau \leq \int_s^R e^{-r(\tau-6)} (1-\iota) w_i \left(h(s), \tau - s; \psi, l\right) d\tau + e^{-r(s-6)} \kappa(s) \tag{3}$$

$$h(s) \leq z_h \left[\int_6^s \psi (e_p(\tau) + e_g(\tau))^\alpha d\tau \right]^{\frac{\gamma}{\alpha}} \tag{4}$$

$$e_p(\tau) \geq 0 \text{ for all } \tau \tag{5}$$

$$\kappa(s) \geq 0$$

$$0 \leq s \leq F$$

Equation (2) suggests that the credit market is not perfect, so individuals cannot borrow as much as they want against their future earnings when $\tau < s$. Their borrowing is constrained by their initial wealth. Nonetheless, they can save part of their unused initial wealth for future use, i.e. $\kappa(s) \geq 0$. During $\tau < s$, apart from consumption and saving choices, individuals also choose private education investment $e_p(\tau)$.

When individuals work, i.e. $\tau > s$, their lifetime income is the discounted present value of their wage income plus saving $\kappa(s)$. In equation (3), sectoral wage $w_i \left(h(s), \tau - s; \psi, l\right)$ is assumed to have the following function form:

$$w_i\left(h(s), \tau - s; \psi, l\right) = \tilde{w}_i\left(h(s); \psi, l\right) e^{\nu_{1i}(\tau - s) + \nu_{2i}(\tau - s)^2}$$

which captures both schooling effect $\tilde{w}_i\left(h(s); \psi, l\right)$ and experience effect $e^{\nu_{1i}(\tau-s)+\nu_{2i}(\tau-s)^2}$ in the Mincer equation. We assume that ν_{1i} and ν_{2i} are sector-specific and will be pinned down using data in Ruggles et al. (2018). We further assume that the sector-specific experience will be lost once the individual switches sectors.[6] An working individual needs to pay income tax at a proportional tax rate ι. The tax is collected by the government, which runs balanced-budget, and is used to fund public education investment $e_g(\tau)$ for all the current students and redistribute as initial wealth for the new born generation (i.e. individuals at $\tau = 6$).

Human capital $h(s)$ is accumulated through schooling. Define $e(\tau) = e_p(\tau) + e_g(\tau)$ as the total education investment. In equation (4), human capital accumulation depends on four factors: 1. the economy-wide efficiency in human capital production captured by z_h; 2. the length of individuals years of schooling captured by s; 3. the education investment in units of aggregate consumption goods captured by $e(\tau)$; and 4. the idiosyncratic efficiency in human capital accumulation captured by ψ. Similar to Córdoba and Ripoll (2013), parameter α determines the degree of substitution of education investment throughout lifetime while γ governs the return to scale of total effective education expenditure.

There are two sectors, agricultural a and nonagricultural m, in the model economy so that $i \in \{a, m\}$. The instantaneous utility function in equation (1) is given by $u(c(\tau)) = c(\tau)^{1-\sigma}/(1-\sigma)$ where

$$c(\tau) = \frac{\tilde{c}(\tau) - p_a(\tau)\bar{c}}{\left[\zeta p_a(\tau)^{1-\eta} + (1-\zeta)p_m(\tau)^{1-\eta}\right]^{\frac{1}{1-\eta}}} \tag{6}$$

can be viewed as composite consumption goods and $\tilde{c}(\tau)$ is the total expenditure on consumption.[7] p_a and p_m are prices of agricultural and nonagricultural goods, respectively. Thus, the composite consumption goods have price index $\left[\zeta p_a(\tau)^{1-\eta} + (1-\zeta)p_m(\tau)^{1-\eta}\right]^{\frac{1}{1-\eta}}$, which is normalized to 1.

Finally, the sectoral choice S is such that $S = \arg\max_{S\in\{0,1\}}\{SV_a(b|\psi, l) + (1-S)V_m(b|\psi, l)\}$.

[6] From Herrendorf and Schoellman (2018), it is found that only small number (0.45%) of workers from 1968-97 switched from agricultural to nonagricultural sector.

[7] This is a indirect utility function that depends on total expenditure $\tilde{c}(\tau)$ as well as price vectors. The expression in equation (6) comes directly from maximizing

$$\left[\zeta^{\frac{1}{\eta}}\left(c_a - \bar{c}\right)^{\frac{\eta-1}{\eta}} + (1-\zeta)^{\frac{1}{\eta}} c_m^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}$$

subject to

$$p_a(\tau)c_a(\tau) + p_m(\tau)c_m(\tau) \leq \tilde{c}(\tau)$$

3.2 Financial Constraint and Education

Denote λ_1 and λ_2 be the two Lagrangian multipliers associated with equations (2) and (3), respectively. The FOC's with respect to consumption $c(\tau)$ when $\tau \in [6, s]$ and $\tau \in [s, T]$ gives:

$$J \equiv \frac{\lambda_1}{\lambda_2} = \frac{u_c(c^S(s))}{u_c(c^W(s))} = e^{(\rho-r)(F-6)} \frac{u_c(c(6))}{u_c(c(F))} \geq 1$$

The last inequality is due to the presence of non-negative borrowing constraint in equation (5). Notice that $J \geq 1$ represents a potential jump in consumption at age $\tau = s$, i.e. $c^S(s) \leq c^W(s)$. If $J > 1$, then $c^S(s) < c^W(s)$ and the individual is constrained. The individual wants to smooth her consumption by borrowing ($\kappa(s) < 0$), but she faces the non-negativity borrowing constraint. So, she will spend all her initial wealth b and $\kappa(s) = 0$.

If $J = 1$, then $c^S(s) = c^W(s)$. The individual is able to smooth consumption across studying and working periods, and her saving at age s is given by:

$$\kappa(s) = \frac{\frac{b-E^*}{D_6^s} - \frac{I_i(s)}{D_s^T}}{e^{-r(s-6)}\left[\frac{1}{D_6^s} + \frac{1}{D_s^T}\right]} > 0$$

where E^* is the discounted present value of private education expenditure, $I_i(s)$ is discounted present value of wage income during the working period and D_x^y is a collection of discounted factors.[8] The expression above is intuitive: saving $\kappa(s)$ is decreasing in both private education expenditure E^* and wage income $I_i(s)$, because higher private education expenditure reduces the unused amount of initial wealth and higher future wage income discourages saving in the study period.

The size of J affects the optimal schooling. To see this, consider the following FOC with respect to s, where left-hand side is the marginal benefit of additional schooling while right-hand side represents the marginal cost:

$$\begin{aligned} &\frac{\partial}{\partial s} \int_s^R e^{-r(\tau-6)} w_i \left(h(s), \tau - s; \psi, l\right) d\tau \\ &= J e^{-r(s-6)} \left[\frac{u(c^W(s)) - u(c^S(s)) + u_c(c^S(s))c^S(s) - u_c(c^W(s))c^W(s)}{u_c(c^S(s))} + e_p(s)\right] \\ &= RHS_{J>1} \end{aligned}$$

and when $J = 1$, $RHS_{J=1} = e^{-r(s-6)} e_p(s)$. It is straightforward to show, with our assumed utilities, $RHS_{J>1} > RHS_{J=1}$, which means that the marginal cost of schooling is higher for individuals who are budget constrained. This is intuitive since the financially constrained individuals have higher marginal utility on consumption (due to lower level of consumption) which makes the utility cost of

[8] To be precise, discounted present value of private education expenditure $E^* = \int_6^s e^{-r(\tau-6)} e_p(\tau) d\tau$, discounted present value of wage income $I_i(s) = \int_s^R e^{-r(\tau-6)} w_i \left(h(s), \tau - s; \psi, l\right) d\tau$ and the collection of discounted factors $D_x^y = \int_x^y e^{-r(\tau-6)} \left(e^{(\rho-r)(\tau-6)}\right)^{-\frac{1}{\sigma}} d\tau$.

education investment higher. So, the financially constrained individuals have less years of schooling.

3.3 Education Policy and Education

In this study, we define public education policies as a pair $\{e_g(\tau), \bar{s}\}$, where $e_g(\tau)$ is public education expenditure per year per pupil at age τ, and $\bar{s}$ is the maximum age of public subsidy provision. Consider a hypothetical situation in which there is no public education expenditure (i.e. $e_g(\tau) \equiv 0$). The optimal private education expenditure in such a hypothetical regime $\hat{e}^*(\tau)$ is given by:

$$
\begin{aligned}
&\hat{e}^*(\tau) \\
&= \left[\frac{\psi\gamma z_h^{\frac{\alpha}{\gamma}} h(s)^{1-\frac{\alpha}{\gamma}} \int_s^R e^{-r(\tau-6)} w_i'(h(s), \tau - s; \psi, l) d\tau}{J}\right]^{\frac{1}{1-\alpha}} e^{\frac{r(\tau-6)}{1-\alpha}} \\
&= \hat{e}(0) e^{\frac{r(\tau-6)}{1-\alpha}}
\end{aligned}
$$

where $\hat{e}(0) \equiv [\psi\gamma z_h^{\frac{\alpha}{\gamma}} h(s)^{1-\frac{\alpha}{\gamma}} \int_s^R e^{-r(\tau-6)} w_i'(h(s), \tau - s; \psi, l) d\tau / J]^{\frac{1}{1-\alpha}}$, which is predetermined by one's endowment and is independent of age τ. This term affects the intercept of $\hat{e}^*(\tau)$ at $\tau = 0$. The function $\hat{e}^*(\tau)$ is strictly increasing in τ, which means that the optimal private education expenditure is increasing in one's age.

Due to the data limitation, we cannot systemically distinguish public education expenditure by age τ, so we assume $e_g(\tau) = e_g$ for $\tau \in [6, \bar{s}]$ and calibrate the average e_g to fit the public education expenditure as a share of GDP. Define total education investment $e(\tau) = e_p(\tau) + e_g(\tau)$, which gives

$$
e(\tau) = \begin{cases} e_g & \text{for } \min\{s, 6\} \leq \tau \leq s_g \\ \hat{e}^*(\tau) & \text{for } s_g \leq \tau \leq s \end{cases}
$$

where $s_g \equiv \min\{s, \bar{s}, s_{ug}\}$ and s_{ug} is defined as $\hat{e}^*(s_{ug}) = e_g$. Notice that s_{ug} is the potential upper bound age (subject to $s_{ug} < \min\{s, \bar{s}\}$) that an individual depends purely on public education expenditure.[9] $e(\tau)$ only depicts the amount of total education investment, it is silent on the compositions from private and public funding.

Figure 5 illustrates three cases of education expenditures.[10] Three individuals A, B and C have their original schedules of purely private education investment, $\hat{e}^*(\tau)$, and are depicted by $O^A A$, $O^B B$ and $O^C C$ in the absence of public education system. If a public education system $\{\bar{s}, e_g\}$ is added as in Figure 5, the solution of $e(\tau)$ is different, except for individual A. Since for Individual A, $\hat{e}^*(\tau) > e_g$ for all $\tau > 6$, she does not solely depend on public education expenditure at any age.

[9] It follows that $s_{ug} = ((1-\alpha)/r) ln\left(e_g/\hat{e}(0)\right) + 6$, which depends negatively on $\hat{e}(0)$ and is related to one's general endowment. s_{ug} satisfies that $\hat{e}^*(s_{ug}) \lesseqgtr e_g$ iff $\tau \lesseqgtr s_{ug}$. If $\hat{e}^*(\tau) > e_g$ for all $\tau > 6$, then set $s_{ug} = 6$.

[10] Technically, the introduction of public education system will also affect the years of schooling decision s and individual private education investment decision $e_p(\tau)$. We abstract from this complication in this graphical illustration to avoid confusion.

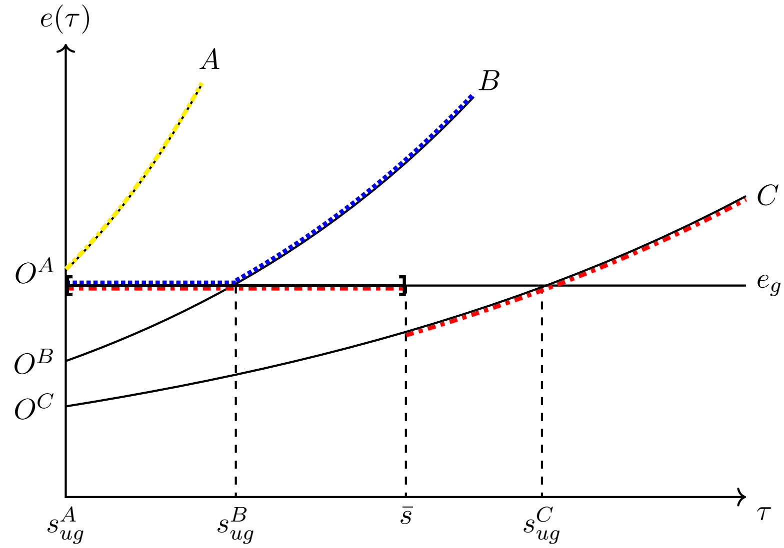

Figure 5: Schematic Figure of Education Expenditure

However, it does not mean that the education expenditure of individual A is not affected. Due to the introduction of the public education system, the private education investment expenditure of individual A is reduced to $\hat{e}^*(\tau) - e_g$.

Individuals B and C are also affected by the introduction of the public education system. Individual B, with the original schedule of education investment $O^B B$, will benefit from switching her private education expenditure to public education during $\tau \in [6, s_{ug}^B]$ since the public education system will increase her human capital without incurring (private) cost. After the age of s_{ug}^B, she starts to invest the portion of $\hat{e}^*(\tau)$ that is beyond e_g. The similar argument applies to individual C with one difference: the public education subsidy stops at age $\bar{s}$ which is is before s_{ug}^C, so she has to depend solely on her own fund for education investment during $\tau \in [\bar{s}, s]$.

Finally, one's human capital is

$$h(s) = z_h \psi^{\frac{\gamma}{\alpha}} \hat{e}(0)^{\gamma} \left[\int_6^{s_g} \left(\frac{e_g}{\hat{e}(0)} \right)^{\alpha} d\tau + \int_{s_g}^{s} e^{\frac{r\alpha(\tau-6)}{1-\alpha}} d\tau \right]^{\frac{\gamma}{\alpha}}$$

3.4 Education Quality

The introduction of public education system potentially increase the education investment during the schooling years, as shown in Figure 5 for individuals B and C. Since the total education investment increases, more human capital can be accumulated given the years of schooling, and hence the quality of education is improved.[11]

[11] In general equilibrium, the introduction of public education system might reduce years of schooling due to the substitution between longer years of schooling (quantity) and higher education investment per schooling year (quality). However, human capital stock can still increase with a better public education system even when quantity of education is reduced, which is the case in our quantitative analysis.

3.5 Government

The government collects wage income tax at a proportional rate ι. The tax revenue is used to meet two needs: public education expenditure and initial wealth endowment for individuals at age $\tau = 6$. We assume the government's budget is balanced at each point in time. Denote individual's set of endowment as $x = \{b, \psi, l\}$. For each point in time, the following balanced-budget equation holds:

$$\iint_{s}^{R} \iota w\left(h(s), \tau - s; \psi, l\right) N(\tau; x) d\Pi(\tau) dG(x) = e_g \iint_{6}^{s_g} N(\tau; x) d\Pi(\tau) dG(x) + e^{\mu_b + \sigma_b^2/2} \int N(6; x) dG(x) \tag{7}$$

$N(\tau; x)$ is the measure of individuals at age τ with the initial endowment x, and Π is individuals' age distribution. The total wage income tax revenue (i.e. the left-hand side) is spent on funding public education, i.e. e_g for everyone at $\tau \in [6, \min\{s, \bar{s}\}])$, and is allocated to all new-born generations at age 6 as initial wealth endowment (which we assume follow lognormal distribution).

The introduction of the government sector allows individuals' initial wealth endowment to depend on the country's development level in our counterfactual exercises. For example, when an economy becomes more productive, wage income rises and so as tax revenues. Given constant public education expenditure to GDP ratio, initial wealth endowment of individuals will rise as well. This changes the tightness of individuals' budget constraint and hence has implications on their human capital investment.

3.6 Production

To close the model, we now introduce the production side. Both sectors in the economy both use efficiency units of labor $\xi_i(h(s); \psi, l)$ as the only input, which has different functional forms across sectors:

$$\xi_a(h(s); l) = \left[\theta_a h(s)^{\frac{1}{\phi_a}} + (1 - \theta_a) l^{\frac{1}{\phi_a}}\right]^{\phi_a}$$

$$\xi_m(h(s); \psi) = \left[\theta_m h(s)^{\frac{1}{\phi_m}} + (1 - \theta_m) \psi^{\frac{1}{\phi_m}}\right]^{\phi_m}$$

While both sectors require human capital, agricultural production depends on workers' idiosyncratic agricultural productivity l, and nonagricultural production depends on ability ψ. We assume that $\theta_m > \theta_a$ so that the nonagricultural sector uses human capital more intensively.[12] The sectoral outputs Y_i are produced using the following technologies:

$$Y_i = A_i \iint_{\Omega_i} \hat{\xi}_i(h(s); \psi, l) N(\tau; x) dG(x) d\Pi(\tau)$$

where A_i is TFP of sector i, Ω_i the endogenous set of individuals self-selected into sector i, and $\hat{\xi}_i = \xi_i e^{\nu_{1i}(\tau - s) + \nu_{2i}(\tau - s)^2}$ efficiency units of labor with experience incorporated. The firm faces a

[12] Notice that $\theta_m > \theta_a$ guarantee the single-crossing property and individuals with higher human capital will more likely to self-select into nonagricultural sector. In the limit case when $\theta_m = 1$ as in Cheung (forthcoming) (that nonagricultural sector uses human capital as sole input), our qualitative results still hold.

competitive market wage rate $\hat{w}_i = p_i A_i$ and its maximization problem implies that:

$$w_i\left(h(s), \tau - s; \psi, l\right) = \hat{w}_i \hat{\xi}_i(h(s); \psi, l)$$

4 Benchmark Calibration

We first calibrate the model for the U.S. economy in the year 2000, which is used as our benchmark model. Then we recalibrate the model for the U.S. around the year 1900 and a set of other countries, ranging from high- to low-income in the world income distribution. We focus on the steady state equilibrium.

4.1 Calibration of the U.S. economy in 2000

When calibrating the U.S. economy in 2000, our strategy is to first set some parameters with values from the literature or data, and then calibrate the rest parameters jointly within the model by searching parameters that minimize the distance of a set of targeted moments between the model and the data. Table 1 summarizes the parameter values. Below we describe the major steps of calibration.

Parameters	Value	Target
Panel A: Predetermined		
Talent	$\mu_\psi = \mu_l = 1$	Normalize
Preference	$\rho = 0.03$, $\zeta = 0.005$, $\sigma = 1.5$, $\eta = 0.85$	Preset or Literature
Human capital	$z_h = 1$, $\bar{s} = 18$	Normalize or Data
Experience	$\nu_{1,a} = 0.0254$, $\nu_{2,a} = -0.0004$, $\nu_{1,m} = 0.0382$, $\nu_{2,m} = -0.0006$	IPUMS USA
Production	$A_a = 1$	Normalize
Life exp. & retirement	$T = 76.6$, $R = 65$	Data
Panel B: Calibrated		
Production	$A_m = 0.37$, $\theta_m = 0.80$, $\phi_m = 4.78$, $\theta_a = 0.75$, $\phi_a = -2.65$	1. Agri. Wage Gap, 2. Var. Agr. Wage, 3. Var Non-agr. Wage, 4. Agr. Emp. Share, 5. Agr. V.A. Share, 6. Agr. School Years, 7. Non-Agr. School Year, 8. Private Exp. on School, 9. Public Exp. on School, 10. Agr. Return to School, 11. Non-agr. Return to School, 12. Wealth-Wage Ratio, 13. S.D. log Wealth, 14. Non-agr. Price Gap, 15. Balanced Budget
Talent/ Wealth	$\sigma_\psi = 0.44$, $\sigma_l = 0.45$, $\rho_{\psi l} = 9.64$, $\mu_b = 5.31$, $\sigma_b = 0.66$	
Human capital	$\alpha = 0.26$, $\gamma = 0.27$, $e_g = 5.34$	
Preference	$\bar{c} = 0.15$	
Tax	$\iota = 0.24$	

Table 1: Summary of Parameter Values, U.S. 2000 (Benchmark)

Distribution of (ψ, l, b). We assume that ψ, l, and b all follow lognormal distributions; i.e., $\ln(y) \sim \mathcal{N}(\mu_y, \sigma_y)$, with *cdf* $G_y(y)$, where $y \in \{\psi, l, b\}$. The distributions of ψ and l are assumed to be interdependent, while that of b is independent. The assumption that ψ and l are interdependent is consistent with Lagakos and Waugh (2013). Thus, the joint distribution of (ψ, l, b) satisfies $G(\psi, l, b) = G_{\psi l}(\psi, l) G_b(b)$, where $G_{\psi l}(\psi, l)$ is the joint distribution of (ψ, l), with parameter $\rho_{\psi l}$ determining the extent of dependence (using Frank copula). We normalize $\mu_\psi = \mu_l = 1$, leaving σ_ψ, σ_l, $\rho_{\psi l}$, μ_b, and σ_b to be calibrated within the model to match sectoral wage and other wealth related moments.

Production. We set $A_a = 1$ and calibrate A_m, θ_m, θ_a, ϕ_m, and ϕ_a within the model.

Preference. We set the subjective discounter rate $\rho = 0.03$, consistent with the macro literature. We set $\zeta = 0.005$ to match the long-run agricultural employment share at around 0.5%. Based on Cooley and Prescott (1995), we set the reciprocal of intertemporal elasticity of substitution, $\sigma = 1.5$, and following Herrendorf, Rogerson and Valentinyi (2013), we set elasticity of substitution between agricultural and nonagricultural goods consumption, $\eta = 0.85$. We then calibrate $\bar{c}$ within the model.

Human capital and experience. In the human capital production function, we set $z_h = 1$ and leave α and γ to be calibrated in the model. To pin down the values of $\bar{s}$ and e_g, we use data from UNESCO and World Bank. We set $\bar{s} = 18$, which is the end of grade 12, when the compulsory education ends in the U.S. We calibrate e_g to match public education expenditure to GDP ratio. Moreover, we estimate the return to experience in each sector from 2000 U.S. Census (Ruggles et al., 2018) and obtain $\nu_{1,a} = 0.0254$, $\nu_{2,a} = -0.0004$, $\nu_{1,m} = 0.0382$, and $\nu_{2,m} = -0.0006$. Thus, return to experience is higher in nonagricultural sector but also depreciates more rapidly.

Life span and retirement age. We set life span T to be 76.6, matching the life expectancy in the U.S. in the 2000s as reported in World Bank and set the retirement age $R = 65$.

Now 15 parameters remain to be calibrated within the model and these are A_m, θ_m, θ_a, ϕ_m, ϕ_a, σ_ψ, σ_l, μ_b, σ_b, $\rho_{\psi l}$, $\bar{c}$, α, γ, e_g, and ι. We calibrate them jointly to match the following 15 targeted moments from the data: sectoral wage gap (w_m/w_a), sectoral (log) wage variance ($Var(w_a)$, $Var(w_m)$), agricultural employment share (L_a/L), agricultural value added share (Y_a/Y), sectoral years of schooling (s_a, s_m), private and public education expenditures to GDP ratios (E_p/Y, E_g/Y), sectoral return to schooling ($\partial w_a/\partial s$, $\partial w_m/\partial s$), wealth-income ratio and standard deviation of (log) wealth at the beginning of work year (W_i/w_i, $SD(\ln(W_i))$), sectoral price ratio (p_m/p_a), and government budget balance equal to zero.

The targeted moments above deserve some explanations. First, sectoral wage gap and wage variance are taken from Lagakos and Waugh (2013), who estimate these moments with non-transitory component of log wages using CPS (1996–2010). Second, agricultural employment share and value added share are taken from Gollin, Lagakos and Waugh (2014), so as sectoral years of schooling. The private and public education expenditure share from World Bank. Third, returns to schooling was estimated to be about 7.5% in Angrist and Keueger (1991) after correcting selection bias; we take this value for the return in the nonagricultural sector, and set that for agriculture to be 5%.[13] Fourth, the wealth-income ratio and standard deviation of (log) wealth at the beginning of working age are computed from PSID (1999–2019), using net worth and labor income data of young individuals aged between 24-29.[14] Finally, sectoral price ratio is taken from Alvarez-Cuadrado and Poschke (2011).

[13] Estimates using U.S. census in different years shows that return to schooling in agriculture is about 40-50% higher than that in agriculture.

[14] When computing standard deviation of log wealth, we set an individual's wealth to be $1e-6$ if it is negative.

4.2 Model Fit

We discretize the distributions of ψ and l into 20 levels each, and the *cdf* of these levels are from 0.025 to 0.975 with an interval of 0.05. We discretize the distributions of b into 5 levels, and the *cdf* of these levels are from 0.1 to 0.9 with an interval of 0.2. Thus, there are in total 2000 ($20 \times 20 \times 5$) types of individuals in our model economy. Then we solve the model for each type of individuals and compute the aggregate moments. Table 2 shows the model fit. The model fits all the targeted moments well.

Target	Numerically	Data	Model
Agri. Wage Gap	$\frac{w_m}{w_a}$	1.427	1.469
Var. Agr. Wage	$Var(w_a)$	0.144	0.153
Var. Nonagr. Wage	$Var(w_m)$	0.224	0.220
Agr. Emp. Share (%)	$\frac{L_a}{L}$	1.50	1.51
Agr. V.A. Share (%)	$\frac{Y_a}{Y}$	1.10	1.03
Agr. School Years	s_a	11.55	11.01
Nonagr. School Years	s_m	13.18	13.92
Private Exp. on School (%)	$\frac{E_p}{Y}$	2.10	2.74
Public Exp. on School (%)	$\frac{E_g}{Y}$	4.95	5.56
Agr. Return to School	$\frac{\partial w_a}{\partial s}$	0.050	0.056
Nonagr. Return to School	$\frac{\partial w_m}{\partial s}$	0.075	0.074
Wealth-Income Ratio	$\frac{W_i}{w_i}$	2.45	1.92
S.D. log Wealth	$SD(ln(W_i))$	11.41	10.52
Price Ratio	$\frac{p_m}{p_a}$	1.60	1.60

Table 2: Model Fit, U.S. 2000 (Benchmark)

Figure 6 compares the model-based years of schooling distribution (which is not targeted in the model) with data as a validity check. The calibrated model matches the pertinent features of sectoral years of schooling distribution quite well, especially for the nonagricultural sector. While the model is also consistent with the years of schooling distribution in the agricultural sector, the goodness of fit, however, is not as good as that in the nonagricultural sector. In particular, the model predicts lower variance in the years of schooling distribution when compared to the data. In reality, however, the heterogeneity of agricultural workers' years of schooling distribution is larger.

5 Quantitative Analysis and Discussion

We use the calibrated model as a framework to understand temporal and cross-country differences in the years of schooling, the agricultural employment share, and the sectoral labor productivity. Some comparative statics exercises are reported in Online Appendix B

5.1 The United States: 1900s VS. 2000s

To draw a view of the U.S. structural transformation in the last century, and to see the role of human capital accumulation in this process, we now calibrate our model to the U.S. economy around the

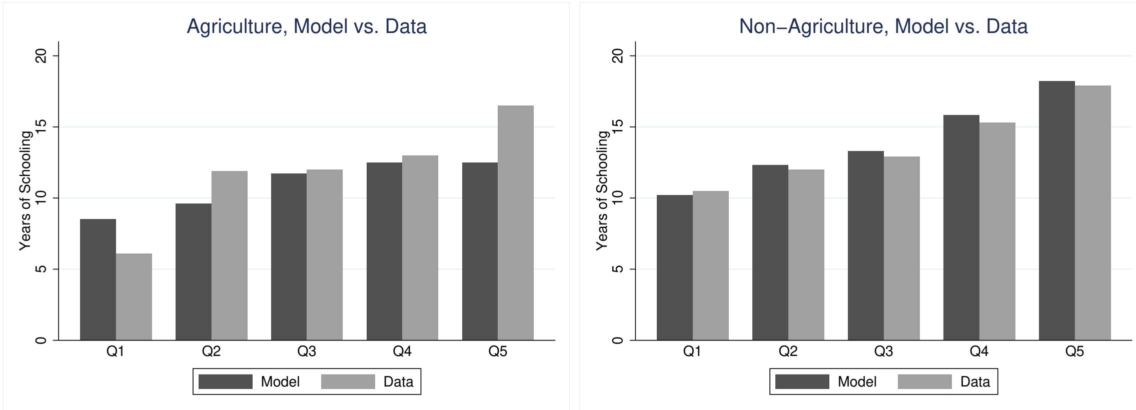

Figure 6: Sectoral Years of Schooling by Quintile, Model vs. Data

year 1900. We reset the parameters related to life expectancy, wealth distribution, compulsory years of schooling, and public education expenditure to the 1900s data, and recalibrate a set of parameters related to production technology in the model to match the relevant moments in 1900s. We set other parameters to the same values as in the benchmark economy, including the distribution of $\{\psi, l\}$. The following Table 3 summarize the parameters in U.S. 1900.

Parameters	Value	Target
Panel A: Predetermined		
Human capital	$\bar{s} = 9.6$	In text
Life exp.	$T = 52$	Manuelli and Seshadri (2009)
Wealth	$\sigma_b = 2.60$, $\sigma_b = 0.85$	World Inequality Database and Piketty and Saez (2014)
Panel B: Calibrated		
Production	$A_a = 0.15$, $A_m = 0.33$, $\theta_a = 0.17$, $\theta_m = 0.34$	1. GDP per worker to U.S. 2000 Ratio, 2. Agr. V.A. Share, 3. Government Balanced Budget, 4. Public Education Expenditure to GDP Ratio,
Human Capital	$e_g = 0.31$	5. Agr. Output per worker to U.S. 2000 Ratio,
Tax	$\iota = 0.24$	6. Nonagr. Output per worker to U.S. 2000 Ratio,

Table 3: Summary of Parameter Values, U.S. 1900

There are a couple of things changed between 2000 and 1900. The life expectancy is taken from Manuelli and Seshadri (2009) and is set $T = 52$. The sectoral productivity $\{A_a, A_m\}$ is backed out by temporal GDP per worker ratio from Manuelli and Seshadri (2009) and agricultural value added share from Caselli and Coleman (2001). The human capital intensity $\{\theta_a, \theta_m\}$ are pinned down by the temporal sectoral output per worker ratio from Chen (2020). They are the education policies on $\{\bar{s}, e_g\}$ so that the public education expenditure is around 1% of GDP and the compulsory schooling were 3.6 years on average.[15] The distribution of G_b is determined by two key moments: GDP per capita and of income inequality in Piketty and Saez (2014), which documents that income accruing

[15] For public education expenditure, the current price GNP was around 19 billion (U.S. Bureau of the Census, 1975, Series F1) and the current price expenditure on public schools was around 0.2 billion (Snyder, 1993, Table 22). There were 31 states allowed for 6 years of compulsory schooling (Goldin and Katz, 2010).

to top decline income earner in 1900 is 40% and that in 2000 is 45%. Table 4 shows that the targeted moments in the model fits the data quite well.

Target	Numerically	Data	Model
GDP per worker to U.S. 2000 Ratio	$\frac{y_{1900}}{y_{2000}}$	0.14	0.12
Agr. V.A. Share (%)	$\frac{Y_a}{Y}$	19.0	18.4
Public Education Expenditure to GDP Ratio (%)	$\frac{E_g}{Y}$	1.00	1.06
Agr. Output per worker to U.S. 2000 Ratio (%)	$\frac{y_{a,1900}}{y_{a,2000}}$	0.03	0.03
Nonagr. Output per worker to U.S. 2000 Ratio (%)	$\frac{y_{m,1900}}{y_{m,2000}}$	0.14	0.12

Table 4: Model Fit, U.S. 1900

Moreover, we look into a number of untargeted moments. The model does a reasonable job in accounting for the data changes over the last century as shown in Table 5. The prediction of the model for schooling and agricultural employment share are not perfect but they are reasonably close to the data. The model predicts 92% increase in the years of schooling in the data and 55% of structural transformation observed in the data reported by Manuelli and Seshadri (2009) and Herrendorf, Rogerson and Valentinyi (2014), respectively.

	Data		Model		$\{e_{g,1900}, \bar{s}_{1900}\} = \{e_{g,2000}, \bar{s}_{2000}\}$	
	2000	1900	2000	1900	PE	GE
Years of Schooling	13.2	5.4	13.9	6.7	11.1	7.0
Agricultural Employment Share	0.02	0.40	0.02	0.23	0.06	0.19
Human Capital (Normalized)	.	.	4.12	1.00	1.96	1.87

Table 5: United States 1900 and 2000

When the education policies are set to their 2000 values (i.e. the public education expenditure increased to 5% of GDP and compulsory schooling is increased to 12 years), the better education policies explain 45% of the structural transformation and 54% of the years of schooling difference between 1900 and 2000. The general equilibrium mechanism, however, attenuates the effect. The increase in years of schooling, without comparative increase in productivity, reduces skilled workers' wage that eventually lowers the demand for human capital and years of schooling (see Goldin and Margo, 1992, for the case of wage compression). Although the effect of education policies on years of schooling is greatly attenuated by the general equilibrium, the effect on human capital is not. In particular, the effect of education policies in general equilibrium is only 5% lower than that in partial equilibrium. Moreover, the education policy alone can explain 28% of the increase in human capital during the last century in general equilibrium.

In addition, the rapid decrease in agricultural employment will increase the price of agricultural goods and eventually increases the supply for agricultural goods as well as the derived demand of farmers. This increases the agricultural employment share from partial equilibrium to general equilibrium.[16] However, the education policy can still explain 19% of the structural transformation

[16]The elasticity of agricultural employment with respect to schooling implied by such exercise is between -4.3 and -2.4, broadly comparable to the values implied by Karachiwalla and Palloni (2019) and Porzio, Rossi and Santangelo (2022) using modern data in Indonesia is around -1.6 to -1.1.

in the model, even in the general equilibrium.

5.2 Cross-Country Analysis

In this subsection, we use the calibrated model to predict cross-country differences in schooling and agricultural employment share. Similar to U.S. 1900, we reset parameter values related to life expectancy, wealth distribution, compulsory years of schooling, and public education expenditure to country-specific data, and recalibrate a set of parameters related to sectoral TFP and human capital intensity for each country. These parameters are calibrate to match the country-specific GDP per worker to U.S. 2000 ratio, agricultural outpur per worker to U.S. 2000 ratio, and sectoral years of schooling. We choose 20 countries (including USA) in this subsection, one in every 5 percentile of income distribution. The list of countries can be found in Table A.1.

The life expectancy is taken from World Bank data and the years of compulsory schooling from UNESCO.[17] We back out G_b using GDP per capita and wealth-to-income ratio between a specific country and the U.S., and adjusted with the ratio of fertility rate of the two countries.[18] We back out σ_b using ratio of top 10% wealth concentration (from World Inequality Database) of both countries and $\sigma_{b,US}$. The sectoral productivity $\{A_a, A_m\}$ are backed out by GDP per worker ratio from World Bank and agricultural output per worker from Gollin, Lagakos and Waugh (2014), all relative to the U.S. The public education expenditure e_g in a specific is given by the public expenditure to GDP ratio taken from UNESCO. Given all these parameters, the human capital intensity $\{\theta_a, \theta_m\}$ determines the stock of sectoral human capital. So, we calibrate $\{\theta_a, \theta_m\}$ to match the sectoral years of schooling reported in Gollin, Lagakos and Waugh (2014).

The model fit is evaluated using agricultural employment share and human capital stock which are not targeted. We use the method and estimate used in Schoellman (2012) to construct the human capital data.[19] We assume that the human capital stock of a country takes the following form

$$H = \exp\left[\frac{(SQ)^{\phi}}{\phi}\right]$$

where S is the years of schooling from data, Q is the return to schooling measured in Schoellman (2012), and $\phi = 0.5$. As the unit of the data and model human capital might not be the same, both the model and data human capital stock are standardized and standard score is reported. The model can generate the data patterns of agricultural employment share and human capital stock.

[17] The retirement age is set to be the same as US, 65, as it is common for people in developing countries to work for prolonged years until their elder ages.

[18] Specifically, mean b is country i is computed as $E_i(b) = e^{\mu_{b,US}+\sigma^2_{b,US}/2} \cdot \frac{wi_{ratio,i}}{wi_{ratio,US}} \cdot \frac{gdppc_i}{gdppc_{US}} / \frac{fert_i}{fert_{US}}$. The wealth-to-income data is from World Inequality Database, and GDP per capita and fertility data are from World Bank

[19] Notice that the return to schooling can be expressed as the following:

$$\frac{\partial \ln(w)}{\partial s} = \frac{\partial \ln(w)}{\partial h(s)} \times \frac{\partial h(s)}{\partial s}$$

So, the return to schooling (Mincer return) can be decomposed into two parts. The first part is how the human capital affects log income $\partial \ln(w)/\partial h(s)$ and the second part is the effect of additional year of schooling on human capital $\partial h(s)/\partial s$. Using the data of Schoellman (2012) allows us to focus on only the second term, since the return to human capital in the U.S. is fixed.

As shown in Figure 7, we cannot reject that the fitted values between model and data are different from the 45-degree line.[20] The model uses education parameters $\{e_g, \bar{s}\}$, without assuming different efficiency in education z_h, does a reasonable job in predicting a country's human capital. Additional discussion on model fit can refer to Appendix C.

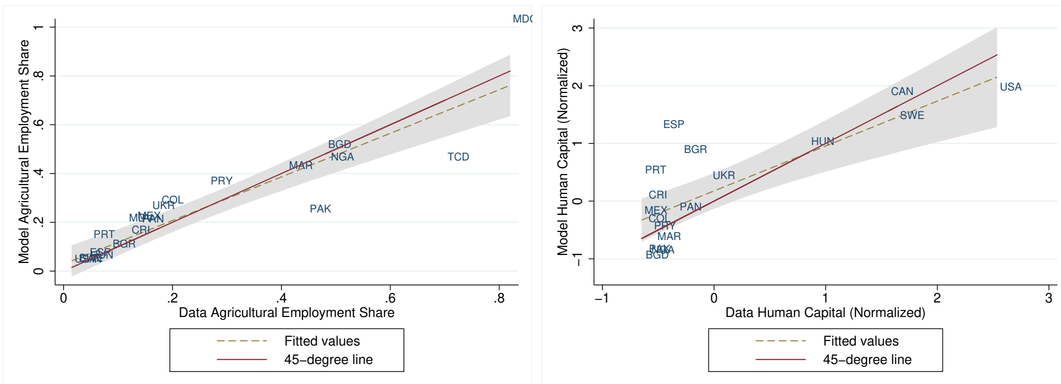

Figure 7: Cross-Country Analysis: Model Fit

5.2.1 Implication on Cross-Country Productivity Difference

In this subsection, we focus on the importance of education system on cross-country productivity difference. We carry out the counterfactual experiment which set each country's education expenditure as percentage of GDP (e_p) and years of subsidized schooling ($\bar{s}$) to the values in U.S. separately. We then document the percentage change in GDP per worker of each country in both experiments. The result is shown in Figure 8.

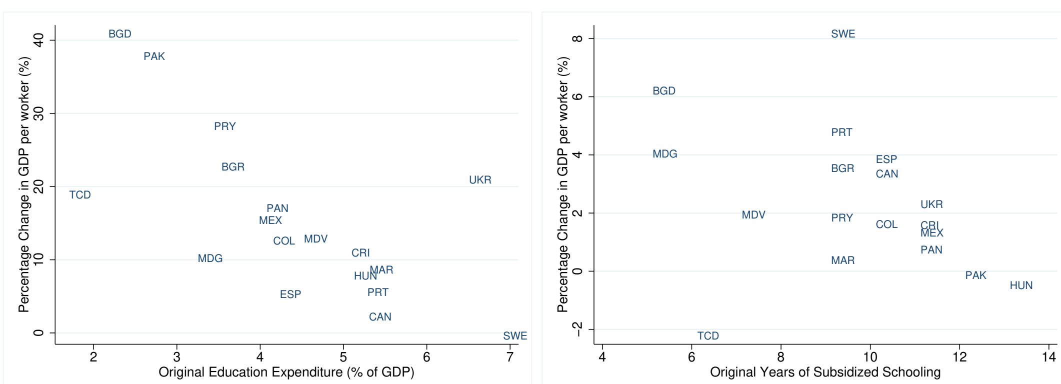

Figure 8: Counterfactual Experiment. Left Panel: e_p; Right Panel: $\bar{s}$

There are two features from Figure 8 which warrant some discussion. The first one is that the effect of education policies (measured by the magnitude of percentage change) declines with a country's original education expenditure and years of subsidized schooling. This is intuitive since

[20] The numerical values of the model performance are reported in Table A.1.

the larger education expenditure and longer years of subsidized schooling make the country more similar to the U.S., so setting their education policies to the U.S. ones will not lead to big changes. Such observation informs us the convergence in labor productivity across country, since the poorer countries (that have worse education policies) gains more from adopting education policies from the U.S. For example, the GDP per worker of country in 90th percentile of the income distribution (i.e. Sweden) is 45 times higher than that in 10 percentile (i.e. Bangladesh), but the difference reduces to 32 times (or more than 29%) after both countries adopt U.S. education policies.

The second feature is that the effect of equalization in education expenditure is much stronger than that of equalization in years of subsidized schooling. This is because a mere extension of subsidized schooling period without increase in education expenditure will reduce the average resource invested into individuals at school. Hence, it will decrease the effectiveness of schooling and leads to insignificant effect of education.[21]

5.2.2 Implication on Agricultural Employment Share

In this subsection, we focus on comparison between U.S. and Bangladesh (which is the comparison between the top income country and the 10th percentile country in our sample). We do three different experiments and all of them show the importance of the public education system in determining the agricultural employment share. The first experiment assumes that the public education policies are removed so that there is no subsidy for public education $e_g = 0$ and the duration of subsidy also goes to zero $\bar{s} = 6$. The years of schooling and human capital stock reduce, while the agricultural employment share increases by more than 35%.

	Baseline	Experiment 1 No Edu Policy	Experiment 2 Edu Policy Quality Equal	Experiment 2′ No YOS Adjustment
Total Years of Schooling	3.73	2.89	4.43	3.30
Human Capital Stock	1.00	0.87	1.40	1.23
Agr. Emp. Share	46.3%	62.3%	17.9%	36.7%

Table 6: Importance of Public Education System

We also perform the second experiment which eliminates the differences in public education policies (e_g and $\bar{s}$). In particular, we assume that $\{e_g, \bar{s}\}_{BGD} = \{e_g, \bar{s}\}_{USA}$. Both years of schooling and human capital stock increase while the agricultural employment share decreases. Finally, in Experiment 2′, we assume that the years of schooling for each of the individuals (in each $\{l, \psi, b\}$ cell) do not change.[22] This experiment shows that the quality of education is important to understand agricultural employment share. Even when the years of schooling remain the same, the better public education policies can impart more human capital in additional year of schooling. This leads to increase in human capital stock with even decreasing total years of schooling. Hence, using only

[21]This observation is supported by empirical data even in developed countries: Meghir and Palme (2005) find an overall insignificant return to schooling due to Swedish schooling reforms in the 1950s; Pischke and Von Wachter (2008) find zero returns to schooling in Germany following a post-World War II schooling expansion; Grenet (2013) finds no returns to schooling in France following 1967 education reform.

[22]The change in the total years of schooling is due to the composition effect.

total years of schooling without considering the quality of education as a measure of human capital can sometimes be misleading. The experiment predicts that the agricultural employment share reduced by 21%, due to the increase in human capital stock by 23%.[23]

6 Conclusion

This paper argues that differences in human capital, which is partly induced by cross-country education policies differences, is important to understand the structural transformation and productivity. Empirically, it is shown that economies with better education policies have higher productivity and smaller agricultural employment share. This is because human capital is relatively more valuable in the non-agricultural sector, people with more human capital choose to work in the non-agricultural sector, leading to structural transformation. Moreover, as human capital is a productive input, more human capital increases income of individuals, and hence strengthen the mechanism of structural transformation through income effect.

This paper considers both quantity and quality of education. The quantity of education refers to the years of schooling while the quality of education considers how much human capital can be imparted per year of schooling. The two dimensions of education policies, namely, years of government subsidized schooling and government expenditure on public education, are important to determine the quantity and quality of education.

Using a heterogeneous-agent life-cycle model featuring years of schooling, education investment and sectoral employment choices, we find that the education policies are as important as sectoral productivity progress to understand the sectoral labor allocation and labor productivity. Our model is able to generate cross-sectional and temporal differences in human capital stock and agricultural employment share in U.S. and across the world. In developing countries, counterfactual experiments show that eliminating public education policies increases agricultural employment share by 35%; while endowing the developing countries with U.S. public education policies reduces the agricultural employment share by 21% even assuming constant schooling years, and reduce cross-country productivity difference by 29%.

[23] In Experiment 2 and 2′, the elasticity of agricultural employment with respect to human capital implied by such exercise is between -2.7 and -1.2, comparable to the values implied by Karachiwalla and Palloni (2019) and Porzio, Rossi and Santangelo (2022) using data in another developing country (Indonesia) which is between -1.6 and -1.1.

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Appendix: Human Capital and Structural Transformation

– For Online Publication

A Additional Figures and Tables

Figure A.1: Schooling Gap

Country	Percentile	Agr. Emp. (%)		Y.O.S.	
		Data	Model	Data	Model
MDG	5	82.0	100.0	4.1	3.4
BGD	10	48.1	48.4	4.3	4.5
TCD	15	70.0	43.4	1.8	2.7
NGA	20	48.6	43.3	6.8	5.5
PAK	25	44.7	22.1	5.1	5.2
MAR	30	40.9	39.9	5.2	5.0
PRY	35	26.5	33.5	7.6	7.8
MDV	40	11.5	18.2	6.3	6.7
UKR	45	15.8	23.4	12.4	11.3
COL	50	17.5	25.6	7.2	6.9
PAN	55	13.9	17.9	9.5	8.3
BGR	60	8.5	7.7	11.7	13.2
CRI	65	12.0	13.5	8.2	8.7
MEX	70	13.1	19.2	7.5	6.9
HUN	75	4.4	3.1	10.3	12.3
PRT	80	5.0	11.6	7.2	8.4
ESP	85	4.3	4.2	9.9	11.2
SWE	90	2.3	2.0	11.5	11.2
CAN	95	2.4	1.6	12.9	13.8
USA	100	1.5	1.5	13.2	13.9

Table A.1: Cross-Country Analysis: Model Fit

B Comparative Statics

B.1 The United States, 2000

In the following counterfactual analysis, we assume each of the exogenous productivity level $\{A_a, A_m\}$, length of the public funding $\bar{s}$ and level of the public funding e_g increase by 10% and recalculate the endogenous responses of the model. Four observations stand out.

First, increase in $\{A_a, A_m, \bar{s}\}$ leads to increase in sectoral years of schooling but the increase in level of the public funding e_g reduce the sectoral years of schooling as seen in rows (I) and (II) of Table B.2. This seemingly counter-intuitive observation can be rationalized by the fact that increase in e_g leads to faster accumulation of human capital since more human capital can be imparted in each schooling years. This is due to the fact that there is a non-decreasing total education expenditure $e(\tau)$ after e_g is introduced as depicted in Figure 5. As there is opportunity cost of schooling (forgone wage), individuals decide to leave schools earlier for work, leading to a reduction in years of schooling.

Second, all the experiments predict increase in the sectoral productivity as shown in rows (IV) and (V) of Table B.2, their mechanism, however, differs. The increase in $\{A_a, A_m\}$ increase the productivity because they are the sectoral TFP. The increase in $\{\bar{s}, e_g\}$ leads to higher productivity by the combination of two factors: years of schooling and education quality. Better education policies result in more human capital accumulated for each individuals on average, and as human capital is productive input in both sectors, the better education policies lead to higher sectoral productivity.

Third, the increase in schooling policies $\{\bar{s}, e_g\}$ works as good as the increase in exogenous sectoral productivity level $\{A_a, A_m\}$ in reducing the share of agricultural employment as shown in rows (III) of Table B.2. The increase in $\{\bar{s}, e_g\}$ leads more years of schooling and/or better education quality. As the non-agricultural sector is more human capital intensive, increase in human capital leads to relative decline in agricultural sector. Moreover, the fact that increase in $\{\bar{s}, e_g\}$ leads to higher sectoral productivity discussed above also promotes the income effect (see row (VII) of Table B.2) of structural transformation.

Forth, the increase in schooling policies $\{\bar{s}, e_g\}$ leads to reduction in the agricultural productivity gap as shown in rows (VI) of Table B.2. The increase in the schooling policies leads to the increase in human capital in the economy. This will then lead to a more equal sectoral human capital distribution, which leads to the reduction in the agricultural productivity gap.

		Baseline	$A_a \uparrow$	$A_m \uparrow$	$\{A_a, A_m\} \uparrow$	$\bar{s} \uparrow$	$e_g \uparrow$ and μ_b fixed
(I)	Agr. YOS	11.01	11.03	11.09	11.02	11.51	10.97
(II)	Non-Agr. YOS	13.99	13.98	14.04	14.04	14.30	13.98
(III)	Agr. Emp. Share	1.54%	1.45%	1.54%	1.46%	1.50%	1.52%
(IV)	Agr. Labor Prod	1.000	1.086	1.007	1.092	1.028	1.014
(V)	Non-Agr. Labor Prod	1.000	1.000	1.116	1.124	1.016	1.011
(VI)	Agr. Prod. Gap	1.000	0.921	1.116	1.029	0.988	0.997
(VII)	Output per worker	1.000	1.001	1.122	1.124	1.016	1.011

Table B.2: Comparative Statics Analysis in USA, Respective Parameters Increase 10%

B.2 Comparison between USA and Bangladesh

If we compare the comparative statics analysis in both the U.S. and Bangladesh as shown in Table B.3, we will discuss the similarity and differences between the two countries.

There are two notable similarities in the analysis. When the agricultural productivity increase, in column (II), the increase in education is not significant. This is because the agricultural sector is relatively less human capital intensive. So, when the wage of the agricultural sector increase, due

	Baseline (I)	$A_a \uparrow$ (II)	$A_m \uparrow$ (III)	$\bar{s} \uparrow$ (IV)	$e_g \uparrow$ and μ_b fixed (V)
Panel A: USA, $\theta_a = 0.75, \theta_m = 0.80$					
Agricultural YOS	11.01	11.03	11.09	11.51	10.97
Non-Agricultural YOS	13.99	13.98	14.04	14.30	13.98
Agricultural Employment Share	1.54%	1.45%	1.54%	1.50%	1.52%
Agricultural Productivity Gap	1.00	0.92	1.12	1.00	0.99
Output per Worker	1.00	1.00	1.12	1.02	1.01
Panel B: BGD, $\theta_a = 0.06, \theta_m = 0.40$					
Agricultural YOS	2.39	2.38	2.40	2.23	2.27
Non-Agricultural YOS	5.89	5.79	5.95	6.26	5.93
Agricultural Employment Share	46.4%	39.1%	44.2%	42.6%	42.7%
Agricultural Productivity Gap	1.00	0.87	1.03	0.90	0.91
Output per Worker	1.00	1.04	1.07	1.02	1.01

Table B.3: Comparative Statics Analysis Comparison, Respective Parameters Increase 10%

to the agricultural productivity progress, it reduce the incentive for the individuals to study. This counteract the income effect on education. So, the reduction in the agricultural employment share in this case is mainly due to the income and productivity effect driven by the productivity progress.

Second, better education policies in columns (IV) and (V) also lead to structural transformation. Similar to the case in the U.S., better education policies is as important as the technological progress in understanding the sectoral allocation of labor. For example, in the case of increase in government expenditure in public education e_g in Panel B, there is an increase in total human capital in the economy by 4 percentage point (even though the years of schooling drops). This leads to more households self-select into the non-agricultural sector.

There are also differences between these two countries. First, the reduction in the agricultural employment share is more responsive to the changes in sectoral productivity and education policies, both in absolute and relative terms. This is the consequence of closed-economy assumption. As each economy needs to supply its own agricultural consumption, which is subject to subsistence constraint, the agricultural employment cannot be too low. So, in the case of the U.S., the lowering of the agricultural employment share will increase the marginal utility of agricultural consumption substantially and leads to increase in agricultural price and wage of agricultural workers, which eventually leads to increase in agricultural employment.

Second, due to the fact that human capital intensity in Bangladesh is very low ($\theta_a = 0.06$), the better education policies in columns (IV) and (V) always lead to reduction in the years of schooling in the agricultural sector. Moreover, in the case of increase in duration of subsidy e_g, the human capital in the agricultural sector even drops. This is due to selection. Using the example in Figure 5, originally individual A who have higher endowment when compared to individuals B and C are more likely to work in the non-agricultural sector. However, if there is an slight increase in e_g, the human capital of individual B and C will increase while that of individuals A is not affected. Then, it is more likely that individual B and C will join the non-agricultural sector, leading to lower years of schooling and hence average human capital in the agricultural sector.

C Additional Model Fit

The calibrated model can also generate some observations in the cross-country income difference. As shown in Table C.4, the model can generate the agricultural output per worker, GDP per worker and agricultural productivity gap between USA and BGD (which is in the 10 percentile of the income distribution) well. However, it cannot generate a satisfactory result for the non-agricultural output per worker. Such problem also presents in most frictionless model. We borrow result between the 90th and 10th percentile countries from Lagakos and Waugh (2013, Table 2) as comparison.

	This Model: USA-BGD		Lagakos & Waugh (2013): 90-10	
	Model	Data	Model	Data
Agricultural output per worker	75.6	79.2	5.5	45
Non-Agricultural output per worker	28.4	3.4	4	4
GDP per worker	43.3	32.4	4.3	22
Agricultural Productivity Gap	3.0	3.7	1.4	5.2

Table C.4: Model Performance, Cross-Country Comparison