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GOVERNMENT EXPENDITURE ON THE PUBLIC EDUCATION SYSTEM

Chao Fu
Shoya Ishimaru
John Kennan

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Chao Fu
Department of Economics
University of Wisconsin - Madison
1180 Observatory Drive
Madison, WI 53706
and NBER
cfu@ssc.wisc.edu

John Kennan
Department of Economics
University of Wisconsin
1180 Observatory Drive
Madison, WI 53706
and NBER
jkennan@ssc.wisc.edu

Shoya Ishimaru
University of Wisconsin
ishimaru@wisc.edu

A data appendix is available at http://www.nber.org/data-appendix/w26425

GOVERNMENT EXPENDITURE ON THE PUBLIC EDUCATION SYSTEM

CHAO FU[A], SHOYA ISHIMARU[B] AND JOHN KENNAN[A]

ABSTRACT. We investigate equilibrium impacts of federal policies such as free-college proposals, taking into account that human capital production is cumulative and that state governments have resource constraints. In the model, a state government cares about household welfare and aggregate educational attainment. Realizing that household choices vary with its decisions, the government chooses income tax rates, per-student expenditure levels on public K-12 and college education, college tuition and the provision of other public goods, subject to its budget constraint. We estimate the model using data from the U.S. Using counterfactual simulations, we find that free-public-college policies, mandatory or subsidized, would decrease state expenditure on and hence the quality of public education. More students would obtain college degrees due to increased enrollment. Over 86% of all households would lose while about 60% of the lowest income quintile would gain from such policies.

1. INTRODUCTION

As one of the most important determinants of one's lifetime income, college education has attracted much policy interest, largely centered around accessibility. For example, the Obama administration proposed free tuition in two-year public colleges; Senator Bernie Sanders has proposed free tuition in all public colleges in his 2016 and 2020 presidential campaigns. Directly, policies of this sort would improve opportunities for disadvantaged college-bound individuals. However, to assess these policies, one needs to go beyond their direct effects and account for at least two factors. First, human capital production is a cumulative process, where later achievements rely on investments made in the past.[1] As

[A]University of Wisconsin and NBER.[B]University of Wisconsin. Contact: cfu@ssc.wisc.edu. We are grateful for helpful comments from conference and seminar participants at the Cowles Conference, CUHK, HKU, Johns Hopkins, Minnesota, the Society for Economic Dynamics, the NBER Summer Institute, Northwestern, Penn State, Rice, University of Houston, UT-Austin, University of Virginia, Wharton and Washington University in St. Louis.

[1]See, e.g., Becker (1975), Todd and Wolpin (2003), Restuccia and Urrutia (2004), Cunha and Heckman (2007), Cunha et al. (2010) and Del Boca et al. (2013).

such, if pre-college investment by households and/or government does not increase for disadvantaged students, free college education alone may not help them effectively.[2] Second, without revenues from college tuition, the government may have fewer resources to invest in the public education system: K-12 and/or college. After all, how free can "free" colleges be?

We develop and estimate an equilibrium model that incorporates the factors mentioned above in a coherent framework. In the model, educational outcomes depend on student characteristics (including past achievement) and monetary inputs, i.e., tuition in the private sector and government expenditure in the public sector, via technologies that may differ across the two sectors. Agents in the model include a government and a distribution of households. The government cares about a weighted average of household welfare (with welfare weights that may differ across household groups) and may also care about aggregate educational attainment. It makes decisions on income tax rates, per-student expenditure levels on public K-12 and college education, college tuition and the provision of other public goods, subject to a budget constraint. Households care about consumption, their children's education and the burden of college loans. Taking as given the government's decision, households make sequential choices between private and public K-12 schools, then between the options of no college, two-year colleges, four-year public colleges and four-year private colleges, and on how much student loan debt to take on. Realizing that household choices and hence equilibrium outcomes vary with its decisions, the government chooses the policy that maximizes its objective.

Although the essence of the model and its main policy implications apply to any public education system, the U.S. is a particularly interesting case. Public expenditure on education in the U.S. is largely controlled at the state level, with significant cross-state variation in education outcomes and in the proportions of revenues allocated to lower and higher education. We treat each state in the U.S. as a single economy in our empirical application. States differ observably in their (non-tax) revenues and distributions of households, and

[2]The parallel argument also holds: if households increase investment in their children's pre-college education in expectation of easier college access, the impact of free tuition policies can be enhanced.

unobservably in how productive their public education systems are, which jointly lead to different government policies and equilibrium outcomes. We use data from the Education Longitudinal Study, the American Community Survey, and the Survey of Governments to estimate the model via indirect inference. In particular, we estimate structural parameters that are essential information for assessing counterfactual education policies, including parameters governing educational production technologies, household preferences, and state government objectives.

We use our estimated model to evaluate two sets of counterfactual free-college policies. The first set mandates that state governments charge zero tuition in public colleges. In response, state governments increase tax rates and decrease per-student expenditure on both K-12 and college education. College enrollment increases but the graduation rate decreases from 62% to 58% in public 4-year colleges; the net effect is a small increase in the fraction of students with a 2-year or 4-year college degree. The welfare effect of this policy is unevenly distributed: 60% of households in the lowest income quintile would gain, but most households in other income groups would lose. Overall, 86% of households lose from the free-college intervention.

In the second (perhaps more realistic) counterfactual scenario, each state government chooses whether or not to make their colleges free, in exchange for a subsidy from the federal government: the subsidy per enrollee amounts to a certain fraction of the state's baseline college tuition. The federal subsidy nationwide is funded via a proportional increase in federal income taxes. The total subsidy is an equilibrium outcome that depends on how many state governments take the subsidy, how they change their own policies and how many students attend public colleges in these states. State and household responses in turn depend on the subsidy rate and the federal tax surcharge. At different federal subsidy rates, we solve for the budget-balancing federal tax surcharge and trace the rate at which states take up the offer, and also the changes in educational outcomes and social welfare. We find that a 10% subsidy rate would induce 12% of states to comply, while all states would comply at a 30% subsidy rate. In general, subsidized free college policies lead to less disturbance in state policies. The welfare effects are similar to those in the mandatory case: fewer than 14% of households would win, and winners are concentrated among the lowest income group.

Our paper relates to several literatures. The first literature studies the effects of cross-state college tuition differences, as summarized in Kane (2006, 2007). A major challenge in these studies is that the variation in tuition levels across states is not random, and that omitted variables may be correlated with both tuition and education outcomes. One approach to tackle this issue has been to use large changes in the net cost of college attendance induced by interventions such as the introduction of the Georgia Hope Scholarship (Dynarski (2000)), the elimination of college subsidies for children of disabled or deceased parents (Dynarski (2003)), and the introduction of the D.C. Tuition Assistance Grant program (Kane (2007)). Using variation in exposure to state budget shocks, Deming and Walters (2017) find large impacts of spending on enrollment and degree completion, with limited impacts of tuition changes. Using a structural model of joint migration and college enrollment decisions, Kennan (2015) finds substantial evidence that both tuition and spending affect enrollment (although the spending result is found only for two-year colleges). Murphy et al. (2017) study the shift of the English higher education system from a free college system to one with high tuition fees, and find that the shift has resulted in increased funding per head, rising enrollments, and a narrowing of the participation gap between advantaged and disadvantaged students.

There is a relatively small recent literature examining education policies while taking into account the dynamic complementarity of human capital investments as highlighted in works such as Cunha and Heckman (2007). For example, Caucutt and Lochner (forthcoming) develop a dynastic model of household investment in children to study the importance of borrowing constraints and uninsured labor market risk. Using the calibrated model, they explore the effects of policies targeted at different ages. Abbott et al. (forthcoming) examine the equilibrium effects of college financial aid policies in an overlapping generations life cycle model and find significant crowd-out of parental transfers by government programs. Also using an overlapping generations life cycle model, Becker et al. (2019) study the interplay of taxation and education subsidy policies. Our paper well complements these studies. While they focus on household responses to given policies, we are more interested in how state policies are chosen in response to federal policies. As such, we embed a simpler and more stylized household decision model in an equilibrium framework with endogenous government policies.

The role of government in education has been studied for a long time (e.g., Friedman (1955)). Hanushek (2002) reviews more recent work and provides an evaluation of various controversial aspects including issues of causality, consumer behavior, and estimation approaches. Although abstracting from some important details, such as those involving political economy considerations, our paper takes a step forward in addressing these issues. We explicitly model dynamic choices by households, the cumulative nature of human capital production, and state governments' endogenous decisions on educational expenditure and tuition. While our work focuses on government decisions at the state level, other studies (e.g., Epple and Sieg (1999), Epple and Romano (2003), Ferreyra (2007) and Epple and Ferreyra (2008)) have explored heterogenous impacts of school finance reforms across local areas within a state.

The rest of the paper is organized as follows. Section 2 describes the model. Section 3 explains our estimation strategy. Section 4 describes the data and our auxiliary models. Section 5 shows the estimation results. Section 6 analyzes the counterfactual experiments. Section 7 concludes. Additional details and tables are in the appendix.

2. Model

There are S states, each treated in isolation. State s is characterized by a state-specific distribution $F_s(x)$ of households with characteristics x (household income, education of the adult(s), and race), state-level observable variables z_s and unobservable productivity vector

$\eta_s = (\eta_{s1}, \eta_{s2})$ for public K-12 (η_{s1}) and public college education (η_{s2}). In the following, we suppress the state and individual subscripts s and i. Time is discrete, with three periods.

- Period 0: the government chooses its policy $\psi = (\tau, \underline{t}, t, e_1, e_2, g)$: an income tax rate τ, tuition for public 2-year college $(\underline{t})$ and public 4-year college (t), per-student expenditure levels for public K-12 education (e_1) and public college education (e_2), and per-capita expenditure on other public goods (g).
- Period 1: with probability $q(x)$, a household with x will have a child, in which case they choose whether or not they would use private K-12 education, denoted as $o_1 \in \{0, 1\}$.[3]
- Period 2: K-12 educational outcomes are realized; households with children make decisions on children's higher education (o_2) and college debt (d), where $o_2 \in \{0, 1, 2, 3\}$, corresponding to {no college, 2-year college, 4-year public college, 4-year private college}.[4]

2.1. **Technology.** There is a finite number of possible outcomes at each educational stage; these are stage-specific stochastic functions of inputs, via technologies that may differ between the public and the private sectors. All children are exposed to K-12 education, and the outcome is denoted as $k_1 \in \{1, .., 5\}$, with $k_1 = 1$ indicating a dropout and $k_1 = 5$ being the highest quartile of achievement (as measured by math test scores). College enrollment is optional, and the outcome is denoted as $k_2 \in \{0, 1, 2\}$ (no college degree, 2-year degree, 4-year degree).

2.1.1. *K-12 Education.* A child can attend the public school for free; the outcome depends on the state and household characteristics z, η_1 and x, as well as the per-pupil government expenditure e_1. A household can also pay p_1 for the child to attend private school, where

[3]Here, we present a simplified model, where a household makes one choice for the entire K-12 education. In the full model that we apply to the data, one choice is made for elementary education and another for secondary education.

[4]In the empirical analysis, students choosing out-of-state public colleges are treated as if they had chosen a private college. We further assume that tuition paid by out-of-state students at public colleges is equal to the amount spent on them, with zero net impact on a state government budget. This assumption, although not ideal, allows us to avoid having to model inter-state-government strategic interactions. See further discussion in Section 2.5.

the outcome depends on p_1, x and z. A child's K-12 outcome (k_1) follows a sector-specific ordered-logit function

$$k_1 \sim \begin{cases} L_1^0(x, z, e_1, \eta_1) & \text{if } o_1 = 0 \\ L_1^1(x, z, p_1) & \text{if } o_1 = 1 \end{cases}. \tag{2.1}$$

2.1.2. *College Education.* Educational outcomes in public colleges depend on x, z, η_2, K-12 achievement (k_1), and the per-student government expenditure on higher education e_2. Within the state public college system, a student can choose either a 2-year college with gross tuition $\underline{t}$, or a 4-year college with gross tuition t. Educational outcomes in the private (4-year) college depend on x, k_1 and tuition p_2.[5] The outcome is deterministic with $k_2 = 0$ (no college) for high school dropouts $(k_1 = 1)$ or those who choose not to attend college $(o_2 = 0)$. Otherwise, the outcome (whether or not one obtains a degree) follows a sector-specific logit function

$$k_2 \sim \begin{cases} L_2^1(k_1, x, z, e_2, \eta_2) & \text{if } o_2 = 1, k_1 > 1 \\ L_2^2(k_1, x, z, e_2, \eta_2) & \text{if } o_2 = 2, k_1 > 1 \\ L_2^3(k_1, x, p_2) & \text{if } o_2 = 3, k_1 > 1 \end{cases}. \tag{2.2}$$

2.1.3. *Unobserved Productivity Differences.* We model $\eta_s \in \left\{\underline{\eta}_1, \overline{\eta}_1\right\} \times \left\{\underline{\eta}_2, \overline{\eta}_2\right\}$ as a draw from a distribution that depends on population characteristics in the state (X_s), given by

$$\begin{aligned} \Pr\left(\eta_{s1} = \overline{\eta}_1 \mid F_s(x)\right) &= \mathbb{L}\left(\rho_0^1 + \rho_1^1 X_s\right) \\ \Pr\left(\eta_{s2} = \overline{\eta}_2 \mid X_s, \eta_1 = \overline{\eta_1}\right) &= \mathbb{L}\left(\rho_0^2 + \rho_1^2 X_s + \rho_2\right) \\ \Pr\left(\eta_{s2} = \overline{\eta}_2 \mid X_s, \eta_1 = \underline{\eta_1}\right) &= \mathbb{L}\left(\rho_0^2 + \rho_1^2 X_s - \rho_2\right) \\ E(\eta_1) &= E(\eta_2) = 0,\ Var(\eta_1) = \sigma_{\eta_1}^2,\ Var(\eta_2) = \sigma_{\eta 2}^2 \end{aligned} \tag{2.3}$$

where $\mathbb{L}$ is the logistic function. The distribution of η_s is governed by parameters $(\rho, \sigma_{\eta_1}, \sigma_{\eta 2})$. The parameters ρ_1^n capture the correlation between a state's educational productivity at

[5]We abstract from private 2-year colleges and model all 2-year colleges as in state and public. Focusing on cross-state heterogeneity in the public sector, we assume a common (average) private 4-year college for students in all states.

level n with state observables; ρ_2 allows for correlation between η's at different education levels conditional on observables. In the estimated model, X_s in (2.3) is the fraction of college-educated adults in the state.[6]

Remark. Two aspects of the production technology deserve comment. First, we allow for unobservable state factors η in the public education production but not in the private education sector, because our data are not rich enough and our focus is on the heterogeneity of public education across states. Second, households within each x group are assumed to be homogeneous up to random shocks. Household unobservable heterogeneity (e.g., unobservable ability) has been the focus of a large literature on household educational choices. We have a different goal of studying the equilibrium impact of federal policies across states and groups of households. In this setting, household-level unobservables are not essential, because as long as the ***distribution*** of household unobservables *conditional on* x is common across states, cross-state variation will still be driven by differences in $F_s(x)$ and other state-level factors. In contrast, state-level unobservables, such as η_s, are important confounding factors to account for in studying effects of state policies.

2.2. **Household Problem.** Given government policy ψ, the problem for households with children can be solved backwards.

2.2.1. *Decision 2: College Education.* Let x_1 be household income, and let $A(C, x, k_1)$ be financial aid, which is a function of college cost (C), household characteristics x and K-12 achievement (k_1). Let $v(x, k_1, k_2, d)$ be the terminal value as a function of household characteristics, educational outcomes (k_1, k_2) and debt level d. A household's problem at

[6]We have estimated a more complicated specification of (2.3) that includes additionally state average income. However, it adds little to improve the fit, so we chose the simpler specification.

the college stage is

$$V_2(x,k_1,\epsilon_2;\psi,z,\eta)=\max_{o_2\in\{0,1,2,3\},d\geq 0}\left\{\ln(c_2)+\theta(x,z)\ln(g)+\sum_{n=1}^{3}\mathbb{I}(o_2=n)\lambda_{2n}(x)+\mathbb{E}v(x,k_1,k_2,d)+\epsilon_2(o_2)\right\}$$

$$s.t.\ c_2+C=y(\tau,\tau_0,x_1)+d+A(C,x,k_1),$$

$$C=\underline{t}\mathbb{I}(o_2=1)+t\mathbb{I}(o_2=2)+p_2\mathbb{I}(o_2=3),$$

$$d=0 \text{ if } o_2=0,$$

$$k_2 \text{ follows } (2.2).$$

Households derive utility from consumption, other government expenditure (g) and college enrollment (which varies by college type). Households with different characteristics may value the last two components differently relative to consumption, hence the preference parameter vectors θ and λ_{2n} are allowed to vary with x. We also allow household preference for g to vary with state observables z. The expectation of $v(\cdot)$ is taken over the realization of k_2. Each college choice o_2 is associated with an i.i.d. payoff shock $\epsilon_2(o_2)$, drawn from the Type-1 extreme value distribution. The first constraint lays out the household's budget, where C is the cost of college, depending on household choices, and $y(\tau,\tau_0,x_1)$ is after-tax income, with τ_0 being the exogenous federal tax and τ being the endogenous state tax. The constraint on d means that is a loan that is available only for college students. Denote the optimal choice as $(o_2^*(x,k_1,\epsilon_2;\psi,z,\eta),d^*(x,k_1,\epsilon_2;\psi,z,\eta))$.

2.2.2. *Decision 1: K-12.* At the K-12 level, the household's problem is

$$V_1(x,\epsilon_1;\psi,z,\eta)=\max_{o_1\in\{0,1\}}\{\ln(c_1)+\theta(x,z)\ln(g)+\lambda_1(x)o_1+\beta\mathbb{E}V_2(x,k_1,\epsilon_2;\psi,z,\eta)+\epsilon_1(o_1)\}$$

$$s.t.\ c_1+p_1o_1=y(\tau,\tau_0,x_1),$$

$$k_1 \text{ follows } (2.1),$$

where preference for private relative to public schools may depend on x. Each choice is associated with an i.i.d. Type-I extreme value payoff shock $\epsilon_1(o_1)$. The expectation of $V_2(\cdot)$ is taken over (k_1,ϵ_2). Denote the optimal choice as $o_1^*(x,\epsilon_1;\psi,z,\eta)$.

2.2.3. *Households without Children.* Households without children do not make decisions in this model. The value function is given by

$$V^0(x;\psi) = (1+\beta)\ln(y(\tau,\tau_0,x_1)) + \theta(x,z)\ln(g) + \beta^2 v(x,0,0,0).$$

2.2.4. *Aggregate Choices.* Given government policy, enrollment in public K-12 education (N_1), enrollments in 2-year (N_{2l}) and 4-year public colleges (N_{2h}) are given by

$$N_1 = \int q(x) I(o_1^*(x,\epsilon_1;\psi,z,\eta)=0)\, dF(x,\epsilon_1),$$

$$N_{2l} = \int \left[q(x) \sum_{o_1\in\{0,1\}} I(o_1^*(\cdot)=o_1) \sum_{k_1} \left(\begin{array}{c} \Pr(k_1|x,o_1)\times \\ \int I(o_2^*(x,k_1,\epsilon_2;\psi,z,\eta)=1)\, dF(\epsilon_2) \end{array} \right) \right] dF(x,\epsilon_1), \tag{2.4}$$

$$N_{2h} = \int \left[q(x) \sum_{o_1\in\{0,1\}} I(o_1^*(\cdot)=o_1) \sum_{k_1} \left(\begin{array}{c} \Pr(k_1|x,o_1)\times \\ \int I(o_2^*(x,k_1,\epsilon_2;\psi,z,\eta)=2)\, dF(\epsilon_2) \end{array} \right) \right] dF(x,\epsilon_1).$$

N_1 is the sum of households who have children (with probability $q(x)$) and choose $o_1^*(\cdot)=0$. To calculate N_{2l}, we start with the inner integral over $I(o_2^*(\cdot)=1)$, which gives the measure of students attending 2-year public colleges given (x,k_1). This measure is integrated over the probability of obtaining k_1 conditional on household x and K-12 choice o_1 (governed by (2.1)), which is in turn integrated over household choices of o_1. Finally, the outermost integral aggregates over the distribution of households. N_{2h} is calculated in the same manner.

2.3. **Government Problem.** A government cares about a weighted average of household expected welfare and may also directly care about aggregate educational attainment.[7] Let Ψ be the discrete set of policy options,[8] including the zero tuition option. The government

[7]Notice that public education provides an option value to all households in expectation, regardless of whether or not they end up using it ex post.

[8]The appendix contains details of these options.

solves the following problem

$$\pi = \max_{\psi \in \Psi} \left\{ \int \omega(x) \left[q(x) EV_1(x, \epsilon_1; \psi, z, \eta) + (1 - q(x)) V^0(x; \psi) \right] dF(x) + W(N_2, K_2) \right\} \tag{2.5}$$

$$s.t.\ z_1 + \int \tau(x_1)\, dF(x) + N_{2l}\underline{t} + N_{2h} t = e_1 N_1 + e_2 (\varphi N_{2l} + N_{2h}) + g,$$

Aggregate choices: (2.4),

where $\omega(x)$ is the welfare weight given to households with characteristics x. This weight is applied to the average welfare of households with and without children. The government's direct preference for aggregate educational outcomes is captured by $W(\cdot)$. The government faces a budget constraint, where the revenue consists of an exogenous part $(z_1 \in z)$, and endogenous parts, i.e., state income tax and tuition at public colleges. The revenue is used to fund public K-12 and college education, as well as other public goods (g).[9]The second constraint requires that aggregate enrollment and education outcomes are consistent with household choices and production technology. A government's optimal choice is denoted by $\psi^*(F(x), z, \eta)$.

To reduce the size of the government choice set, we assume the following structure for the income tax schedule

$$\tau(x_1) = \tau^R \cdot \tau^b(x_1),$$

where $\tau^b(x_1)$ is the common base schedule, estimated using NBER TAXSIM. We assume that each state chooses its own τ^R but not $\tau^b(x_1)$.

Remark. Instead of a political economy framework, we model a state government as a maximizer that cares about various factors. We estimate the parameters governing $\omega(x)$ and $W(\cdot)$ from the data, without specifying the underlying forces. For example, $W(\cdot)$ may reflect possible spillover effects of education that individual households do not internalize; it may also come from a government's political concerns.

2.4. **Equilibrium.** We define an equilibrium as follows

[9]The parameter φ is set at 0.5, to account for the different lengths of 2-year versus 4-year education.

Definition (Equilibrium)**.** An equilibrium is a tuple $\{o_1^*(\cdot), o_2^*(\cdot), d^*(\cdot), \psi^*(\cdot)\}$ such that

1. Given (ψ, z, η), $o_1^*(x, \epsilon_1; \psi, z, \eta)$ is an optimal K-12 choice for every (x, ϵ_1), $o_2^*(x, k_1, \epsilon_2; \psi, z, \eta)$ and $d^*(x, k_1, \epsilon_2; \psi, z, \eta)$ are optimal college and loan choices for every (x, k_1, ϵ_2).
2. Given $(F(x), z, \eta)$, $\psi^*(F(x), z, \eta)$ solves the government problem (2.5).

2.5. **Discussion.** Some aspects of the model deserve further discussion. First, we treat each state in isolation and government decisions as being static. Related to the former, a household's choice depends on the equilibrium quality of public education in its home state but not on the quality of public education in other states; we also abstract from migration and treat the distribution of households $F_s(x)$ as policy-invariant.[10] We thereby avoid having to model strategic interactions among state governments. Similarly, viewing government decisions as static abstracts from complications such as time consistency and commitment issues in dynamic policy-making settings. Extensions in either dimension would require a more complicated equilibrium model, which we leave for future work.

Second, we model public investments in both K-12 and college education as being determined at the state level, abstracting from within-state variation in K-12 educational funding. We make this choice for both tractability and data reasons.[11] The current model nevertheless captures the essential message of this paper: to design an effective educational policy, regardless of the level at which it is determined, one needs to recognize that human capital development is a cumulative process and that resources are to be allocated across different public goods, including different educational stages.

Third, we model household investment as choices between different types of schools and colleges, while abstracting from more detailed choices, such as investment in terms of parental time, books and tutoring services. Incorporating these choices to the model would make the predication in our counterfactual policy analysis more precise, but it would require much richer data.

[10]Thus our counterfactual policy impacts are best interpreted as short-run impacts.

[11]Otherwise we would need to model the interaction across local governments and we would need local-level data on government expenditure, household characteristics, choices and outcomes.

3. Estimation Strategy

We estimate parameters governing the college financial aid function $A(C, x, k_1)$ outside of the model. All the other model parameters (Θ) are estimated via indirect inference, which consists of two steps. The first step estimates a set of "auxiliary models" that summarize the patterns in the data to be targeted for the structural estimation. The second step involves repeatedly simulating data with the structural model, computing corresponding auxiliary models using the simulated data, and searching for the model parameters that cause the auxiliary model estimates computed from the simulated data and from the true data to match as closely as possible. Let $\overline{\beta}$ denote our chosen set of auxiliary model parameters computed from data. Let $\widehat{\beta}(\Theta)$ denote the corresponding auxiliary model parameters obtained by simulating datasets from the model (parameterized by a particular vector Θ) and computing the same estimators. The structural parameter estimator then solves

$$\widehat{\Theta} = \text{argmin}_{\Theta} \left[\widehat{\beta}(\Theta) - \overline{\beta}\right]' \mathcal{W} \left[\widehat{\beta}(\Theta) - \overline{\beta}\right],$$

where $\mathcal{W}$ is a weighting matrix. We obtain standard errors for $\widehat{\beta}(\Theta)$ by numerically computing $\frac{\partial \widehat{\Theta}}{\partial \overline{\beta}}$ and applying the delta method to the variance-covariance matrix of $\overline{\beta}$.

3.1. **Identification.**

We discuss identification of the three categories of parameters in our model, governing household preferences, education production technologies and the government objective. First, as in other discrete choice models, the observed distribution of household choices conditional on x identifies the relative value of each option for these households. The option-specific value is a combination of the value households attach to achievement and direct tastes for enrollment in different types of schools. Two assumptions allow us to separate these elements: (A1) conditional on x, the distribution of household preferences is common across states, (A2) there are no unobserved ability differences across households.[12] Given A2, the expected achievement gap between private and public schools for given x within each state is observed. Given A1, for households

[12]These assumptions are strong, yet as discussed in the model section, within-x variation is not the focus of the paper.

with characteristics $x,$ the cross-state covariation of public-private achievement gaps and household choices identifies how much the households value achievement. The remaining unexplained part of household choices arises from direct preferences over different types of schools. The dispersion of taste shocks is identified from the sensitivity of school choice to tuition levels, given that utility is measured as the log of household consumption.

Identification of the education production technology needs to tackle a standard endogeneity problem: education productivity (η_s) affects government investment in education but is unobserved. Other factors affecting expenditure policies include state-level observables z_s and the distribution of households $F_s(x)$. We allow η_s to be correlated with some but not all of these factors: specifically, we exclude state racial composition and the government's outside revenue from the η_s distribution. These excluded variables then serve as model-consistent instruments for education expenditure. Thus regressions of education outcomes on x and instrumented expenditure identify the productivity of these inputs. Contrasting the expenditure effect with state fixed-effect regressions informs us of the distribution and importance of η_s.

Finally, to identify the government objective function, notice that a government faces essentially a discrete choice problem. The value of choice ψ is essentially given by

$$\sum \omega_x F_s(x) \underline{V(x, \psi, \eta_s)} + \theta_x \underline{g(\psi, z_{1s})} + \gamma \sum F_s(x) \underline{K(\psi, x, \eta_s)}. \tag{3.1}$$

Given parameters governing household preference and education technologies, including the unobserved productivity distribution, the three underlined components in (3.1) are known functions of ψ. That is, (3.1) is known up to parameters ω_x, θ_x, γ, the identification of which follows the usual argument in identifying discrete choice models. However, with one state being an observation, the limited sample size restricts the flexibility in our specification. For this reason, we have assumed that ω_x and θ_x varies only with income, instead of all dimensions of x. These identification arguments guide our choice of auxiliary models, which are described in the next section.

4. Data and Auxiliary Models

For our empirical analysis, we combine information from the Education Longitudinal Study (ELS) of 2002, the American Community Survey (ACS) of 2002, the Census of Population (CP) of 2000, the Census of Governments (CG) of 2002, and the National Center for Education Statistics (NCES).

ELS interviewed 15,244 individuals from a representative sample of 10th-graders in 2002, with follow-ups in 2004, 2006, and 2012. It provides a wide range of information on household characteristics, education choices and outcomes at high school and college levels. We use the base-year (2002) interview data to determine household income and other characteristics (x), as well as high school choices (private vs public). We measure K-12 achievement k_1 by the standardized math test score in 2004 and the eventual high school dropout status. We use the college attendance history in 2006 and 2012 interviews to determine college choice o_2, the outstanding college loan level in 2006 to measure d, and degree completion status in 2012 for the college outcome k_2. ELS also contains administrative Pell grant information, which we use along with self-reported aid information to estimate the college financial aid function $A(\cdot)$.

Since primary school choice information is not available in ELS, we use primary school students in ACS to measure the private primary school attendance rate given state s and household characteristics x. We also use pairs of siblings at different stages of K-12 (primary vs high school) in ACS to get private high school attendance rates conditional on primary school choices.

Our sample from CP consists of households with women aged 35-40 (regardless of marital status) and those with single men aged 37-42. The age range of women is chosen such that the binary fertility outcome in our model is likely to have been realized for the household, with the child still living in the household (and thus observable in CP). The age range of single men is chosen such that they were in approximately the same marriage market as the women, so that the sample is expected to represent one cohort of households. We use this sample to estimate the state-specific demographic distribution $F_s(x)$ and the fertility rate $q_s(x)$. Combined with ELS and ACS, this allows us to obtain state-level household choices and outcomes. We also combine this sample with the NBER TAXSIM program to estimate the federal tax income schedule $\tau^0(\cdot)$ and the baseline state tax schedule $\tau^b(\cdot)$.

From NCES, we obtain information on private college tuition, state-specific public college tuition and region-specific private K-12 tuition.[13] Data counterparts are still needed for state-specific non-tax revenue, tax rate, K-12 expenditure, college expenditure and other expenditure, which we obtain from CG. We use the combined budgets of state and local governments of the 48 contiguous U.S. states. For each state in the sample, we construct per-household measures of state and local government revenues from taxes, educational institutions, and other sources (i.e., z_1); and net expenditure on K-12 and colleges. Other public expenditure is then defined as the difference between total revenue and total education expenditure. The appendix contains details of the data construction.

4.1. **Empirical Definitions of Model Variables.** The components of the household characteristics vector x include income quintile, minority status, and whether or not any adult in the household went to college.[14] State observables z include state state non-tax revenue (z_1) and a dummy for the Northeast Census Region.[15]

We consider the discrete probability distribution over households' education choices and outcomes, as well as the amount of college loans. Choices include public or private schools at the primary and secondary levels, 2-year or 4-year public or 4-year private at the tertiary level, as well as college loans. K-12 outcomes fall into 5 levels: the lowest level corresponds to high school dropouts, and the higher levels correspond to quartiles of the 12-th grade math score distribution. College outcomes are graduation or not conditional on the type of colleges attended.

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[13]NCES does not provide reliable state-specific private K-12 tuition information due to small sample sizes. We assume a common private K-12 tuition within each region.

[14]Within each income quintile, household income is assumed to equal to the within-quintile median.

[15]We include a region dummy in household preference for private colleges to absorb some possible regional differences in the distribution of private colleges.

Government choices ψ_s to be matched include 5 variables: per-household tax revenue (in logs), government expenditure on K-12 and on college; and 2-year and 4-year public college tuition levels.

4.2. **Auxiliary Models.** We target the following auxiliary models, guided by our identification argument.

(1) At the household level, we match coefficients from regressions of choices and outcomes on household characteristics x_{is} and other relevant observables w_{is}.
   (a) For primary school choice and high school choice, we use linear probability regressions, where w_{is} consists of log per-household K-12 expenditure and private tuition.
   (b) For loans taken by students attending each type of college, we use OLS regressions, where w_{is} is college tuition net of financial aid.
   (c) For college choice, we use a multinomial logit regression with the latent utility being

$$\begin{cases} u_{0is} = \epsilon_{0is} \\ u_{jis} = \alpha w_{jis} + x_{is}'\beta_j + \epsilon_{jis} \quad j = 1, 2, 3 \end{cases}$$

   where w_{jis} is the net tuition for each college option j, x_{is} consists of household characteristics, high school outcome dummies, a private high school dummy, log per-household college expenditure and a Northeast state dummy.[16]
   (d) We map the five K-12 outcome categories to numerical scores, where we use the within-category median score as the test score for all students in the same outcome group.[17] We treat these scores as the dependent variable in an OLS

[16]We use the derivatives of the log likelihood as targets instead of the coefficient vector $\phi = (\alpha, \beta_1, \beta_2, \beta_3)$ to reduce computational time. In particular, let $p_j(x, w; \hat{\phi})$ be the choice probability evaluated at the $\hat{\phi}$ coefficient estimated using the actual data. We match $E\left[\sum_{j=1,2,3} w_{jis}\left(d_{jis} - p_j(x_{is}, w_{is}; \hat{\phi})\right)\right]$ and the regression coefficients of $d_{jis} - p_j(x_{is}, w_{is}; \hat{\phi})$ on x_{is} between the actual data and the model. These auxiliary statistics are zero in the data due to the first order conditions of the multinomial logit.

[17]The structural production function is ordered logit and logit for K12 and college outcomes, respectively. To summarize the data, we use linear regressions in auxiliary models, because IV and fixed effect analyses are better suited in a linear setting and linear regressions are computationally more economical. See the appendix for the detailed mapping between ordinal and cardinal outcomes in these auxiliary models.

regression, where w_{is} is log of per-household K-12 expenditure for public schools and private tuition for private schools.

(e) For graduation among students attending each type of college, we use linear probability regressions, where w_{is} includes high school outcome dummies, a private high school dummy, and in the case of public colleges, w_{is} also includes log per-household college expenditure.

(f) We also run IV variants of the regressions in $1\,(d)$ and $1\,(e)$, in which log per-household expenditure $\ln(e)$ is replaced by its projection on the minority fraction and government extraneous revenue. We target coefficients associated with the instrumented $\ln(e)$.

(2) To identify the distribution of education productivity levels (η_{s1}, η_{s2}) as specified in (2.3), we run state fixed effect variants of the regressions in $1\,(d)$ and $1\,(e)$ and target the standard deviations of state fixed effects at both education levels, covariance of the two fixed effects, the fraction of each fixed effect above its mean, and regression coefficients of each of the two fixed effects on the fraction of college-educated adults.

(3) We run OLS regressions of government policy choices ψ_s on state-level observables, and we treat the regression coefficients from these regressions and the cross-state variance of ψ as targets to be matched. The regressors in each case include the mean and standard deviation of log income across households, the fraction of households with college-educated adults, the fraction of minority households, log-revenue from extraneous sources, and a Northeast dummy.

4.3. **Summary Statistics.** Table 1 summarizes the distribution of choices and outcomes by household characteristics. Students from lower-educated, minority and low-income households are less likely to attend private high schools and 4-year colleges (especially 4-year private), but are more likely to attend 2-year colleges. Cross-group differences in achievement are also substantial. In standardized high school tests, 70% of students from the highest income group score above the median, compared with 24% among the lowest

TABLE 1. Household Choices

	HS	College Enrollment			HS Score	College	
	Private	Public		Private	>median	Graduation	
%		2-year	4-year	4-year		2-year	4-year
All	7.5	27.6	31.2	24.4	47.3	43.7	61.9
Non-College Parents	2.8	34.9	22.1	14.5	28.3	47.5	49.2
Minority	3.9	34.7	24.5	20.5	26.2	41.8	47.2
Income Quintile 1	2.4	36.3	20.1	15.6	23.5	40.7	46.1
Income Quintile 2	3.4	33.4	25.6	17.9	32.4	43.3	49.6
Income Quintile 3	5.1	29.7	30.6	20.1	43.8	45.3	56.3
Income Quintile 4	7.3	27.4	35.1	24.3	53.5	42.9	62.1
Income Quintile 5	15.6	17.9	38.2	36.5	69.7	46.2	72.4

TABLE 2. Government Policies

	Mean	Std	Regression Coefficients					
		Dev	Income (log)		Household Fractions		Outside	Northeast
Expenditure Fractions			Mean	Std	College	Minority	Revenue	
K-12	0.29	0.03	0.09	-0.22	-0.06	0.07	-0.05	0.01
College	0.07	0.02	-0.02	-0.19	0.02	0.05	0.01	-0.03
Other	0.63	0.03	-0.07	0.42	0.04	-0.12	0.03	0.02
Tuition ($1,000)								
2-year	2.08	0.93	0.68	-15.25	-1.29	0.21	0.01	1.01
4-year	3.87	1.28	2.34	-24.07	-6.50	1.06	0.83	2.11
tax per HH (log)	1.98	0.18	1.50	0.85	-0.16	0.10	0.27	0.11

income group. Conditional on enrolling in a 4-year college, the graduation rate is 72% for the highest income group and 46% for the lowest income group.

Table 2 summarizes state government policies. The greatest disparity across states is in the fraction of expenditure on college education and college tuition levels. The rightmost columns show coefficients from regressions of each of the policy variables on the 6 state-level characteristics (Auxiliary Model 3). Controlling for other factors, K-12 expenditure fraction, college tuition levels are positively correlated with average household income and negatively correlated with income dispersion, while tax revenue per household is positively correlated with both the mean and the dispersion of household income.

TABLE 3. **Selected Parameter Estimates**

A. High School Achievement (Ordered Logit)*					
	Gov Expenditure ($\ln(e_1)$)				
	Low Income	High Income	Private tuition	Public HS	
HS k_1	0.60 (0.08)	0.76 (0.01)	0.08 (0.03)	-2.01 (0.17)	
B. College Graduation (Logit)*					
	Gov Expenditure ($\ln(e_2)$)		HS score	$(\text{HS score})^2$	Private HS
	Low Income	High Income			
2-year college	**0.28** (0.04)	**-0.002**(0.07)	**-1.18**(0.22)	**0.52** (0.25)	**0.18** (0.13)
4-year public	**1.21** (0.03)	**1.29** (0.04)	**1.40** (0.21)	**0.71** (0.26)	**0.17** (0.10)
4-year private	-	-	**3.07** (0.41)	**-0.18** (0.42)	**0.47** (0.11)
C. Educational Productivity Distribution Parameters					
	Constant	F(college HH)	ρ_2		std σ_η
K-12 η_{s1}	**-0.56** (0.61)	**-0.88** (6.69)	-		**0.20** (0.03)
College η_{s2}	**0.37** (0.32)	**9.88** (7.02)	**1.96**(0.66)		**0.49** (0.09)
	Implied values of η		$\Pr(\eta_{s1}, \eta_{s2})$ across states		
	Low	High	$\Pr(\eta_{s1}, \eta_{s2})$	$\underline{\eta}_1$	$\overline{\eta}_1$
K-12	$\underline{\eta}_1$ =-0.15	$\overline{\eta}_1$ =0.26	$\underline{\eta}_2$	0.37	0.07
College	$\underline{\eta}_2$ =-0.56	$\overline{\eta}_2$ =0.43	$\overline{\eta}_2$	0.27	0.29
D. Government Objective Function					
	Welfare Weights ω		Aggregate Education Outcome		
Low Income	Middle Income	High Income	Col. Enrollment	2-year Grads	4-year Grads
0.48 (0.06)	1.0 (normalized)	**1.47** (0.10)	0.78 (0.16)	**3.32** (0.32)	**3.57** (0.29)

Low Income refers to the first two income quintiles; High Income refers to the top two income quintiles.
*Estimates of the effects of other inputs are in the appendix.

5. Estimation Results

5.1. **Parameter Estimates.** We present estimates of selected parameters in Table 3 (with more detail in the appendix); standard errors are shown in parentheses. Panels A and B show the estimated education production parameters associated with expenditure, school type and previous achievement. There are two noticeable observations. First, all else equal, the effect of government educational expenditure (e) is slightly higher for higher income groups at both K-12 and 4-year college levels. For 2-year college outcomes, public expenditure is effective only for the lower income group. Second, high school test scores contribute positively to college graduation probabilities.[18] Enrollment in private high schools also has a direct positive effect on college outcomes.

[18]High school outcome is ordinal, but to save on parameters, we use the median test score within each quartile as inputs in the college production function.

Panel C shows the estimated parameters for the educational productivity distribution. The fraction of college-educated adults is positively correlated with a state's (unobserved) college productivity, but not directly with its K-12 productivity. The two productivity levels are positively correlated. Given these estimates, we report the support of the productivity distribution (the mean is normalized to zero), and the joint distribution $\Pr(\eta_{s1}, \eta_{s2})$ across the 48 states in our sample; we find that 37% of states have low productivity at both K-12 and college levels (and 29% have high productivity at both K-12 levels)

Panel D reports parameter estimates of the government's objective function. The welfare weights are strongly tilted in favor of the higher income groups. In addition to household welfare, government directly cares about aggregate education outcomes, which is necessary to rationalize the observed government policies.

5.2. **Model Fit.** Table 4 shows model fit results for household choices and outcomes. The first two columns of Table 5 show the fit for the mean and standard deviation of each of the government policy variables, while the other columns show the fit of the auxiliary regression models. In these tables, asterisks indicate predictions that are outside the 95% confidence interval for the corresponding statistic in the data. With a few exceptions, the equilibrium model predictions closely match the data.

TABLE 4. Model Fit: Household Choices and Outcomes

		Enrollment Choices				Education Outcomes			
%		Priv HS	2yr col	4yr pub	4yr Pri	HS > Median	Graduation / 2year Enroll	Graduation / 4year Pub	Graduation / 4year Priv
All	Data	7.5	27.6	31.2	24.4	47.3	43.7	61.1	62.9
	Model	7.3	27.8	31.2	24.0	47.4	43.5	61.6	61.9
Low Edu	Data	2.8	34.9	22.1	14.5	28.3	47.5	53.0	43.3
	Model	3.3*	35.0	22.5	15.2	27.7	46.0	46.7*	48.5
Minority	Data	3.9	34.7	24.5	20.5	26.2	41.8	51.6	41.9
	Model	4.4*	34.2	24.4	21.0	27.3	40.0	52.1	42.1
Low Inc	Data	3.0	34.6	23.2	16.9	28.5	42.1	52.4	42.5
	Model	4.0*	34.3	23.0	17.1	29.2	39.6	52.5	42.8
High Inc	Data	11.9	22.1	36.8	31.1	62.5	44.4	66.1	71.2
	Model	10.3*	22.2	37.0	30.7	62.8	47.1	66.2	71.6

*Outside the 95% confidence interval.

TABLE 5. Model Fit: Government Policies

		Mean	Std dev	Regression Coefficients: Income (log) Mean	Income (log) Std dev	Household fractions college	Household fractions minority	Outside Revenue	Northeast
$\frac{\text{K12 Exp}}{\text{Total Exp}}$	Data	0.29	0.03	0.09	-0.22	-0.06	0.07	-0.05	0.01
	Model	0.29	0.04	0.12	-0.56	-0.04	0.04	-0.09*	-0.01
$\frac{\text{College Exp}}{\text{Total Exp}}$	Data	0.07	0.02	-0.02	-0.19	0.02	0.05	0.01	-0.03
	Model	0.07	0.01*	0.01	-0.07	0.06	-0.01	-0.01*	-0.03
$\frac{\text{Other Exp}}{\text{Total Exp}}$	Data	0.63	0.03	-0.07	0.42	0.04	-0.12	0.03	0.02
	Model	0.64	0.04*	-0.12	0.63	-0.01	-0.03	0.10*	0.04
2-year tuition	Data	2.08	0.93	0.68	-15.25	-1.29	0.21	0.01	1.01
	Model	2.12	1.07	1.77	-14.70	1.27	0.63	-0.11	0.29*
4-year tuition	Data	3.87	1.28	2.34	-24.07	-6.50	1.06	0.83	2.11
	Model	3.87	1.25	4.03	-7.61*	-4.23	2.59	-0.36	2.03
Tax per HH (log)	Data	1.98	0.18	1.50	0.85	-0.16	0.10	0.27	0.11
	Model	1.99	0.13*	1.25	0.40	-0.21	-0.08	0.02*	0.01*

*Outside the 95% confidence interval.

6. COUNTERFACTUAL EXPERIMENTS

We use the estimated model to evaluate equilibrium impacts of free public college policies, implemented in two different ways.[19] In the first set of experiments, free public college policies are mandatory; in the second, the federal government offers subsidies to induce state governments to charge zero college tuition.

6.1. **Free Public Colleges (Mandatory).** Under a mandatory free-college policy, the choice set of a state government is restricted to be $\Psi^c \subset \Psi$, such that for all $\psi \in \Psi^c$, $\underline{t} = 0$, and t is no greater than the baseline 4-year college tuition if 2-year colleges are required to be free, and $\underline{t} = t = 0$ if all public colleges are required to be free. Table 6 shows the policy impacts. The state government decreases per-student expenditure at both levels of education, and increases tax rates. While state taxes are increased proportionally for all income groups, we illustrate this change by showing the case for the middle income group only. When 2-year tuition is free, in many cases the state government re-optimizes by *reducing*

[19]We treat parameters governing fertility and household terminal value functions as invariant to our counterfactual policies. Thus our policy impacts are best interpreted as short-run rather than long-run equilibrium impacts.

TABLE 6. Free Public Colleges (Mandatory)

A. Gov Policy (Mean)

	Per student e ($\$1,000$)		State Tax (%)	Tuition ($\$1,000$)	
	K12	College	(MidInc)	2year	4year
Baseline	7.65	14.94	13.29	2.12	3.87
Free 2-year	7.61	14.70	13.32	0	3.68
Free 2&4-year	7.56	14.26	13.95	0	0

B. College Enrollment and Graduation

	Enrollment				$\frac{College\ Grad}{College\ Enroll}$		College Grad	
%	None	2year	4year pub	4yr pri	2year	4year pub	2year	4year (pub+pri)
Baseline	20.9	26.5	29.7	22.9	43.5	61.6	11.5	32.4
Free 2-year	20.2	28.3	29.2	22.3	42.9	61.3	12.2	31.8
Free 2&4-year	16.5	22.5	43.8	17.2	44.0	58.2	9.9	36.3

C. Winners %

	All	Inc=1	Inc=2	Inc=3	Inc=4	Inc=5
Free 2-year	18.1	25.3	26.4	22.7	15.1	7.4
Free 2&4-year	13.7	59.5	10.0	9.1	0.0	0.0

4-year college tuition, which helps to reduce enrollment shifts from 4-year public colleges to free 2-year colleges.[20]

Panel B of Table 6 shows the impact on the college enrollment rate, the graduation rate, and the fraction of all students with a college degree. For example, when both 2-year and 4-year public colleges are free, enrollment in 4-year public colleges increases, while it decreases in private 4-year colleges.[21] The graduation rate in public 4-year colleges decreases from 62% to 58%.

Panel C of Table 6 shows the fraction of households whose welfare is improved, across all households and by income groups.[22] Holding state policies fixed, any individual household would gain under zero-tuition policies, but these gains may vanish when the resource constraint and the government's policy choices are taken into account. Indeed, our results show that most households would lose from the free-tuition policy; the distribution of winners is uneven across income groups, with nearly all of the winners in the lowest income

[20]This response is substantially more likely when unobserved educational productivity is high.

[21]In the text, we fix private college tuition at its baseline level. In the appendix, we allow private tuition to adjust to maintain the baseline enrollment level. The results are similar.

[22]Household welfare is measured by the ex ante value before fertility is realized, i.e., $q(x)\,EV_1(\cdot) + (1-q(x))\,V^0(\cdot)$.

group. For example, when all public colleges are free, although the fraction of winners is only 14% among all households it is 60% for the lowest income group.

6.2. **Free Public Colleges (Subsidized).** In this experiment, the free college policy is voluntary, and complying states obtain a subsidy from the federal government. Such a voluntary cost-sharing policy is similar in spirit to many other policies (e.g., the expansion of Medicaid) and is perhaps more realistic. There are different ways to implement the subsidy, one of which is to subsidize a fraction r of the original college tuition. To balance the federal budget, we assume that the subsidy is funded via a federal tax surcharge with the new tax rate $\tau_0'(x_1) = (1+\kappa)\,\tau_0(x_1)$,[23] such that the increased federal income tax revenue equals the total tuition subsidy $\mathcal{S}(\kappa, r)$ from the federal government to the states, i.e.,

$$\mathcal{S}(\kappa, r) \quad = \quad \sum_s \int_x \left(\tau_0'(x_1) - \tau_0(x_1)\right) dF_s(x)$$

To calculate $\mathcal{S}(\kappa, r)$, we need to solve the state's problem first. Given the federal policy (κ, r), the problem for state s is modified as

$$\pi_s^v(\kappa, r) = \max\left\{\pi_s(\kappa), \pi_s'(\kappa, r)\right\},$$

where the superscript v refers to voluntary. A state chooses between non-complying with value $\pi_s(\kappa)$ and complying with value $\pi_s'(\kappa, r)$. Here $\pi_s(\kappa)$ is the optimal value from (2.5) under the new federal income tax $\tau_0'(x_1) = (1+\kappa)\,\tau_0(x_1)$. The value of complying is given by

$$\textbf{(6.1)}\quad \pi_s'(\kappa, r) = \max_{\psi^c \in \Psi^c}\left\{\int \omega(x)\begin{bmatrix} q(x)\,EV_1(\cdot;\kappa) + \\ (1-q(x))\,V^0(\cdot;\kappa)\end{bmatrix} dF_s(x) + W(N_{2s}, K_{2s})\right\}$$

$$s.t.\ z_{s1} + \int \tau(x_1)\,dF_s(x) + r\left(\underline{t}_s^* N_{s2l} + t_s^* N_{s2h}\right) = e_1 N_{s1} + e_2\left(0.5 N_{s2l} + N_{s2h}\right) + g,$$

Aggregate choices: (2.4),

[23] We keep the federal tax unchanged if it is negative in the baseline.

TABLE 7. Compliance Rate and State Characteristics

	Compliance Rate %	State Characteristics by Complying Status under $r = 0.1$	Complying States (12.2%)	Non Complying States
		Low Inc Fraction	0.41	0.36
$r = .1$	12.2	High Inc Fraction	0.42	0.47
$r = .2$	90.9	Pr $(\eta_{s1} = \overline{\eta}_1)$	0.12	0.40
$r = .3$	100	Pr $(\eta_{s2} = \overline{\eta}_2)$	0.13	0.63
		Outside Revenue z_1	4.51	3.98

where $\underline{t}_s^*$ and t_s^* are the original optimal tuition choices associated with (2.5) in the baseline. Compared with (2.5), (6.1) requires that the policy be chosen from the constrained choice set Ψ^c with $\underline{t} = t = 0$; in return, the state receives a total subsidy of $r\left(\underline{t}_s^* N_{s2l} + t_s^* N_{s2h}\right)$.

The federal subsidy nationwide is therefore given by

$$\mathcal{S}(\kappa, r) \quad = \quad \sum_s \mathbb{I}\left(\pi_s(\kappa) < \pi_s'(\kappa, r)\right) r\left(\underline{t}_s^* N_{s2l} + t_s^* N_{s2h}\right)$$

which is an equilibrium outcome that depends on how many state governments take the subsidy, how they change their own policies and how many students attend public colleges in the new equilibrium in these states. State and household responses in turn depend on the subsidy rate (r) and the federal tax surcharge (κ). Thus solving for κ given r involves a fixed point problem. At different subsidy rates r, we can trace the take-up rates and changes in outcomes and welfare (solving for κ to balance the federal budget). To illustrate, we show the equilibrium effects of subsidizing at rates of $r = 0.1,\ 0.2$ and 0.3 under the condition that both 2-year and 4-year public colleges are free in complying states.

The first column of Table 7 shows the fraction of subsidy-taking states: at $r = 0.1$, only 12% of states would take the subsidy while all states would comply at $r = 0.3$. Using the case of $r = 0.1$ as an example, the rest of Table 7 compares state-level characteristics between complying and non-complying states. Complying states tend to have more low-income households, who are more likely to benefit from the policy. More significantly, complying states are much less likely to have high education productivity levels. Because educational productivity and expenditure are complements in producing educational outcomes, states with higher productivity are more reluctant to reduce tuition to zero, which may lead to less expenditure per student. Finally, complying states also tend to have higher outside revenue, which acts as a buffer against the loss of tuition revenue.

Panel A of Table 8 shows the equilibrium outcomes across all states in the baseline, in each of the three subsidy cases, and in the mandatory policy case. In general, subsidized free college policies lead to smaller changes in state policies. For example, comparing the last two rows in Panel A, although public colleges are free in all states in both cases (since all states comply when $r = 0.3$), state investment in public education is higher in the subsidy case, leading to a slightly higher fraction of college graduates.

TABLE 8. Free 2-year and 4-year Public Colleges (Subsidized)

A. Policy & Outcomes	Per student e ($1,000)		State Tax %	College Graduates %	
	K12	College	(MidInc)	2yr	4yr (pub+pri)
Baseline	7.65	14.94	13.29	11.5	32.4
Subsidy $r = .1$	7.64	14.85	13.37	11.5	32.8
Subsidy $r = .2$	7.59	14.52	13.90	10.3	36.0
Subsidy $r = .3$	7.61	14.66	13.92	9.9	36.7
Mandatory Free 2&4-year	7.56	14.26	13.95	9.9	36.3

B. Benefit & Cost	Winners %		△Welfare				Cost	
			Complying		Non-Complying		Subsidy	κ
	All	Inc=1	All	Inc=1	All	Inc=1	$ per HH	%
Subsidy $r = .1$	1.8	6.5	-0.055	0.013	-0.001	-0.0001	44	0.05
Subsidy $r = .2$	13.4	63.3	-0.064	0.023	-0.011	-0.003	861	0.9
Subsidy $r = .3$	13.7	64.2	-0.066	0.020	-	-	1,433	1.5
Mandatory Free 2&4-year	13.7	59.5	-0.061	0.011	-	-	-	-

Panel B of Table 8 reports the benefit and cost of each subsidy policy. We report welfare effects for all households, and particularly for the lowest income quintile, who are most likely to benefit from the policy.[24] Households in all states are affected by the subsidized free-tuition policy due to the federal tax surcharge, which implies a flow of resources from non-complying to complying states. The first two columns show that the fraction of winners increases with the subsidy rate but is always small. When all states comply, the fraction of winners among all households is the same as it is under the mandatory free college policy (13.7%). However, the benefit is even more concentrated among the lowest income

[24]For each of the other 4 income quintiles, the policy effect on average household welfare is negative.

TABLE 9. Change in Welfare with Alternative Uses of Federal Subsidy

	Alternative 1		Alternative 2		Subsidize college	
$ per HH	All	Inc=1	All	Inc=1	All	Inc=1
44	0.0003	0.002	-0.0003	-0.0002	-0.007	0.002
861	0.007	0.030	0.002	0.002	-0.059	0.020
1,433	0.011	0.050	0.005	0.013	-0.066	0.020

groups, partly because higher income groups are more affected by the federal tax increase. The next four columns show the change in welfare levels. In complying states, the overall impact is negative, but welfare increases for the lowest income group.[25]. The last two columns show the cost of subsidies measured in terms of dollars per household and the tax surcharge (κ).

To provide a better benefit-cost measure, we examine how household welfare would change if the same amount of the additional federal tax revenue $S(\kappa, r)$ were to be spent in two alternative ways. Note that neither of the two alternatives should be considered as competitors of the subsidized free college program; rather, they merely serve to measure the relative welfare impact of this program. Under Alternative 1, we allocate federal money to mandated spending on other public goods (g). This is a naive calculation since it holds state policies fixed. Under Alternative 2, we allocate the federal money to states in the form of increased outside revenue, and search for the new equilibrium where the state government re-optimizes over its original policy space Ψ.[26]

Table 9 shows the results. Given the same amount of federal money per household (as shown in Panel B of Table 8), the (weakly) dominant alternative is mandated spending on other public goods (with other government choices held fixed). When state government responses are taken into account, an average household would rather spend the additional federal tax revenue to increase a state's revenue than spend it to subsidize free public college, while the lowest income group would have the opposite preference.

[25]In non-complying states, the welfare effect is of course negative for all households.

[26]To the extent that the additional federal tax burden increases with household income, this policy measures the equilibrium effect of a re-distribution of resources from richer to poorer states.

7. Conclusion

The idea of "free" public colleges is politically seductive. But of course a college education can't actually be free – someone must pay for it. We develop a model that can be used to systematically analyze some of the implications of this simple observation. We emphasize that since education is a cumulative process, allocating additional resources to the college stage may be self-defeating if this entails a reduction of public expenditure in the earlier stages. As has been stressed by Cunha and Heckman (2007), this is not just a question of the overall level of investment in public education, since investments at earlier stages enhance the returns to later investments.

Our analysis interprets data on government tuition and expenditure policies, household enrollment choices, and educational achievement, as an equilibrium outcome of a Stackelberg game in which the government chooses an optimal policy, anticipating the best responses of households. We treat each state in isolation, and use the cross-state variation in the data to estimate the underlying parameters governing household and government preferences and educational technologies, and we then use the estimated model to predict the consequences of free college policies introduced at the federal level. Our main finding is that such policies would lead to lower per-student expenditure on K-12 and college education, and thus lower welfare for a typical household. But we also find that these policies tend to slightly benefit households in the lowest income group.

Our framework and empirical findings are promising for future research, with several important yet challenging extensions worth pursuing. The first is to allow for migration, in which state governments best respond to each others' policy choices. This extension will help us better understand the ripple effects of policies implemented in some but not all states.[27] The second extension is to fine tune the model to better fit the U.S. educational system, where K-12 education is funded mainly via local property taxes. This extension will better address issues such as cross-district inequality within a state, which, however,

[27]The state of New York recently launched the Excelsior Scholarship to make four-year colleges free for those with annual family income lower than $125,000.

requires local-level data on government expenditure, household characteristics and outcomes. Finally, given the static nature of government choices, our model is best suited to answer policy questions in the short run. A third extension would add dynamics into the government problem to better answer long-run policy questions.

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Appendix A. Empirical Specification Details

Household characteristics x consists of income x_1, with 5 discrete levels, an indicator x_2 for the presence of at least one adult with some college education, and an indicator x_3 signifying that a student is not White or Asian.

A.1. K-12 Education.

We adjust the utility function and the budget constraint to reflect the actual length of each schooling stage in the empirical version of the model. Private K-12 choice is denoted by $o_1 = (o_{1L}, o_{1H})$, a pair of indicators referring to primary school (o_{1L}) and high school (o_{1H}). Taking the typical durations of primary and high school education into account, the utility from consumption during the K-12 stage is specified as

$$\sum_{t=1}^{8} \beta^{t-1} \ln\left(y(\tau, \tau_0, x_1) - p_1 o_{1L}\right) + \sum_{t=9}^{12} \beta^{t-1} \ln\left(y(\tau, \tau_0, x_1) - p_1 o_{1H}\right),$$

where $\beta = 0.95$ is the annual discount factor. The taste function for K-12 choice is given by

$$\lambda_1(o_1, x) = o_{1L}\lambda_{1L} + o_{1H}\lambda_{1H} + \left(\frac{2}{3}o_{1L} + \frac{1}{3}o_{1H}\right)\left(\lambda_{1P}^1 x_1 + \lambda_{1P}^2 x_2 + \lambda_{1P}^3 x_3\right) + \lambda_{1S}\mathbb{I}\{o_{1L} \neq o_{1H}\},$$

where taste heterogeneity across x is restricted to be proportional to private enrollment intensity $\frac{2}{3}o_{1L} + \frac{1}{3}o_{1H}$. The parameter λ_{1S} can be interpreted as a switching cost associated with different types of schools across primary and high school levels. The K-12 outcome k_1 is generated from an ordered logit model with latent outcome function

$$\begin{aligned}\ell_1(o_1, x, e_1, \eta_1, p_1) = {} & \mu_1^1(x_1) + \mu_1^2 x_2 + \mu_1^3 x_3 + \left(\frac{2}{3}o_{1L} + \frac{1}{3}o_{1H}\right)\left(\mu_1^{pr} p_1\right) \\ & + \left(\frac{2}{3}(1 - o_{1L}) + \frac{1}{3}(1 - o_{1H})\right)\left(\mu_1^{pu,1} + \mu_1^{pu,2} x_1 \ln e_1 + \eta_1\right).\end{aligned}$$

Private and high school stages are assumed to affect the final K-12 education outcome proportionally to their durations.

A.2. **College Education.** We specify the utility from consumption during the college period as

$$\begin{cases} \sum_{t=1}^{4} \beta^{t-1} \ln\left(y\left(\tau, \tau_0, x_1\right)\right) & \text{if } o_2 = 0 \\ \sum_{t=1}^{2} \beta^{t-1} \ln\left(y\left(\tau, \tau_0, x_1\right) + d + A_{o_2}\left(C, x, k_1\right) - C\right) + \sum_{t=3}^{4} \beta^{t-1} \ln\left(y\left(\tau, \tau_0, x_1\right)\right) & \text{if } o_2 = 1 \\ \sum_{t=1}^{4} \beta^{t-1} \ln\left(y\left(\tau, \tau_0, x_1\right) + d + A_{o_2}\left(C, x, k_1\right) - C\right) & \text{if } o_2 \in \{2, 3\} \end{cases}$$

We use the conditional mean of an estimated Tobit model as the aid function:

$$A_{o_2}\left(C, x, k_1\right) = \mu_{o_2}^{A}\left(C, x, k_1\right) \Phi\left(\mu_{o_2}^{A}\left(C, x, k_1\right)\right) + \sigma_{o_2}^{A} \phi\left(\mu_{o_2}^{A}\left(C, x, k_1\right)\right).$$

The taste for college education is given by

$$\lambda_{2o_2}\left(x, k_1, o_1, z\right) = \lambda_{2o_2}^{1}\left(x_1\right) + \lambda_{2o_2}^{2} x_2 + \lambda_{2o_2}^{3} x_3 + \lambda_{2o_2}^{4} k_1 + \lambda_{2o_2}^{5} o_{1H} + \lambda_{2o_2}^{6} \mathbb{I}\left(o_2 = 3\right) z_3,$$

where z_3 is an indicator for states in the Northeast region, to reflect the fact that this region is historically endowed with more private college options. The college outcome (k_2) is generated from a logit model with the following latent outcome functions ℓ_{2o_2} with $o_2 \in \{1, 2, 3\}$.

$$\begin{aligned} \ell_{21}\left(x, k_1, o_1, e_2, \eta_2\right) &= \mu_2^{pu_1,1} x_1 + \mu_2^{pu_1,2} x_2 + \mu_2^{pu_1,3} x_3 + \mu_2^{pu_1,4} k_1 + \mu_2^{pu_1,5} o_{1H} + \mu_2^{pu_1,6} x_1 \ln e_2 + \eta_2 \\ \ell_{22}\left(x, k_1, o_1, e_2, \eta_2\right) &= \mu_2^{pu_2,1} x_1 + \mu_2^{pu_2,2} x_2 + \mu_2^{pu_2,3} x_3 + \mu_2^{pu_2,4} k_1 + \mu_2^{pu_2,5} o_{1H} + \mu_2^{pu_2,6} x_1 \ln e_2 + \mu_2^{pu_2,7} \eta_2 \\ \ell_{23}\left(x, k_1, o_1\right) &= \mu_2^{pr,1} x_1 + \mu_2^{pr,2} x_2 + \mu_2^{pr,3} x_3 + \mu_2^{pr,4} k_1 + \mu_2^{pr,5} o_{1H} \end{aligned}$$

A.3. **Terminal Value.** We assume that the terminal value function is additively separable in debt, K-12 outcome and college outcome, such that

$$v\left(x, k_1, k_2, d\right) = f\left(d, x_1\right) + b_{1x_1} k_1 + b_{2x_1} \mathbb{I}\left(\text{2-year degree}\right) + b_{3x_1} \mathbb{I}\left(\text{4-year degree}\right),$$

where each of the b_{nx_1} $(n = 1, 2, 3)$ parameters takes two values, for lower and higher income households respectively. The borrowing cost function is given by

$$f(d, x_1) = \gamma_1(x_1) \ln\left(1 - \gamma_2(x_1) \cdot R_{o_2} \cdot \left(d + \gamma_3 \max\{0, d - (C - A(C, x, k_1))\}\right)\right).$$

Note that $f(d, x_1) = 0$ if $d = 0$. The parameter γ_3 allows for an extra cost associated with borrowing more than the net tuition $(C - A(C, x, k_1))$, which helps to fit the borrowing statistics in the data. R_{o_2} is the ratio of the final outstanding debt to the annual borrowing d, which is set to

$$R_{o_2} = \begin{cases} \sum_{t=1}^{2}(1+r)^{4-t+1} & \text{if } o_2 = 1 \\ \sum_{t=1}^{4}(1+r)^{4-t+1} & \text{if } o_2 = 2, 3. \end{cases}$$

The annual gross interest rate $1 + r$ is set to the inverse of the annual discount factor.

A.4. **Preference for other public expenditures.** We specify the household's preference for other public expenditure g as $\theta(x, z)\ln(g)$, where

$$\theta(x, z) = \exp\left(\theta_0\left(1 - \mathbb{I}(x_1 = 1)\right) + \theta_1 \mathbb{I}(x_1 = 1) + \theta_2 \ln(z_2)\right).$$

The preference for g among the lowest income group may differ from the other groups (for example, low-income households are more likely to benefit from welfare programs). We also allow a systematic correlation between federal transfer z_2 (z_2 is one part of z_1, $z_2 \leq z_1$) and the "preference" for g, to allow for the possibility that federal transfers may reflect a state's need to spend on public goods other than education. The exponential function is used to guarantee non-negative preference for g.

A.5. **Government Policies.** In the tax schedule $\tau(x_1) = \tau^R \cdot \tau^b(x_1)$, $\ln \tau^b(x_1)$ is given by the income group fixed effects in a regression of log tax rate on state dummies and income dummies from TAXSIM. The estimated income-specific $\tau^b(x_1)$ values are 1.00, 1.15, 1.21, 1.26, and 1.35 for each $x_1 \in \{1, \ldots, 5\}$, with the lowest income group as the reference group.

We set the space for state choices $\psi = \left[\tau^R, e_1, e_2, \underline{t}, t\right]$, with $7 \times 8 \times 8 \times 7 \times 8 = 25,088$ support points. Along each dimension of the policy choices, the grid is wider than the support of the observed policy distribution to allow for the possibility that government choices may be out of the empirical range in counterfactual scenarios, and the grid points are assigned to provide good coverage of the empirical distribution (see the online appendix).

TABLE 10. Free Public Colleges (Mandatory)

A. Government Policy (Mean)					
	Per student e ($1,000)		State Tax (%)	Tuition ($1,000)	
	K12	College	(MidInc)	2yr	4yr
Free 2&4-year	7.56	14.26	13.95	0	0
Free 2&4-year (P)	7.62	13.44	13.72	0	0

B. College Enrollment and Graduation								
	Enrollment				$\frac{College\ Grad}{College\ Enroll}$		College Grad	
%	Non	2yr	4yr pub	4yr pri	2yr	4yr pub	2yr	4yr (pub+pri)
Free 2&4-year	16.5	22.5	43.8	17.2	44.0	58.2	9.9	36.3
Free 2&4-year (P)	16.1	21.4	39.6	22.9	44.1	56.6	9.5	36.0

C. Winners %						
	All	Inc=1	Inc=2	Inc=3	Inc=4	Inc=5
Free 2&4-year	13.7	59.5	10.0	9.1	0.0	0.0
Free 2&4-year (P)	28.6	76.3	45.0	29.8	4.8	0.2

APPENDIX B. COUNTERFACTUAL POLICY: A ROBUSTNESS CHECK

In conducting our counterfactual analyses, we have kept private college tuition fixed at its baseline level. Although it is beyond this paper to predict how private colleges would respond to free public college policies, as a robustness check on our counterfactual policy experiment, we consider one arguably reasonable scenario: when all public colleges are made free, private tuition adjusts such that the private college enrollment rate is maintained at its baseline level. We do so for the most extreme counterfactual experiments in the main text, i.e., a mandatory zero tuition policy for all public colleges. We find that private tuition would need to decrease by 7.1% to maintain the baseline level enrollment in the new equilibrium, labeled as (P) in Table 10. State governments respond to the reduction in private tuition by cutting college expenditure even further, while increasing K-12 expenditure and reducing tax toward the baseline levels. The final fractions of college graduates in the population are similar in these two cases. A higher fraction of households would win under the free-college policy when private tuition adjusts, and now 76% of the lowest income group benefits. However, overall, winners are still in the minority (28.6%).

APPENDIX C. OTHER PARAMETER ESTIMATES

TABLE 11. Other Parameter Estimates: Production

A. High School Achievement (Ordered Logit, Latent Outcome)						
	Linear income*	$\mathbb{I}(\text{inc} \geq 4)$	college	minority	K-12 TFP η_1	
HS k_1	1.41 (0.11)	-0.32 (0.15)	0.70 (0.04)	-1.03 (0.04)	1.0 (normalized)	
B. High School Achievement (Ordered Logit, Cutoffs)						
	dropout-1q	1q-2q	2q-3q	3q-4q		
HS k_1	-3.20 (0.18)	-0.86 (0.18)	0.39 (0.17)	1.72 (0.17)		
C. College Graduation (Logit)						
	Linear income*	$\mathbb{I}(\text{inc} \geq 4)$	college	minority	College TFP η_2	intercept
2yr college	1.07 (0.17)	0.43 (0.17)	-0.25 (0.10)	-0.25 (0.11)	1.0 (normalized)	-1.09 (0.16)
4yr public	0.13 (0.22)	-0.36 (0.16)	0.48 (0.11)	-0.19 (0.10)	0.33 (0.14)	-4.33 (0.08)
4yr private	1.25 (0.33)	-0.24 (0.24)	0.05 (0.15)	-0.52 (0.11)	-	-1.89 (0.11)

*Linear income term is in $100,000.

TABLE 12. Other Parameter Estimates: Household Preferences

A. Scale of Household Preference Shock			B. Household Preference for Private K-12			
K-12	College			primary	high school	switching cost
7.34 (0.57)	0.51 (0.05)		private K-12	-7.28 (1.10)	-16.07 (1.48)	-12.44 (1.05)

C. Household College Preference						
	intercept	HS score	HS score^2	Private HS	Northeast	
2yr college	-2.62 (0.11)	2.09 (0.42)	-1.08 (0.46)	0.11 (0.20)	-	
4yr public	-1.04 (0.11)	2.17 (0.34)	-1.01 (0.31)	0.52 (0.10)	-	
4yr private	2.92 (0.09)	-0.83 (0.20)	0.91 (0.29)	0.74 (0.12)	0.14 (0.06)	
D. Household Preference Interaction with x						
	inc=2	inc=3	inc=4	inc=5	college	minority
private K-12	-2.64 (0.52)	-1.66 (0.58)	-3.68 (1.02)	0.52 (1.25)	7.35 (0.58)	-4.94 (0.46)
2yr college	-0.11 (0.07)	-0.27 (0.09)	-0.61 (0.27)	-1.41 (0.34)	0.42 (0.13)	0.42 (0.14)
4yr public	0.06 (0.07)	0.17 (0.08)	-0.88 (0.16)	-0.94 (0.20)	0.11 (0.06)	0.08 (0.06)
4yr private	-1.18 (0.09)	-2.41 (0.10)	-3.57 (0.16)	-3.88 (0.21)	0.26 (0.07)	0.18 (0.07)

E. Public Good				F. Terminal Values		
inc≠1	inc=1	$\ln z_2$			$\mathbb{I}(\text{inc} \leq 3)$	$\mathbb{I}(\text{inc} \geq 4)$
-2.36 (0.05)	-1.58 (0.15)	0.60 (0.04)		HS score	-0.13 (4.41)	43.90 (4.68)
				2-yr grad	6.32 (0.29)	8.55 (0.67)
				4-yr grad	1.04 (0.26)	3.88 (0.41)

G. Borrowing Cost*				
γ_{11}	γ_{12}	γ_{21}	γ_{22}	γ_3
0.28 (0.07)	0.08 (0.06)	-4.57 (0.06)	-0.75 (0.06)	0.18 (0.05)

*$\ln \gamma_1(x_1) = \gamma_{11} + \gamma_{12} \ln x_1$ and $\ln \gamma_2(x_1) = \gamma_{21} + \gamma_{22} \ln x_1$.