GOVERNMENT EXPENDITURE ON THE PUBLIC EDUCATION SYSTEM

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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 our 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. Our counterfactual simulations suggest that free-public-college policies, mandatory or subsidized, would decrease state expenditure on public education. More students would obtain college degrees, although the large increase in enrollment is substantially offset by a decrease in graduation rates. Such policies would have negative welfare effects for most households and reduce average welfare.

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 proposed free tuition in all public colleges in his 2016 and 2020 presidential campaigns; the American Families Plan proposed by President Biden would guarantee two years of free community college. Directly, policies of this sort would improve opportunities for disadvantaged college-bound individuals. However, to assess these policies, one needs to look beyond their direct effects and account for at least two factors. First, human capital production is a cumulative process, in that later achievements rely on investments made in the

Date: May, 2021.
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past.[1] As 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 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 household welfare (with welfare weights that may differ across household categories) 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 the government's decision as given, households first choose between private and public K-12 schools. Then, given how well students have performed at the K-12 level, households may choose further education at the college level. The college options consist of two-year colleges and four-year public or private colleges, and the household may use student loans to cover some of the college costs. 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.

[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).

[2]Conversely, 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.

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 unobservably in how productive their public education systems are, which jointly lead to different government policies and equilibrium outcomes. We estimate the model via indirect inference; our main data sources are the Education Longitudinal Study, the American Community Survey, and the Survey of Governments. 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 57% 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. A large majority 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 enrolled student amounts to a certain fraction of the state's baseline college tuition. The federal subsidy is funded via a proportional increase in federal income taxes paid by all households (including those in states that do not adopt the free college policy). 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 8% of states to comply, while 98% of 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.

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 (2018) 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 (2020) 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 (2020) 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. (2019) 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. (2018) 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 government policy choices.

The role of government in education has been studied for a long time.[3] In a general equilibrium model of school attendance, labor supply, wage determination, and aggregate production, Hanushek et al. (2003) compare tuition subsidy and alternative redistribution devices and find that wage subsidies generally dominate tuition subsidies. There is also a literature focusing on the performance of government in providing education, as reviewed by Hanushek (2002), who 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' 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 heterogeneous 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, a vector of observed characteristics z, and an unobserved productivity vector $\eta_s = (\eta_{s1}, \eta_{s2})$ for public K-12 (η_{s1}) and public college

[3] See Friedman (1955), for example

education (η_{s2}).[4] We will suppress the state and individual subscripts s and i except where they are needed to avoid confusion. Time is discrete, with three periods.

- Period 0: The state government chooses its policy $\psi = (\tau, \underline{t}, t, e_1, e_2, g)$: an income tax schedule 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 characteristics x will have a child, in which case they choose public or private K-12 education, denoted as $o_1 \in \{0, 1\}$.[5]
- Period 2: K-12 educational outcomes are realized; households with children make decisions on 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}.[6]

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 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-student government expenditure e_1. A household can alternatively pay p_1 for the child to attend private school, where the outcome depends on z, x and p_1. The K-12 outcome (k_1) is given by a sector-specific

[4]The household characteristics are income (x_1), parental education (x_2), and race (x_3). The observed state characteristics are non-tax revenue (z_1), which includes federal transfer revenue (z_1^f), and region (z_2).
[5]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 (see Appendix A.1)
[6]In the empirical analysis, students choosing out-of-state public colleges are treated as if they had chosen a private college (of all four-year college enrollees in our sample, 8% attended out-of-state public colleges). 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.

ordered-logit function

$$\tilde{k}_1 \sim \begin{cases} L_1^0(x,z,e_1,\eta_1) & \text{if } o_1 = 0 \\ L_1^1(x,z,p_1) & \text{if } o_1 = 1 \end{cases}. \tag{2.1}$$

2.1.2. *College Education.* Students can choose a 2-year public college with (gross) tuition $\underline{t}$, or a 4-year public college with tuition t, or a private (4-year) college with tuition p_2.[7] Educational outcomes in public colleges depend on z, η_2, x, K-12 achievement (k_1), and per-student government expenditure on higher education e_2. Educational outcomes in the private college depend on x, k_1 and p_2. To distinguish two-year degrees from four-year degrees, we denote the outcome variable as $k_2 \in \{0,1\}$ (no degree, 2-year degree) for two-year college outcomes, and $k_2 \in \{0,2\}$ (no degree, 4-year degree) for four-year college outcomes. 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 k_2 is given by a sector-specific logit function

$$\tilde{k}_2 \sim \begin{cases} L_2^1(k_1,x,z,e_2,\eta_2) & \text{if } o_2 = 1, k_1 > 1 \\ L_2^2(k_1,x,z,e_2,\eta_2) & \text{if } o_2 = 2, k_1 > 1 \\ L_2^3(k_1,x,p_2) & \text{if } o_2 = 3, k_1 > 1 \end{cases}. \tag{2.2}$$

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

$$\begin{aligned} \Pr(\tilde{\eta}_1 = \overline{\eta}_1 \mid X) &= \mathbb{L}(\rho_{10} + \rho_{11}X) \\ \Pr(\tilde{\eta}_2 = \overline{\eta}_2 \mid X, \eta_1 = \overline{\eta}_1) &= \mathbb{L}(\rho_{20} + \rho_{21}X + \rho_{22}) \\ \Pr\left(\tilde{\eta}_2 = \overline{\eta}_2 \mid X, \eta_1 = \underline{\eta}_1\right) &= \mathbb{L}(\rho_{20} + \rho_{21}X - \rho_{22}) \\ \mathbb{E}(\tilde{\eta}_1) &= \mathbb{E}(\tilde{\eta}_2) = 0,\ Var(\tilde{\eta}_1) = \sigma_{\eta_1}^2,\ Var(\tilde{\eta}_2) = \sigma_{\eta_2}^2 \end{aligned} \tag{2.3}$$

[7]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.

where $\mathbb{L}$ is the logistic function. The parameters (ρ_{11}, ρ_{21}) capture the correlation between a state's educational productivity at the K-12 and college levels and observed state characteristics, while ρ_{22} allows for correlation between productivity at the two education levels conditional on the state characteristics. In the estimated model, X in (2.3) is the fraction of college-educated adults in the state.[8]

2.1.4. *Comment on the Production Technology.* Two aspects of the production technology deserve comment. First, we allow for unobserved state factors η in the public but not the private education sector, because our data are not rich enough and our focus is on the heterogeneity of public education across states.[9]

Second, households within each x group are assumed to be homogeneous up to random shocks, i.e., we abstract from household unobserved heterogeneity (e.g., unobserved ability), which has been the focus of a large literature on households' education choices. Relative to this literature, we have a different goal: studying the equilibrium impact of federal policies across states and across households of different socio-economic statuses (x). An important confounding factor in studying these effects is unobserved state-level characteristics which might be correlated with state policies. In particular, a state government chooses its educational expenditure with the knowledge of how productive its investment would be, presumably using more information than we have. A given level of government expenditure in education might yield higher achievements in a state where the educational technology is better or the overall ability of children is higher. However, we cannot distinguish between these two explanations. As a way to account for state-level unobservable characteristics, based on which governments make decisions, we allow for differences in educational productivity (η_s).[10]

[8]We have estimated an expanded version of (2.3) that includes state average income. Since this does little to improve the fit, we chose the simpler specification.

[9]Private K-12 schools differ observably in their tuition levels across states.

[10]Consider adding unobserved ability (a) to the model, such that the distribution of household characteristics in state s is given by $F_s(x,a) = F_s(a \mid x) F_s(x)$. Assume that the distribution of a conditional on (x, η_s) is common across states, i.e., $F_s(a \mid x) = F_0(a \mid x, \eta_s)$. Then η_s can reflect differences in $F_s(a \mid x)$ across states; moreover, the difference across s arises from differences in $F_s(x)$, z_s and η_s, rather than household-level a.

Another concern is that abstracting from household unobserved ability may bias our estimated effect of private schools on achievement, if households sort into private schools based on unobserved ability. Previous studies on this issue have found little evidence of such selection (e.g., Evans and Schwab (1995), Neal (1997), Rouse (1998) and Altonji et al. (2005)). To gauge the selection problem in our data, we have also estimated a set of regressions of various measures of educational attainment on observables, comparing OLS and IV specifications.[11] Consistent with previous studies, this comparison using our data fails to suggest that households attending private schools have higher unobserved ability.[12]

2.2. **Household Problem.** Given government policy ψ, the problem for households with children can be solved backwards.[13]

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 college debt d. The terminal value function includes an interaction between x and d so that the cost of debt differs across households, to allow for the possibility that different households may face different borrowing constraints or other frictions. A household's problem at the college stage is

$$
\begin{aligned}
V_2(x, k_1, \epsilon_2; \psi, z, \eta) &= \theta(x, z)\ln(g) + \max_{o_2, d \geq 0}\left\{\ln(c_2) + \lambda_2(o_2, x) + \delta\mathbb{E}v\left(x, k_1, \tilde{k}_2(o_2), d\right) + \sigma_2\epsilon_2(o_2)\right\} \\
\text{s.t. } y(\tau, \tau_0, x_1) + d &= c_2 + C(o_2) - A(C(o_2), x, k_1), \\
C(o_2) &= \underline{t}\mathbb{I}(o_2 = 1) + t\mathbb{I}(o_2 = 2) + p_2\mathbb{I}(o_2 = 3), \\
d &= 0 \text{ if } o_2 = 0,
\end{aligned}
$$

[11]Details are in the online appendix.

[12]Since the distribution of private schools may vary with urbanicity levels, we have explored the role of urbanicity in the same set of achievement regressions. Controlling for household characteristics (x in our model), the coefficient of private school attendance is unaffected by the inclusion of the urbanicity variable.

[13]To ease notation, we present the model as if the length of each decision stage (K-12, college) is 1 period; in the empirical application, we explicitly account for the fact that the number of periods vary between K-12 and college stages and between 2-year and 4-year colleges. Details are in Appendix A.1.

Households derive utility from consumption, other government expenditure (g) and college enrollment (depending on college type). Households with different characteristics may value public goods and colleges differently (relative to consumption), hence θ and λ_2 are allowed to vary with x.[14] The expectation of $v(\cdot)$ is taken with respect to the random variable $\tilde{k}_2$, which is defined by (2.2); δ is the annual discount factor. Each choice o_2 is associated with an i.i.d. payoff shock $\epsilon_2(o_2)$, drawn from the standard Type-I extreme value distribution, scaled by the parameter σ_2. The first constraint is the household's budget, where $C(\cdot) - A(\cdot)$ is the net cost of college, and $y(\tau, \tau_0, x_1)$ is after-tax income, given the state tax schedule τ and federal tax schedule τ_0:

$$y(\tau, \tau_0, x_1) = x_1 (1 - \tau(x_1) - \tau_0(x_1))$$

The constraint on d means that loans are 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

$$\begin{aligned} V_1(x, \epsilon_1; \psi, z, \eta) &= \theta(x, z) \ln(g) + \max_{o_1 \in \{0,1\}} \left\{ \ln(c_1) + \lambda_1(o_1, x) + \delta \mathbb{E} V_2\left(x, \tilde{k}_1(o_1), \tilde{\epsilon}_2; \psi, z, \eta\right) + \sigma_1 \epsilon_1(o_1) \right\} \\ \text{s.t.} \quad & c_1 + p_1 o_1 = y(\tau, \tau_0, x_1) \\ & \tilde{k}_1(o_1) \text{ follows } (2.1) \end{aligned}$$

where the term $\lambda_1(o_1, x)$ allows the preference for private relative to public schools to depend on x. Each choice is associated with an i.i.d. payoff shock $\epsilon_1(o_1)$, drawn from the standard Type-I extreme value distribution, scaled by the parameter σ_1. The expectation of $V_2(\cdot)$ is taken with respect to $\left(\tilde{k}_1, \tilde{\epsilon}_2\right)$. Denote the optimal choice as $o_1^*(x, \epsilon_1; \psi, z, \eta)$.

[14] Note that although we have rich micro-data on household choices, these choices are not affected by g, because household preferences are assumed to be additively separable. As will be explained below, we can nevertheless identify this aspect of household preferences indirectly, using information on choices made by governments in different states on behalf of their constituent households. Since we have data for only a relatively small number of governments, we cannot hope to obtain useful estimates of preferences for g unless we restrict the specification of these preferences so that it involves few unknown parameters.

2.2.3. *Households without Children.* Households without children make no decisions in this model. The value function is given by

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

2.2.4. *Aggregate Choices and Outcomes.* Given government policy, enrollments in public K-12 education (N_1), 2-year colleges (N_{21}), 4-year public colleges (N_{22}) and 4-year private colleges (N_{23}) are given by

$$N_1 = \sum_x F(x)\,q(x)\Pr\left(o_1^*(x,\tilde{\epsilon};\psi,z,\eta)=0\right), \tag{2.4}$$

$$N_{2j} = \sum_x F(x)\,q(x)\left[\sum_{o_1\in\{0,1\}}\Pr\left(o_1^*(\cdot)=o_1\right)\sum_{k'}\Pr\left(\tilde{k}_1=k' \mid x,o_1\right)\Pr\left(o_2^*\left(x,k',\tilde{\epsilon};\psi,z,\eta\right)=j\right)\right], j\in\{1,2,3\}$$

N_1 is the expected number of households who have children (with probability $q(x)$) and choose $o_1^*(\cdot)=0$ (the probability expression here refers to the probability that the realization of the random variable $\tilde{\epsilon}$ is such that public education is the optimal choice). To calculate N_{21}, we take the probability that the 2-year public college is optimal, given the high school outcome, and integrate over the possible high school outcomes and the K-12 choices (governed by (2.1)), and then aggregate over the distribution of household types. N_{22} and N_{23} are calculated in the same way, and we write $N_2=(N_{21},N_{22},N_{23})$. Similarly, the expected numbers of college graduates are given by

$$K_{21} = \sum_x F(x)\,q(x)\left[\sum_{o_1\in\{0,1\}}\Pr\left(o_1^*(\cdot)=o_1\right)\sum_{k'}\Pr\left(\tilde{k}_1=k' \mid x,o_1\right)\Pr\left(o_2^*(\cdot,k',\cdot)=1\right)\Pr\left(\tilde{k}_2=1 \mid k',o_2=1\right)\right] \tag{2.5}$$

$$K_{2j} = \sum_x F(x)\,q(x)\left[\sum_{o_1\in\{0,1\}}\Pr\left(o_1^*(\cdot)=o_1\right)\sum_{k'}\Pr\left(\tilde{k}_1=k' \mid x,o_1\right)\Pr\left(o_2^*(\cdot,k',\cdot)=j\right)\Pr\left(\tilde{k}_2=2 \mid k',o_2=j\right)\right], j\in\{2,3\}$$

where $\tilde{k}_2=1,2$ denotes a 2-year and a 4-year degree, respectively, and we write $K_2=(K_{21},K_{22},K_{23})$.

2.3. **Government Problem.** A government cares about a weighted average of household expected welfare and may also directly care about aggregate educational attainment. Household expected welfare is calculated before the fertility outcome is realized, and is given by[15]

$$V(x;\psi,z,\eta) \;=\; q(x)\,EV_1(x,\epsilon_1;\psi,z,\eta) + (1-q(x))\,V^0(x;\psi) \tag{2.6}$$

Let Ψ be the finite set of policy options,[16] including the zero tuition option. The government solves the following problem

$$\pi(F,z,\eta,\varepsilon) = \max_{\psi\in\Psi}\left\{\sum_x \omega_x F(x)\,V(x;\psi,z,\eta) + W(N_2,K_2) + \varepsilon(\psi)\right\} \tag{2.7}$$
$$\text{s.t. } z_1 + \sum_x F(x)\,\mathcal{T}(x_1) + N_{21}\underline{t} + N_{22}t = e_1 N_1 + e_2(\varphi N_{21} + N_{22}) + g,$$

where $\mathcal{T}(x_1) = \tau(x_1)\,x_1$ is tax revenue and where aggregate enrollments and college outcomes are determined by (2.4) and (2.5). Here ω_x is the welfare weight given to households with characteristics x, which is applied to the average welfare of households with and without children. The government's direct preference for aggregate educational outcomes is captured by $W(\cdot)$. Finally, $\varepsilon(\psi)$ is a random shock associated with choosing policy vector ψ; this is drawn from a generalized extreme value distribution detailed in Appendix A.5. The government faces a budget constraint, where revenue includes state income tax and tuition revenues that depend on government choices, as well as non-tax revenue z_1, which is taken as given. Government revenue is used to fund public K-12 and college education, as well as other public goods (g).[17] A government's optimal choice is denoted by $\psi^*(F,z,\eta,\varepsilon)$.

Focusing on state governments' choices, we model the state tax schedule τ as an equilibrium object while taking the observed federal tax schedule τ_0 as given. For state tax schedules, we follow the tradition in the public finance literature (e.g., Feldstein (1969)),[18]

[15] Notice that public education provides an option value to all households in expectation, regardless of whether they use it ex post.

[16] See Appendix A.5 for details of these options.

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

[18] See Heathcote et al. (2017) for a recent example .

and model the state tax rate faced by a household with income x_1 as

$$\tau(x_1) = 1 - \tau^a x_1^{-\tau^b}, \tag{2.8}$$

which is governed by two policy parameters τ^a and τ^b. This state tax schedule is progressive if $\tau^b > 0$, regressive if $\tau^b < 0$, and flat with a rate of $1 - \tau^a$ if $\tau^b = 0$.[19]

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 ω_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.**

Definition. An equilibrium is a set of choice functions $\{o_1^*(\cdot), o_2^*(\cdot), d^*(\cdot), \psi^*(\cdot)\}$ 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), and $o_2^*(x, k_1, \epsilon_2; \psi, z, \eta)$ 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 $(F, z, \eta, \varepsilon)$, $\psi^*(F, z, \eta, \varepsilon)$ solves the government problem (2.7).

2.5. **Discussion.** Some aspects of the model warrant further discussion. First, we treat each state in isolation. 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.[20] We thereby avoid having to model strategic interactions among state governments. We model each state government as a Stackelberg leader, which sets state policies to maximize its own objective accounting for equilibrium responses from households in the state. Were we to consider migration (or other cross-state spillovers), we would have to model strategic

[19] In our implementation, we model a state's choices of $\tau(x_1)$ for middle-income households and τ^b, which is equivalent to specifying (τ^a, τ^b).

[20] Thus our counterfactual policy impacts are best interpreted as short-run impacts. Kennan (2020) analyzes higher education policies in an individual decision model that allows for interstate migration, but with no consideration of the main focus of this paper, i.e., the government choices and the interaction between higher education and K-12 education.

interactions among state governments. Estimation of such an equilibrium model is a very challenging problem.[21]

Second, we view government decisions as being static, thereby abstracting from complications such as time consistency and government commitment issues in dynamic policy-making settings.[22] Similarly, our model does not consider the impact of policy choices on labor market equilibrium in the long run. One setting in which labor market equilibrium could be considered would be overlapping-generations models. Examples related to our study include Abbott et al. (2019) and Becker et al. (2018). Complementary to these papers, we adopt a different approach and focus on government choices instead.

Third, 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.[23] We make this choice for both tractability and data reasons.[24] 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.

Fourth, we model household educational investments as a set of 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 such choices in the model would make the predictions in our counterfactual policy analysis more precise, but it would require much richer data.

[21]For example, multiple equilibria may exist in such a setting. In our current model without cross-state interactions, the Stackelberg leader game in each state has a unique equilibrium.

[22]In particular, we do not explicitly consider the possibility that governments may borrow against the future. Instead, we count all other components of the government budget, including non-education expenditure and possibly a debt component, in “other expenditure” (g).

[23]However, we do allow for the possibility that state expenditure may be differentially productive for different households within the same state, which is captured via an interaction between expenditure and household income levels in our educational production functions.

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

3. Estimation

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 estimated from data. Let $\widehat{\beta}(\Theta)$ denote the corresponding estimates of the auxiliary model parameters obtained using data generated by the model (parameterized by a particular vector Θ). 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 (which is described in Appendix A.7). We obtain standard errors for $\widehat{\Theta}$ by applying the delta method based on the variance matrix of $\overline{\beta}$ with $\frac{\partial \widehat{\Theta}}{\partial \beta}$ computed numerically.

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, the observed distribution of household choices conditional on x identifies the relative value of each option for these households. The option-specific value depends on both the value households attach to educational outcomes and their direct tastes for enrollment in different types of schools. We rely on two assumptions that allow us to separate these two components: (A1) conditional on x and region, the distribution of household preferences is common across states,[25] (A2) there are no unobserved ability differences across

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

households.[26] Given A2, the expected achievement gap between private and public schools for given x within each state is observed. Given A1, for households 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 choices to tuition levels, given that utility is measured as the log of household consumption.

Identification of the education production technology needs to deal with 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 allow η_s to be correlated with a state's income and (parental) education distribution, but exclude state racial composition and the government's non-tax revenue from the η_s distribution.[27] 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, we must identify the government objective function, and household preferences for g. For $W(.)$, we assume that the government cares about the total college enrollment rate $\left(N_2 = \sum_j N_{2j}\right)$ and the total fractions of 2-year graduates (K_{21}) and 4-year graduates $(K_{22} + K_{23})$. Let ψ_{-g} be the policy vector excluding g. Rewrite the deterministic part of the government objective (2.7) as

$$\max_{\psi_{-g}} \left\{ \sum_x \omega_x F(x) \left(\widetilde{V}(x; \psi_{-g}, z, \eta) + \theta(x, z) \ln(g) \right) + \gamma_1 N_2 + \gamma_2 K_{21} + \gamma_3 (K_{22} + K_{23}) \right\} \tag{3.1}$$

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

[27]By controlling for income and education composition in a state, we seek to minimize the potential impact of a violation of our exclusion restriction assumption, which is untestable given that η_s is unobserved. As we will show in Section 5, our estimated effect of expenditure on educational outcomes is reasonable.

with the understanding that g is determined from the government budget constraint. Notice that $\widetilde{V}$ is the part of a household's utility that varies with its choice and hence this is identified from household choices; the household's utility from g does not vary with its choice and hence preferences with respect to g must be identified from government choices.

Given the parameters governing household preferences and education technologies, including the unobserved productivity distribution, everything in (3.1) is a known function of ψ, except for the parameters $\omega_x, \theta(x,z), \gamma_1, \gamma_2, \gamma_3$. Since each feasible choice for the government maps into an equilibrium that determines the value of the government's objective function, the identification of these parameters follows a standard revealed preference argument. In particular, the estimated parameters have to explain the correlation between government choices and state-level characteristics, including non-tax revenue and the state-specific household distribution $F_s(x)$, with the unexplained part attributed to the random policy choice shocks $\varepsilon(\psi)$. However (as was pointed out in footnote 14), with one state being an observation, data limitations restrict the flexibility in our specification. For this reason, we have assumed that ω_x varies only with income, instead of all dimensions of x, while $\theta(x,z)$ varies only with income and the federal transfer component of non-tax revenue (as specified in Appendix A.4).

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 the 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 and household characteristics (z, x). We also use pairs of siblings at different stages of K-12 (primary and high school) in ACS to get private high school attendance rates conditional on primary school choices.

Our sample from CP consists of households including 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 schedule $\tau_0(x_1)$ and to infer tax policy variables chosen by each state in the observed equilibrium, including the state-specific tax rate for middle-income households and state-specific progressivity τ^b.

From NCES, we obtain information on private college tuition, state-specific public college tuition and region-specific private K-12 tuition.[28] Data counterparts are still needed for

[28]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.

state-specific non-tax revenue z_1, K-12 expenditure e_1, and college expenditure e_2; these we obtain from CG, using the combined budgets of state and local governments of the 48 contiguous U.S. states. The online 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, demographic group, and whether or not any adult in the household went to college.[29] State observables z include state non-tax revenue (z_1) and a dummy for the Northeast Census Region. We consider the discrete probability distribution over households' education choices and outcomes, as well as the amount of college loans. Government choices ψ_s to be matched include 6 variables: $\tau(x_1)$ for middle-income households; tax progressivity parameter τ^b; 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-student 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.

[29]Income in the ELS is recorded in 13 categories. We define our income groups by collapsing these categories so that each group corresponds approximately to one quintile of the national income distribution. The resulting group cutoff levels are \$20,000, \$35,000, \$50,000 and \$75,000. Within each income group, household income is approximated by the within-group median. We divide households into two demographic groups, one including Whites and Asians, the other including Blacks and Hispanics and all others. For convenience, we refer to the second group as the "minority" group.

(c) For college choice, we use a multinomial logit regression with the latent utility being

$$\begin{cases} u_{0is} = \epsilon_{0is} \\ u_{jis} = \alpha_0 w_{jis} + x'_{is}\alpha_{1j} + \epsilon_{jis} \quad j = 1, 2, 3 \end{cases}$$

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-student college expenditure and a Northeast state dummy.[30]

(d) We map the five K-12 outcome categories to numerical scores, assigning the median score in each outcome group as the test score for all students in that group.[31] We treat these scores as the dependent variable in an OLS regression, where w_{is} is log per-student 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-student college expenditure.

(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, and the fraction of each fixed effect above its mean. We also include the following targets:

[30]We use the derivatives of the log likelihood as targets instead of the coefficient vector to reduce computational time. In particular, let $p_j\left(x, w; \hat{\phi}\right)$ 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 $d_{jis} - p_j\left(x_{is}, w_{is}; \hat{\phi}\right)$ 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.

[31]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.

(a) OLS regression coefficients of each of the two fixed effects on log per-student expenditure and the fraction of college-educated adults, controlling for log average income.

(b) IV variants of the regressions above ($2(a)$), in which log per-student expenditure is replaced by its predicted value from the regression described in (3) below. We target coefficients associated with the predicted log expenditure.

(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) non-tax revenue z_1, 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 private colleges), 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% from the lowest 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 the marginal distribution of household characteristics across states. We calculate, for each state, the fraction of households with each characteristic and report the mean and standard deviation of these fractions across states. For example, states vary in the fractions of households belonging to the lowest income group: the average fraction is 17.9%, with a standard deviation of 4.4%. The most noticeable difference across states is in the fraction of minority households.

Table 3 summarizes state government policies. The greatest disparity across states is in college tuition levels, per-student expenditure on college education and tax progressivity.

TABLE 1. **Household Choices**

%	HS Private	College Enrollment Public 2-year	Public 4-year	Private 4-year	HS Score >median	College $\frac{Graduates}{Enrollment}$ 2-year	4-year	Observations (ELS)
All	7.5	27.6	31.2	24.4	47.3	43.7	61.9	15,058
Non-College Parents	2.8	34.9	22.1	14.5	28.3	47.5	49.2	3,918
Minority	3.9	34.7	24.5	20.5	26.2	41.8	47.2	5,000
Income Quintile 1	2.4	36.3	20.1	15.6	23.5	40.7	46.1	2,211
Income Quintile 2	3.4	33.4	25.6	17.9	32.4	43.3	49.6	2,692
Income Quintile 3	5.1	29.7	30.6	20.1	43.8	45.3	56.3	2,831
Income Quintile 4	7.3	27.4	35.1	24.3	53.5	42.9	62.1	3,080
Income Quintile 5	15.6	17.9	38.2	36.5	69.7	46.2	72.4	4,244

The counts in the last column refer to ELS respondents in the 48 contiguous U.S. states.

TABLE 2. **Summary of State-Specific Composition of Households**

%	Income Quintiles 1(low)	2	3	4	5(high)	Minority	College
Mean	17.9	18.7	17.5	22.3	23.6	20.2	56.3
Std dev.	4.4	2.5	1.5	1.9	6.4	12.5	6.1

Statistics for the 48 contiguous U.S. states. "Minority" : not white or Asian. "College" : at least one adult in the household has some college education.

TABLE 3. **Government Policies**

	Mean	**Std Dev**	**Regression Coefficients** log Income Mean	Std	Household Fractions College	Minority	Non-tax Rev. (log)	Northeast
Expenditure ($1,000/Enrollment)								
K-12	7.50	1.46	1.28	0.06	-0.81	-0.16	0.34	0.22
College	15.78	2.45	0.91	-2.29	-1.02	0.20	0.22	0.09
Tuition ($1,000/Year)								
2-year	2.28	0.99	0.67	-12.69	-1.16	-0.49	-0.33	0.99
4-year	4.14	1.29	3.78	-20.97	-6.90	0.77	0.53	1.85
Tax rate (%, middle income)	9.88	0.89	-0.46	6.57	-0.60	-2.34	0.49	0.02
Tax progressivity τ^b ($\times 100$)	1.31	0.76	-0.91	-2.53	0.63	0.37	0.56	0.24

K-12 and college expenditures are log-transformed in computing regression coefficients.

The rightmost columns show coefficients from regressions of each policy variable on the 6 state-level characteristics (Auxiliary Model 3). For example, controlling for the other characteristics, per-student K-12 and college expenditures are positively correlated with average household income and a state's non-tax revenue and negatively correlated with the fraction of college-educated households.

5. Estimation Results

5.1. **Parameter Estimates.** We present estimates of selected parameters in Table 4 (with more detail in Appendix C); 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 notable observations. First, all else equal, the effect of government educational expenditure is slightly stronger for higher income groups at both K-12 and 4-year college levels. Our estimates imply that the marginal effect of a 10% increase in e_2 (evaluated at the average graduation rate of 61.9%) is approximately a 3 percentage point increase in the 4-year graduation rate, which is comparable to the effect implied by the estimates in Deming and Walters (2018). For 2-year college outcomes, the public expenditure is negligible for the higher income group. Second, high school test scores contribute positively to four-year college graduation probabilities.[32]

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 negatively correlated with its K-12 productivity. The two productivity levels are not significantly correlated. Given these estimates, we report the support of the productivity distribution (the mean is normalized to zero), and the joint distribution $\Pr(\eta_{s1}, \eta_{s2})$; we find that 18% of states have low productivity at both K-12 and college levels, and 28% have high productivity at both levels.

Panel D reports parameter estimates of the government's objective function. The welfare weights are strongly tilted toward high-income households, which would mean that the government cares more about such households. But household utilities are concave in consumption, which increases the sensitivity of the government's objective with respect to the welfare of low-income households. Together with other factors, these two opposite forces jointly determine the relative importance of various income groups in the government's optimization problem. The last three columns in Panel D show that the government directly

[32] The high school outcome is ordinal, but to save on parameters, we assign numerical values to the outcome based on test score percentiles, and we assume that the latent logit functions are quadratic in these values.

TABLE 4. **Selected Parameter Estimates**

A. High School Achievement (Ordered Logit)*					
	Gov Expenditure $(\ln(e_1))$		Private tuition	Public HS	
	Low Income	High Income			
HS k_1	0.42 (0.14)	0.68 (0.13)	0.04 (0.03)	-2.02 (0.25)	
B. College Graduation (Logit)*					
	Gov Expenditure $(\ln(e_2))$		HS score	$(\text{HS score})^2$	Private HS
	Low Income	High Income			
2-year college	0.30 (0.05)	0.09(0.07)	-1.22(0.55)	0.52 (0.53)	0.14 (0.13)
4-year public	1.15 (0.10)	1.23 (0.10)	1.42 (0.79)	0.92 (0.78)	0.12 (0.10)
4-year private	-	-	3.22 (0.79)	-0.48 (0.71)	0.47 (0.11)
C. Educational Productivity Distribution Parameters					
	Constant	F(college HH)	ρ_2		std σ_η
K-12 η_{s1}	0.21 (0.69)	-5.54 (4.71)	-		0.21 (0.03)
College η_{s2}	0.21 (0.19)	7.50 (4.18)	-0.19(1.57)		0.64 (0.10)
	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	$\underline{\eta}_1$ =-0.23	$\overline{\eta}_1$ =0.19	$\underline{\eta}_2$	0.18	0.27
College	$\underline{\eta}_2$ =-0.71	$\overline{\eta}_2$ =0.58	$\overline{\eta}_2$	0.27	0.28
D. Government Objective Function					
	Welfare Weights ω		Aggregate Education Outcome		
Low Income	Middle Income	High Income	Col. Enrollment	2-year Grads	4-year Grads
0.32 (0.11)	1.0 (normalized)	1.86 (0.42)	1.00 (0.23)	3.90 (0.41)	3.68 (0.30)

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 Table 11 in Appendix C.

cares about aggregate education outcomes, which is necessary to rationalize the observed government policies.

5.2. **Model Fit.** Model fit results are shown in Tables 5 and 6. Table 5 shows results for household choices and outcomes. The first two columns of Table 6 show the fit for the mean and standard deviation of each of the government policy variables, while the other columns show the fit of auxiliary regression models, which summarize the correlation between the state policy choices and the observed state characteristics. 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 5. **Model Fit:** Household Choices and Outcomes

%		Enrollment Choices: Priv HS	2yr col	4yr pub	4yr Pri	Education Outcomes: 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	27.9	31.1	23.7	47.3	43.2	61.5	61.9
Low Edu	Data	2.8	34.9	22.1	14.5	28.3	47.5	53.0	43.3
	Model	3.3*	35.2	22.6	14.3	28.1	46.6	46.5*	48.3
Minority	Data	3.9	34.7	24.5	20.5	26.2	41.8	51.6	41.9
	Model	4.4*	34.4	24.5	20.3	27.5	39.9	52.1	41.5
Low Inc	Data	3.0	34.6	23.2	16.9	28.5	42.1	52.4	42.5
	Model	4.1*	33.8	24.0	17.0	29.1	40.7	52.9	42.8
High Inc	Data	11.9	22.1	36.8	31.1	62.5	44.4	66.1	71.2
	Model	10.2*	23.3	35.9	30.0	63.0	44.4	66.3	72.1

*Predictions that are the 95% confidence interval for the corresponding statistic in the data.
Low Income refers to the first two income quintiles; High Income refers to the top two quintiles.
Low education means that no adult in the household went to college.

TABLE 6. **Model Fit:** Government Policies

		Mean	Std dev	Regression Coefficients: Income (log) Mean	Income (log) Std dev	Household fractions college	Household fractions minority	Non-tax Rev. (log)	Northeast
K-12 expenditure	Data	7.50	1.46	1.28	0.06	-0.81	-0.16	0.34	0.22
($1,000/Enrollment)	Model	7.49	1.14	1.41	-0.47	-0.15*	-0.01	0.03*	-0.03*
College expenditure	Data	15.78	2.45	0.91	-2.29	-1.02	0.20	0.22	0.09
($1,000/Enrollment)	Model	15.74	1.69*	0.89	-0.52	0.05*	0.13	0.02*	-0.06*
2-year tuition	Data	2.28	0.99	0.67	-12.69	-1.16	-0.49	-0.33	0.99
($1,000/Year)	Model	2.27	1.15	0.99	-11.30	1.61	-0.20	-0.11	0.34
4-year tuition	Data	4.14	1.29	3.78	-20.97	-6.90	0.77	0.53	1.85
($1,000/Year)	Model	4.23	1.37	2.35	-9.41	-4.67	1.85	-0.02	1.75
Tax rate	Data	9.88	0.89	-0.46	6.57	-0.60	-2.34	0.49	0.02
(%, middle income)	Model	9.74	1.12*	-3.51	3.93	-1.98	-2.52	-0.98*	0.21
Tax progressivity τ^b	Data	1.31	0.76	-0.91	-2.53	0.63	0.37	0.56	0.24
($\times 100$)	Model	1.31	0.85	1.75	2.60	-1.05	-0.28	0.04	0.17

*Outside the 95% confidence interval.
K-12 and college expenditures are log-transformed in computing regression coefficients.

6. COUNTERFACTUAL EXPERIMENTS

We use the estimated model to evaluate equilibrium impacts of free public college policies, implemented in two different ways.[33] In the first set of experiments, free public college policies are mandatory; in the second, the federal government offers subsidies to induce state

[33]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.

governments to charge zero college tuition. Notice that our estimated government preference parameters indicate that a state government's objective differs from that of a benevolent social planner. As such, the equity-efficiency implication is theoretically ambiguous when state governments' choices are distorted, for example, by a free-college mandate. We study these implications empirically in the following counterfactual policy simulations.

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 7 shows the policy impacts. The state government decreases per-student expenditure at both levels of education, and increases tax levels while reducing tax progressivity. When 2-year tuition is zero, in many cases the state government re-optimizes by reducing 4-year college tuition, which helps to reduce enrollment shifts from 4-year public colleges to free 2-year colleges. Overall, government and household reactions to the counterfactual policy are stronger at the college stage than at the K-12 stage, which seems reasonable.

Panel B of Table 7 shows the impact on the college enrollment rate, the graduation rate, and the fraction of all students with a college degree.[34] 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.[35] The proportion of graduates (unconditional on enrollment) increases, although the large increase in enrollments is offset to a substantial extent by a decrease in graduation rates.

The government objective (2.7) includes a direct preference $W(\cdot)$ over aggregate education outcomes, which may capture factors such as political concerns of the government and educational externalities. We do not attempt to gauge the relative importance of such factors. Instead, we present our welfare analysis using two measures of welfare based on two

[34]The baseline data here are not conditional on high school graduation, and for this reason they are not quite the same as the corresponding numbers in Table 5.

[35]Here private college tuition is fixed at its baseline level. In Appendix B, we allow private tuition to adjust to maintain the baseline enrollment level. The results are similar.

TABLE 7. **Free Public Colleges (Mandatory)**

A. Government Policy (Mean)

	Per student e (\$1,000) K12	College	State Tax (MidInc) (%)	$\tau^b(\times 100)$	Tuition (\$1,000) 2year	4year
Baseline	7.49	15.74	9.74	1.34	2.27	4.23
Free 2-year	7.47	15.48	9.80	1.33	0	4.03
Free 2&4-year	7.39	14.45	10.42	1.22	0	0

B. College Enrollment and Graduation

%	Enrollment None	2year	4year pub	4yr pri	$\frac{Graduates}{Enrollment}$ 2year	4year pub	Graduates 2year	4year (pub+pri)
Baseline	21.2	26.6	29.7	22.6	43.2	61.5	11.5	32.3
Free 2-year	20.6	28.0	29.3	22.1	42.6	61.3	11.9	31.7
Free 2&4-year	16.7	22.7	43.3	17.3	43.6	56.7	9.9	35.5

C. Welfare

		Winners	Welfare Changes All	Income Group 1 (low)	2	3	4	5 (high)
V only	Free 2-year	19.4%	-0.34	0.29	-0.18	-0.26	-0.48	-0.78
	Free 2 and 4-year	17.5%	-6.40	-2.96	-5.58	-6.00	-7.93	-8.50
V and W	Free 2-year	30.1%	-0.08	0.50	0.04	-0.02	-0.20	-0.49
	Free 2 and 4-year	31.4%	-2.59	0.21	-2.24	-2.34	-3.75	-4.09

D. Welfare Changes

	All	Income Group 1 (low)	2	3	4	5 (high)
Free 2 and 4-year (V)	-6.40	-2.96	-5.58	-6.00	-7.93	-8.50
tuition	6.02	10.83	6.57	5.30	4.80	3.54
education expenditure	-1.43	-0.43	-0.44	-0.47	-2.71	-2.52
tax	-9.45	-10.11	-9.63	-9.28	-8.96	-9.14
public expenditure (g)	-1.54	-3.25	-2.08	-1.54	-1.06	-0.38

different interpretations of $W(\cdot)$. The first measure reflects only household preferences, represented by the ex ante value $V(\cdot)$, defined in equation (2.6), with $W(\cdot)$ interpreted purely as the government's political value. Alternatively, we use a second welfare measure that views $W(\cdot)$ as capturing a positive externality where having more college-educated workers would benefit the entire cohort, each of whom would get an additional value of $W(\cdot)$.[36] Our overall findings, as shown below, are similar for these two measures.

[36] The second welfare measure is $V(\cdot) + q(x)W(\cdot)$. That is, ex post, all households with children enjoy the same W from having more college educated workers in their child's cohort; ex ante, every household benefits from W.

Panel C of Table 7 shows the fraction of households whose welfare is improved and also the average changes in welfare, according to either of the two welfare measures.[37] 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. For example, when all public colleges are free, based on the V-only measure, the fraction of winners is 18%; based on the broader measure, this fraction is 31%. By either measure, average welfare decreases.[38]

Panel D provides details regarding the sources of these results, by showing the breakdown of the welfare changes resulting from the separate components of the governments' policy responses.[39] In the naive free-tuition case, average welfare increases for all households, and the gain is larger for lower-income households. It is true that the poorest households are more likely to receive financial aid,[40] but even so, their marginal utility of consumption is relatively high and they are more likely to respond to the cost of college. The welfare effects of expenditure changes are relatively minor on average but heterogeneous: the effect of educational expenditures is larger for higher-income groups and that of other public spending is larger for lower-income groups. The fourth row of Panel D shows the average welfare changes resulting from the change in tax rates, where losses are similar across income groups.

[37]The welfare numbers in this and later tables are scaled up by a factor of 100.

[38]Welfare losses are smaller under the second measure because free-college policies increase aggregate education achievement.

[39]We start from the naive "free" scenario where tuition is zero but all other state government policies are fixed at their baseline levels, then, we adjust education expenditure to its level in the new equilibrium, while keeping tuition at zero, then we adjust tax rates, and finally other public expenditure. In each step, the previous adjustments are maintained, and households respond optimally, and the last step brings us to the full new equilibrium, shown in row 1. We show results for the case where both 2-year and 4-year colleges are free, based on the V measure. The decomposition for other cases gives similar results. Moreover, the order in which the policy variables are changed makes virtually no difference.

[40]Financial aid can exceed tuition for some students, and it does not go to zero when tuition is zero.

6.2. **Free Public Colleges (Subsidized).** In this experiment, states that set tuition to zero in all public colleges qualify for a federal subsidy.[41] The free college policy is not mandated, although it is funded by a mandatory federal tax surcharge, which is levied on households in all states. Complying states obtain, for each enrolled student in the new equilibrium, a subsidy that is a fraction r of its original tuition level. To balance the federal budget, the surcharge rate κ is such that the increased federal tax revenue $\mathcal{K}(\kappa)$ equals the total tuition subsidy $\mathcal{S}(\kappa, r)$ from the federal government to the states. The surcharge revenue is given by[42]

$$\mathcal{K}(\kappa) = \kappa \sum_{s} \sum_{x_1} \mathcal{N}_s(x_1) \max(\tau_0(x_1) x_1, 0)$$

where $\mathcal{N}_s(x_1)$ is the number of households in income group x_1 in state s (that is, the number of such households in our Census of Population sample, as described in Section 4).

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

$$\tilde{\pi}_s(\kappa, r) = \max\{\pi_s(\kappa), \pi'_s(\kappa, r)\}$$

A state chooses between not complying with value $\pi_s(\kappa)$ and complying with value $\pi'_s(\kappa, r)$. Here $\pi_s(\kappa)$ is the optimal value from a modified version of (2.7), reflecting the effects of the surcharge on household value functions and optimal choices, and the implications of these choices for aggregate enrollments and college outcomes, as determined by (2.4) and (2.5). The value of complying is given by

$$\begin{aligned} \pi'_s(\kappa, r) &= \max_{\psi^c \in \Psi^c} \left\{ \sum_x \omega_x F_s(x) V_\kappa(x; \psi^c, z_s, \eta_s) + W(N_{s2}, K_{s2}) + \varepsilon_s(\psi) \right\} \qquad (6.1) \\ \text{s.t.} \quad z_{s1} &+ \sum_x F_s(x) \mathcal{T}_s(x_1) + r(N_{s21} \underline{t}_s^* + N_{s22} t_s^*) = e_{s1} N_{s1} + e_{s2}(\varphi N_{s21} + N_{s22}) + g_s \end{aligned}$$

[41] Such a voluntary cost-sharing policy is similar in spirit to many other policies (e.g., the expansion of Medicaid).

[42] No surcharge is applied if the federal tax is negative in the baseline (which is the case for the lowest income group). Thus for a household with income x_1, the surcharge is $\kappa \max(\tau_0(x_1) x_1, 0)$.

where V_κ is the household value function as described in Section 2.2 given that income $y(\tau, \tau_0, x_1)$ is reduced by the amount of the tax surcharge. Aggregate enrollments and college outcomes are again determined by (2.4) and (2.5), given optimal household choices at the new after-tax income and tuition and educational expenditure levels, and $\underline{t}_s^*$ and t_s^* are the original optimal tuition choices associated with (2.7) in the baseline. Compared with (2.7), (6.1) requires that the government policy be chosen from the constrained choice set Ψ^c with $\underline{t} = t = 0$; in return, the state receives a subsidy of $r(\underline{t}_s^* N_{s21} + t_s^* N_{s22})$.

The total federal subsidy can be written as

$$\mathcal{S}(\kappa, r) = r \sum_s \mathcal{N}_s \mathbb{E}_{\eta_s, \varepsilon_s} [\mathbb{I}(\pi_s(\kappa) < \pi_s'(\kappa, r))(N_{s21}\underline{t}_s^* + N_{s22}t_s^*)]$$

where $\mathcal{N}_s$ is the total number of households in state s, and the expectation is taken over the distribution of a state's unobserved education productivity η_s and policy shocks ε_s. This 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 the new equilibrium in these states. State governments' and households' decisions in turn depend on the subsidy rate and the federal tax surcharge. At different subsidy rates r, we calculate the compliance rates and changes in outcomes and welfare, solving for κ to satisfy the constraint $\mathcal{S}(\kappa, r) = \mathcal{K}(\kappa)$. To illustrate, we show the equilibrium effects of subsidizing at rates of $r = 0.1$, 0.2, and 0.3.

TABLE 8. **Compliance Rate and State Characteristics**

	Compliance Rate (%)	State Characteristics by Complying Status under $r = 0.2$	Complying States (73.9%)	Non Complying States
$r = .1$	7.8	Low Inc Fraction	0.36	0.38
		High Inc Fraction	0.47	0.44
$r = .2$	73.9	Frac. High-Edu Parents	0.57	0.55
		Pr $(\eta_{s1} = \overline{\eta}_1)$	0.55	0.56
$r = .3$	98.4	Pr $(\eta_{s2} = \overline{\eta}_2)$	0.58	0.47
		Non-tax Rev. z_1 ($1,000)	4.11	4.17

The first column of Table 8 shows the fraction of subsidy-taking states: at $r = 0.1$, about 8% of states would comply, while over 98% of states would comply at $r = 0.3$.[43] Using the case of $r = 0.2$ (with a compliance rate of 74%) as an example, a comparison of the last two columns in Table 8 shows how state-level characteristics differ between complying and non-complying states. Complying states appear to have slightly more high-income households and are more likely to have high unobserved productivity in college education.

Panel A of Table 9 shows the equilibrium outcomes across all states in the baseline, in each of the three subsidy cases, and in the mandatory policy case for comparison. Panel B of Table 9 shows the benefit and cost of each subsidy policy.[44] Using the alternative welfare measures discussed in Section 6.1, we report the fraction of winners among all households, and welfare changes for households overall and for those in complying and non-complying states separately. The fraction of winners increases with the subsidy rate but is always small: At the subsidy rate of 0.3, the fraction of winners among all households is 15% according to the narrower welfare measure, and 25% according to the broader measure. Recall that 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. As the federal tax surcharge is small, so is the average welfare loss for households in non-complying states. Using the narrower welfare measure, average welfare loss is larger in complying states than in non-complying states; using the broader welfare measure, average welfare loss in complying states is closer to that in non-complying states. The last two columns show the cost of subsidies in terms of dollars per household, and the federal tax surcharge. For example, to fund the subsidy with $r = 0.3$ requires a 1.41% surcharge, with the cost being $\$1,514$ per household.

[43] States are quite responsive to the federal cost-sharing policy in our counterfactuals. This arises partly from the fact that college tuition revenue is only a small fraction of a state's overall budget, and hence the distortion introduced by the subsidized free tuition policy is limited.

[44] Note that the subsidy policy provides not only a direct incentive for eliminating tuition fees but also, *relative to the mandatory free-tuition policy,* an indirect incentive for increasing enrollment (partly through higher per-student expenditure), because the subsidy amount depends on enrollment in the new equilibrium. In addition, the progressive federal tax surcharge induces a small transfer from high-income states to low-income states.

TABLE 9. **Free 2-year and 4-year Public Colleges (Subsidized)**

A. Policy & Outcomes

	Per student e ($1,000) K12	College	State Tax % (MidInc)	$\times 100$ τ^b	College Graduates % 2-year	4yr (pub+pri)
Baseline	7.49	15.74	9.74	1.34	11.5	32.3
Subsidy $r = .1$	7.49	15.71	9.82	1.33	11.4	32.6
Subsidy $r = .2$	7.43	15.07	10.25	1.23	10.4	34.9
Subsidy $r = .3$	7.42	14.89	10.34	1.19	9.9	35.8
Mandatory Free 2&4-year	7.39	14.45	10.42	1.22	9.9	35.5

B. Benefit & Cost

	Winners %	Welfare Change All	Complying	Non-Complying	Cost Subsidy $ per HH	κ %
B1. V only						
Subsidy $r = .1$	1.7	-0.42	-4.86	-0.05	40	0.04
Subsidy $r = .2$	13.0	-4.70	-6.05	-0.90	767	0.71
Subsidy $r = .3$	15.3	-6.69	-6.77	-1.73	1,514	1.41
Mandatory Free 2&4-year	17.5	-6.40	-6.40	-	-	-
B2. V and W						
Subsidy $r = .1$	2.9	-0.09	-0.60	-0.05	40	0.04
Subsidy $r = .2$	23.5	-1.52	-1.73	-0.92	767	0.71
Subsidy $r = .3$	24.8	-2.29	-2.30	-1.76	1,514	1.41
Mandatory Free 2&4-year	31.4	-2.59	-2.59	-	-	-

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 game in which the government chooses a policy to maximize its objective, 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 would have negative welfare effects for a large majority of households.

It should be noted that we have assumed away some potentially important frictions in deriving our policy implications. For example, we do not account for the possibility that households may over-estimate the (net) cost of college, nor do we consider the possibility that procedural barriers such as financial aid forms can discourage students from applying. A recent field experiment study by Dynarski et al. (2018) suggests that these frictions can be non-trivial for high-achieving low-income students.[45] As such, a free-college policy would serve to reduce these frictions in addition to reducing the financial cost.

In addition, our framework has some other important yet challenging extensions worth pursuing. The first is to allow for migration, with state governments responding optimally to each others' policy choices. This extension would help us better understand the ripple effects of policies implemented in some but not all states.[46] The second extension is to expand the model to better fit the U.S. educational system, where K-12 education is funded mainly via local property taxes. This extension would better address issues such as cross-district inequality within a state, which, however, 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.

[45]Earlier studies (e.g., Hoxby and Avery (2013)) find that even among well-prepared students, there are substantial gaps in college enrollment and the quality of college attended.
[46]For example, New York state recently launched the Excelsior Scholarship to make four-year colleges free for those with annual family income below $125,000.

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Appendix A. Empirical Specification Details

Household characteristics x consist of income x_1, with 5 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 now denoted by $o_1 = (o_{1L}, o_{1H})$, a pair of indicators referring to private 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

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

We set $\delta = 0.95$. The taste function for K-12 choice is specified as

$$\lambda_1\left(o_1, x\right) = o_{1L}\lambda_{1L} + o_{1H}\lambda_{1H} + \frac{1}{12}\left(8o_{1L} + 4o_{1H}\right)\left(\lambda_{1P}^1\left(x_1\right) + \lambda_{1P}^2 x_2 + \lambda_{1P}^3 x_3\right) + \lambda_{1S}\mathbb{I}\left(o_{1L} \neq o_{1H}\right),$$

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} represents the cost of switching between public and private schools when moving from primary to high school. The K-12 outcome k_1 is generated from an ordered logit model with latent outcome function

$$\begin{aligned} \ell_1\left(o_1, x, e_1, \eta_1, p_1\right) &= \mu_1^1\left(x_1\right) + \mu_1^2 x_2 + \mu_1^3 x_3 + \left(\frac{2}{3}o_{1L} + \frac{1}{3}o_{1H}\right)\mu_1^4 p_1 \\ &\quad + \left(\frac{2}{3}\left(1 - o_{1L}\right) + \frac{1}{3}\left(1 - o_{1H}\right)\right)\left(\mu_1^5 + \mu_1^6\left(x_1\right)\ln e_1 + \eta_1\right). \end{aligned}$$

The primary 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 in the college period as

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

For each college type o_2, we use the conditional mean of an estimated Tobit model as the aid function:[47]

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

The taste for college education is given by

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

where z_3 is an indicator for states in the Northeast region, to reflect the fact that this region has more private college options.

The (binary) college outcomes are generated by the following logit models:

$$\begin{aligned} \Pr\left(k_2=1\mid o_2=1\right) &= \mathbb{L}\left(\mu_{21}^{1}\left(x_1\right)+\mu_{21}^{2}x_2+\mu_{21}^{3}x_3+\mu_{21}^{4}\left(k_1\right)+\mu_{21}^{5}o_{1H}+\mu_{21}^{6}\left(x_1\right)\ln e_2+\eta_2\right) \\ \Pr\left(k_2=2\mid o_2=2\right) &= \mathbb{L}\left(\mu_{22}^{1}\left(x_1\right)+\mu_{22}^{2}x_2+\mu_{22}^{3}x_3+\mu_{22}^{4}\left(k_1\right)+\mu_{22}^{5}o_{1H}+\mu_{22}^{6}\left(x_1\right)\ln e_2+\mu_{22}^{7}\eta_2\right) \\ \Pr\left(k_2=2\mid o_2=3\right) &= \mathbb{L}\left(\mu_{23}^{1}\left(x_1\right)+\mu_{23}^{2}x_2+\mu_{23}^{3}x_3+\mu_{23}^{4}\left(k_1\right)+\mu_{23}^{5}o_{1H}\right) \end{aligned}$$

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

$$v\left(x,k_1,k_2,d\right)=f\left(d,x_1\right)+b_1\left(x_1\right)k_1+b_2\left(x_1\right)\mathbb{I}\left(k_2=1\right)+b_3\left(x_1\right)\mathbb{I}\left(k_2=2\right)$$

[47] Details of the Tobit model specification and the estimated coefficients are given in the online appendix.

where each of the $b_n(x_1)$ $(n = 1, 2, 3)$ parameters takes two values, for lower and higher income households respectively. The borrowing cost function is given by

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

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

$$R_{o_2} = \sum_{t=1}^{2} (1 + r)^{4-t+1} + \mathbb{I}(o_2 \in \{2, 3\}) \sum_{t=3}^{4} (1 + r)^{4-t+1}$$

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

$$\theta(x, z) = (\theta_0 + \theta_1 \ln(x_1)) \exp\left(\theta_2 \ln\left(z_1^f\right)\right).$$

The preference for g differs across income groups if $\theta_1 \neq 0$ (for example, low-income households are more likely to benefit from welfare programs). We also allow for a systematic correlation between the federal transfer component of non-tax revenue $\left(z_1^f\right)$ and the "preference" for g, because federal transfers may reflect a state's need to spend on public goods other than education. The exponential function is used to guarantee a positive preference for g given that $\ln z_1^f$ varies substantially across states. For ease of interpretation, instead of θ_0 we present $\theta(x, z)$ for the middle income households with $\ln z_1^f$ being the average across 48 states in Table 12 below, in addition to (θ_1, θ_2).

A.5. **Government Policies.** Letting $\tau(x_1 \mid x_1 = mid)$ denote the tax rate for the middle income group, the grid for state choices $\psi = \left[\tau(x_1 \mid x_1 = mid), \tau^b, e_1, e_2, \underline{t}, t\right]$ has $7 \times 5 \times 8 \times 8 \times 7 \times 8 = 125,440$ points. In each dimension of the policy choices, the grid points are assigned to provide good coverage of the empirical policy distribution, but the grid is wider than the support of the observed distribution to allow for the possibility that government choices may be outside the empirical range in counterfactual scenarios (see Section 1.2.1 in the online appendix).

We assume that the government policy shocks $\varepsilon(\psi)$ follow a generalized extreme value distribution with a nested logit structure. Let $\bar{V}(\psi)$ be the deterministic part of the government value function. Split the policy vector as $\psi = (\psi_1, \psi_2)$, where $\psi_1 = \left(\tau(x_1 \mid x_1 = mid), \tau^b\right)$ corresponds to the tax schedules and $\psi_2 = (e_1, e_2, \underline{t}, t)$ refers to the education-related choices. The probability of choosing the vector ψ is

$$P(\psi) = \frac{\exp\left(\frac{\bar{V}(\psi_1,\psi_2)}{\sigma^P \cdot \sigma^N}\right)}{\sum_t \exp\left(\frac{\bar{V}(\psi_1,t)}{\sigma^P \cdot \sigma^N}\right)} \frac{\left[\sum_t \exp\left(\frac{\bar{V}(\psi_1,t)}{\sigma^P \cdot \sigma^N}\right)\right]^{\sigma^N}}{\sum_s \left[\sum_t \exp\left(\frac{\bar{V}(s,t)}{\sigma^P \cdot \sigma^N}\right)\right]^{\sigma^N}}, \tag{A.1}$$

where $\sigma^P > 0$ is the scale parameter and $\sigma^N \in (0,1)$ is the nesting parameter. The model collapses to the standard multinomial logit model as $\sigma^N \to 1$.

Using the results from Cardell (1997) and Stephenson (2003), $\varepsilon(\psi)$ can be expressed as

$$\frac{\varepsilon(\psi)}{\sigma^P} = \sigma^N \varepsilon_0(\psi) + \varepsilon_1(\psi_1),$$

where $\varepsilon_0(\psi)$ follows a standard Type I extreme value distribution and $\varepsilon_1(\psi_1)$ follows a distribution parameterized by σ^N. In this expression, $\varepsilon_0(\psi)$ is specific to each possible policy choice ψ and i.i.d. across ψ, while $\varepsilon_1(\psi_1)$ is specific to each possible tax schedule ψ_1 and i.i.d. across ψ_1. Thus for each tax schedule ψ_1, $\varepsilon_1(\psi_1)$ takes on the same value across policy choices $\psi = (\psi_1, \psi_2)$ with different education-related choices ψ_2. Our estimate of σ^N (in Table 12 below) indicates that random shocks are far more important for explaining tax policies than for explaining education-related policies. We follow Stephenson (2003) to simulate random draws of $\varepsilon(\psi)$, which are kept the same throughout counterfactual simulations to ensure that each state faces the same shocks across different scenarios.

A.6. **Government Budget.** As in (2.7), a budget constraint of a local government is

$$z_1 + \sum_x F(x)\, \mathcal{T}(x_1) + N_{21}\underline{t} + N_{22}t = e_1 N_1 + e_2(\varphi N_{21} + N_{22}) + g. \tag{A.2}$$

Recall that we model one cohort of households for periods of length equal to the duration of K-12 and college education. The government budget constraint is expressed in terms of per-household total revenue and expenditure throughout these periods. In the empirical implementation of our model, a K-12 period lasts for 12 years and a college period lasts for 4 years. As seen in A.1 and A.2, a household pays taxes every year. Therefore, in calculating the total revenue, we compute the tax revenue $\mathcal{T}(x_1)$ as the 16-year total tax revenue collected from a household with income x_1, $N_{21}\underline{t}$ as the total two years of tuition revenue from 2-year college enrollees, and $N_{22}t$ as the total four years of tuition revenue from 4-year public college enrollees. Similarly, for total expenditure, we calculate e_1N_1 as the total K-12 expenditure on students for the total number of years they are enrolled in public schools (recall that we allow households to switch between private and public schools in the primary-secondary transition), and we calculate $e_2(\varphi N_{21} + N_{22})$ as the total college expenditure throughout college years. The government policy variables $(e_1, e_2, \underline{t}, t)$ we present are all annual numbers. The per-household subsidy presented in Section 6.2 is the total rather than the annualized amount.

A.7. **The Weighting Matrix.** The optimal choice of the weighting matrix $\mathcal{W}$ used in the indirect inference criterion is the inverse of the variance matrix V_β of the auxiliary statistics $\hat{\beta}$. However, the variance matrix has to be estimated in practice, which is known to cause finite sample problems when the number of the auxiliary statistics is large. For this reason we ignore covariances and give each statistic a weight that is proportional to the inverse of the estimated variance. Since the number of observations for the household-level data far exceeds the number of observations for the state-level data, we attach an importance weight w_k to each statistic, since otherwise the weighting scheme would put much lower weight on the auxiliary statistics from the state-level data, despite their economic importance. Thus the criterion function is given by

$$\left[\widehat{\beta}(\Theta) - \overline{\beta}\right]' \mathcal{W} \left[\widehat{\beta}(\Theta) - \overline{\beta}\right] = \sum_k \frac{w_k}{\widehat{Var}\left(\overline{\beta}_k\right)} \left(\widehat{\beta}_k(\Theta) - \overline{\beta}_k\right)^2,$$

where $\overline{\beta}_k$ is one of the auxiliary statistics from the data and $\widehat{\beta}_k(\Theta)$ is the corresponding statistic from the model simulation, given structural parameter Θ. The government-level regression coefficients, state fixed effect-related statistics, and coefficients of state level variables such as tuition and per-student expenditure in household-level regressions are assigned an importance weight $w_k = 10$, while all the other auxiliary statistics have importance weight $w_k = 1$.

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 the scope of this paper to predict how private colleges might respond to free public college policies, as a robustness check 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 consider the most extreme counterfactual experiment in the text, i.e., a mandatory zero tuition policy for all public colleges. We find that private tuition would need to decrease by 7.5% 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 changing taxes toward the baseline levels. The final fractions of college graduates in the population are similar in these two cases. A slightly higher fraction of households would gain under the free-college policy when private tuition adjusts.

TABLE 10. **Free Public Colleges (Mandatory)**

A. Government Policy (Mean)						
	Per student e ($1,000)		State Tax		Tuition ($1,000)	
	K12	College	(MidInc) (%)	$\tau^b(\times 100)$	2yr	4yr
Free 2&4-year	7.39	14.45	10.42	1.22	0	0
Free 2&4-year (P)	7.44	13.86	10.19	1.33	0	0

B. College Enrollment and Graduation								
	Enrollment				$\frac{College\ Grad}{College\ Enroll}$		College Grad	
%	None	2yr	4yr pub	4yr pri	2yr	4yr pub	2yr	4yr (pub+pri)
Free 2&4-year	16.7	22.7	43.3	17.3	43.6	56.7	9.9	35.5
Free 2&4-year (P)	16.1	21.8	39.5	22.6	43.7	55.8	9.5	35.6

C. Welfare							
		Welfare Changes					
	Winners	Income Group					
		All	1 (low)	2	3	4	5 (high)
Free 2&4-year	17.5%	-6.40	-2.96	-5.58	-6.00	-7.93	-8.50
Free 2&4-year (P)	32.1%	-1.65	4.42	-0.59	-1.78	-3.88	-5.04

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	1.40 (0.11)	-0.45 (0.15)	0.66 (0.04)	-1.00 (0.04)	1.0 (normalized)	
B. High School Achievement (Ordered Logit, Cutoffs)						
	dropout-1q	1q-2q	2q-3q	3q-4q		
HS k_1	-3.58 (0.22)	-1.23 (0.22)	0.01 (0.22)	1.33 (0.21)		
C. College Graduation (Logit)						
	Linear income*	$\mathbb{I}\,(\text{inc} \geq 4)$	college	minority	College TFP η_2	intercept
2yr college	1.01 (0.30)	0.14 (0.33)	-0.26 (0.11)	-0.26 (0.11)	1.0 (normalized)	-1.26 (0.19)
4yr public	-0.04 (0.35)	-0.38 (0.42)	0.50 (0.13)	-0.16 (0.10)	0.52 (0.10)	-4.24 (0.29)
4yr private	1.06 (0.39)	-0.02 (0.26)	0.10 (0.16)	-0.58 (0.12)	-	-1.90 (0.28)

*The income unit is $100,000.

TABLE 12. **Other Parameter Estimates:** Preferences

A. Scale of Household Preference Shock			B. Household Preference for Private K-12			
K-12	College			primary	high school	switching cost
7.14 (1.26)	0.55 (0.05)		private K-12	-6.69 (2.31)	-15.52 (3.18)	-12.10 (2.18)
C. Household College Preference						
	intercept	HS score	HS score^2	Private HS	Northeast	
2yr college	-2.93 (0.40)	2.42 (0.76)	-1.16 (0.74)	0.17 (0.23)	-	
4yr public	-0.97 (0.18)	2.29 (0.55)	-0.93 (0.51)	0.62 (0.10)	-	
4yr private	3.11 (0.19)	-0.64 (0.47)	1.12 (0.40)	0.85 (0.12)	0.20 (0.06)	
D. Household Preference Interaction with x						
	inc=2	inc=3	inc=4	inc=5	college	minority
private K-12	-3.12 (0.59)	-2.31 (0.82)	-4.20 (1.20)	-0.16 (1.71)	7.34 (1.33)	-4.85 (0.93)
2yr college	-0.14 (0.10)	-0.36 (0.16)	-0.38 (0.54)	-1.21 (0.68)	0.47 (0.18)	0.50 (0.16)
4yr public	0.05 (0.07)	0.11 (0.08)	-0.83 (0.21)	-0.89 (0.25)	0.17 (0.08)	0.03 (0.06)
4yr private	-2.11 (0.17)	-2.72 (0.19)	-3.89 (0.28)	-4.12 (0.39)	0.33 (0.08)	0.17 (0.07)
E. Public Good				F. Terminal Values		
Const. (inc=3)	$\ln x_1$	$\ln z_1^f$			$\mathbb{I}(\text{inc} \leq 3)$	$\mathbb{I}(\text{inc} \geq 4)$
0.20 (0.02)	-0.17 (0.04)	0.88 (0.11)		HS score	0.03 (8.78)	42.69 (9.66)
				2-yr grad	7.23 (0.93)	9.41 (1.66)
				4-yr grad	0.96 (0.43)	3.48 (0.50)
G. Borrowing Cost: $\ln \gamma_1(x_1) = \gamma_{11} + \gamma_{12} \ln x_1$ and $\ln \gamma_2(x_1) = \gamma_{21} + \gamma_{22} \ln x_1$.						
γ_{11}	γ_{12}	γ_{21}	γ_{22}	γ_3		
0.28 (0.13)	0.09 (0.10)	-4.58 (0.12)	-0.74 (0.09)	0.25 (0.06)		
F. Government Policy Shocks						
Scale (σ^P)	0.004 (0.002)		Nesting (σ^N)	0.0002 (0.09)		