College Choice, Private Options, and The Incidence of Public Investment in Higher Education*

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Abstract

Previous measures of the incidence of public investment in higher education focus on the transfer to public college students. However, they miss potential general equilibrium effects on the private college and labor markets. We show that capturing these spillovers is important for characterizing incidence using a model of higher education that we validate with quasi-experimental variation in state spending. Unlike previous measures, we find that high-income-modest-ability students especially benefit since they are only admitted to high-quality private colleges when spending is high. Decreased investment also reduces educational attainment, raising the college wage premium. This exacerbates private college market power.

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Understanding who benefits and who bears the burden of public investment in higher education is increasingly important for state and federal policy. Some states are greatly reducing support, while many Democrats and the Biden administration call for tuition-free public college and an expanded Pell Grant. However, since the controversial findings of Hansen and Weisbrod (1969), the merits of public higher education as a redistributive tool have been called into question. They found that while higher education is mainly financed through progressive income taxes, take-up is predominately by higher income households. Pechman (1970, 1972), using the same data as Hansen and Weisbrod, and more recently William Johnson (2006) using a nationally representative survey, argue that Hansen and Weisbrod misinterpret their findings. When stratifying by income, Pechman and Johnson show that net subsidies flow from high income families whose children often attend private colleges to the moderate income whose children often attend the publics.

Previous approaches that measure incidence implicitly ignore general equilibrium considerations. Pechman and Johnson's method uses an accounting approach that sums the amount spent on educating an individual student at public institutions and subtracts the amount paid in public college tuition and taxes. As Johnson acknowledges, these calculations leave out possible general equilibrium effects of state subsidies to public colleges.[1] It is plausible that competition from public colleges affects who the private colleges admit and the tuition they charge. States' investments in public colleges have indirect effects on those who, in equilibrium, attend private colleges. Public investment also increases the size of the college educated workforce, affecting the relative wages of college and high school graduates.

How important are the general equilibrium implications of public investment for characterizing who benefits and who bears the burden? For what types of students do these effects matter the most? We build on the previous approaches to understand the redistributive implications of state divestment in general equilibrium. We first show empirically that public investment affects private college pricing and selectivity, which previous measures miss, using variation from private colleges' exposure to different state spending changes over time. However, these spillovers have

[1] Conlisk (1977) shows that net benefits measured here are not a good indicator of the intergenerational equity implications. However, the focus of this paper is at a given point in time.

ambiguous welfare implications for students based on their income and test scores. We therefore combine these results with a general equilibrium model of higher education based on Epple et al. (2006, 2017, 2019) to study the role of college choice and market power for incidence in a compensating variation (CV) framework. The model allows us to consider the welfare effects of private college responses to changes in public funding, especially who private colleges admit and how they set their (sticker) prices, and on the effect that such changes have on wages.

We first measure the spillover effects of public investment on private college sticker, or maximum, prices. Sticker price responses capture changes in private college market power because they affect both revenue and the extent that colleges can price discriminate. These responses also affect college quality and enrollment. We implement an empirical strategy that is similar to a shift-share design and uses within-state, between private college variation based on where they historically draw their students, combined with across state variation over time in public higher education expenditure. Private colleges, especially those that are likely close substitutes for public colleges based on their average SAT scores, increase their sticker prices in response to state divestment. However, the magnitude is quite small.

Although sticker prices minimally respond, we find much larger price increases on lower income households based on the same research design. The results suggest that private colleges use financial aid to compete with the less expensive public colleges. When state spending falls, prices at the public colleges increase while quality decreases, and so the private colleges can attract more low-income-high-ability students even at higher prices. In line with this result, we find that state divestment increases average SAT scores at the most selective private colleges. The implied change in peer effects benefits students who enroll, but may also crowd out lower ability students who enrolled when state spending was high.[2]

The price and selectivity responses are not sufficient for measuring the welfare effects in general equilibrium. Who benefits also depends on how changes in these quantities affect college admission and student enrollment decisions. We therefore calibrate a model of the higher educa-

[2]State divestment also decreases average SAT scores at less selective privates, consistent with lower-ability students enrolling there after being crowded out of the most selective.

tion market to match national college attendance patterns and variation in prices by income and test scores, or ability. We additionally build on the previous models[3] by endogenizing sticker prices, which allows us to better study market power. The model replicates the main findings from the accounting approach as well as our empirical findings on spillovers. Our work therefore also uses policy variation to validate this class of models.

Our model-based framework for measuring incidence addresses the concerns about the accounting approach by comparing the baseline equilibrium to one with lower levels of public investment. CV measures how much additional income a household would need to be given, in excess of taxes, to be just as well off after a state spending decrease. Like the accounting approach, this method measures the direct effect of spending on the value of enrolling in a public college. We additionally capture the value of changes in price, quality, admissions, enrollment, and the changes in the labor market– the benefits are not only for those who attend publics.

We measure CV in two steps. First, we decrease state appropriations per student by 10 percent and hold private college sticker prices fixed. This exercise puts a lower bound on the extent to which private market power increases because the colleges can only raise their prices to a limited extent and not at all on students who pay the sticker price before the shock to state spending. However, with more aggregate demand, the privates increase their maximum prices. We then allow the sticker prices to adjust to highlight the importance of private market power for incidence.

While our results imply that public investment is weakly progressive, we find that the accounting approach mischaracterizes incidence because the general equilibrium responses are large in magnitude but vary in sign with income and ability. High-income-modest-ability students benefit the most from public investment because they are only admitted to the highest quality private college when state spending is sufficiently high. As spending decreases, public colleges charge higher tuition and become lower quality, which leads low-income-high-ability students to switch sectors. The change in enrollment patterns from the spending cut crowds out modest-ability students. However, since the high-income-modest-ability are very likely to attend the privates under

[3]Rothschild and White (1995); Winston (1999); Epple et al. (2006, 2017, 2019); Chade et al. (2014); Fu (2014); Gordon and Hedlund (2018); and Fu et al. (2019).

the current spending level and pay high taxes, the accounting approach implies that they subsidize the system, rather than benefit.

Our results for high-income-modest-ability students are driven by private college price setting behavior. The sticker prices imply a minimum ability required for admission. These students are crowded out of the private market unless they are able to sufficiently compensate the colleges for their negative effects on peer quality. Since average SAT scores at highly selective privates increase with state divestment, the peer effects cost of being modest ability increases as well.[4] They are only admitted if the sticker price is high enough. As private market power and (sticker) prices increase, the minimum ability thresholds fall for two reasons. First, students can pay more to offset the negative peer effects. Second, at higher prices, fewer low-income-high-ability students enroll in the privates and so average peer quality does not increase as much. Since private sticker prices only minimally increase when state support falls, these students bear much of the burden.

In aggregate, enrollment changes affect the labor market returns to college as well. When state support decreases, the public colleges become more expensive and lower quality, while the privates restrict access through admission and prices. This makes college human capital scarce, driving up the college wage premium. When the privates increase their sticker prices, even more students are priced out. This pushes up the wage premium further. As college wages rise, so does private college market power and vice versa. Students who never attend a public or private college benefit from the effects of public investment on the private market.

Increases in private market power and the college wage premium from decreases in state support have the largest benefits for high-income-high-ability students. They are always admitted to the high quality privates and pay the sticker price. When state support falls, their colleges become higher quality when the labor market returns to quality are higher, but pay nearly the same tuition and less in taxes. These students look very similar to the high-income-modest-ability in the accounting approach, but our measure provides starkly different estimates of the welfare implications for these two groups. This is because the general equilibrium effects are large in magnitude, but

[4]College quality is partially determined by average ability, or SAT scores. Students with ability above the college's average therefore create positive peer effects, while those below create negative.

the sign varies with income and ability.

Overall, our findings contribute to our understanding of who benefits from public investment of higher education. Recent empirical work has shown that higher levels of state support increase student achievement because it reduces crowding, increases resources per student (Bound and Turner 2007; Bound et al. 2010), and increases persistence and graduation (Deming and Walters 2018). State funding also affects public college admission decision and pricing (Bound et al. 2019, 2020). These results focus public college students. While those results are consistent with our model, we additionally show that the equilibrium effects from spillovers onto the private college and labor markets are important for characterizing who benefits.

1. Measuring Incidence

Much of the previous empirical literature on the incidence of public investment in higher education (e.g. William Johnson 2006) uses an accounting approach. The net benefits capture a transfer to those who attend, measured by the sum of subsidies received from instructional and capital expenditure at public institutions less public tuition and tax payments. State appropriations directly affect this transfer value of public college attendance because it affects expenditure, tuition, and tax rates.

The accounting exercise misses general equilibrium effects summarized by Figure 1. It only considers the farthest left arrow– a decrease in state appropriations creates a smaller transfer for public college students. When the transfer value decreases, fewer students enroll. Instead, some switch to the private sector (Peltzman 1973), or do not enroll in any college. With increased demand, private colleges have more market power; they charge tuition even further above marginal cost. A high quality, well-funded public college puts competitive pressure on the privates, which creates benefits for those students. When fewer students enroll in any college, college-educated workers becomes scarce and the college wage premium rises.

These mechanisms importantly interact, as indicated by the double sided arrows. For example, enrollment changes from state divestment affect college quality through peer effects, which determines who the privates admit and how much they charge. Some students are crowded out of

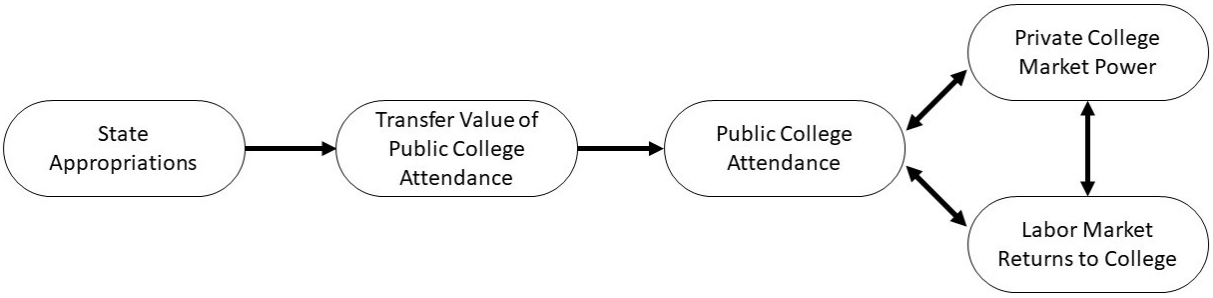


Figure 1: General Equilibrium Implications of State Appropriations

the private sector, further altering enrollment. Implications in the college market then spill over to the labor market. Increased wages for college workers increase demand for higher education and therefore feed back onto private college market power. This compounds the effects on enrollment and restarts the cycle.

This paper provides empirical evidence that state investment in public higher education matters for private college market power and proposes a framework to incorporate the general equilibrium implications to measure incidence. We first build on the model of the higher education market from Epple et al. (2017) that replicates our empirical findings. We then implement a CV measure that captures the amount of money one would need to give a household, in excess of tax and tuition revenue, so that it is indifferent between the current policy and a 10 percent decrease.[5] From the observed baseline, we simulate the general equilibrium effects of divestment. CV computes the welfare effects by comparing the two equilibria.

The objective here is to measure the value inclusive of the general equilibrium effects, v, in dollars, of higher education appropriations rather than just the direct transfer to those who attend. Let $U(y_p, b; z)$ denote the utility of student with parental income y_p and ability b when states spend z in appropriations per student. CV for counterfactual spending $0.9z$ compared to the baseline level

[5]From the peak in 2001 to the trough in 2012, spending per student decreased by 31.6 percent. Since 2001, the average year-on-year decrease is 1.3 percent.

is then

$$CV = \nu - (t(z) - t(0.9z))y_p - (T(z) - T(0.9z)) \tag{1}$$
$$\text{such that } U(y_p, b; z) = U(y_p + \nu, b; 0.9z)$$

where $t(z)$ and $T(z)$ are tax rates, and tuition paid to public colleges as a function of the state spending, respectively. Our analysis is similar to Epple et al. (2019) who measure the welfare effect of moving from a state with only the lowest quality public college to a state with four different levels of quality. However, their analysis does not capture the general equilibrium effects on the college and labor markets that are the focus of our analysis.[6]

2. Private College Responses to Public Investment

In general equilibrium, the incidence of public investment in higher education depends on the extent to which it affects private college market power, or the difference between price and effective marginal cost, EMC. Since colleges offer financial discounts based on income and ability, or test scores, they can respond to increased demand by increasing both the sticker price on all students and the net tuition for different types of students. The second component of market power, EMC, is the sum of the marginal resource cost from expenditure and marginal peer cost of enrolling a student, or how an individual student's test score affects the average. If colleges value being highly selective, then students with scores that lower the average will have high marginal peer costs. Based on these components, private college market power varies across students based on their income and ability.

2.1 Price Responses to Public Investment

We first estimate the elasticity of private college sticker prices with respect to state appropriations, κ_p, from:

$$\log(P^c_{j(s)t}) = \kappa_p \log(z_{j(s)t}) + \pi_{j(s)} + \psi_{st} + u_{jt}, \quad \text{where } z_{j(s)t} = \sum_i z_{it} \frac{k_{ij,1998}}{k_{j,1998}} \tag{2}$$

[6] Kasman and Guyot (2019) study the implications of college subsidies using an agent-based model, although they do not consider private college market power. Our analysis is complementary to Fu et al. (2021) who measure the effects of college locations and tuition, but not state spending.

$P^c_{j(s)t}$ is private college j's sticker price in state s in year t, z_{it} is the average appropriations in student i's state in year t, $z_{j(s)t}$ computes the relevant state appropriations for college j by weighting z_{it} by the fraction of j's students from i in 1998, and $\pi_{j(s)}$ and ψ_{st} are institution and state-by-year fixed effects, respectively.

Equation 2 is similar to a shift-share design where z_{it} captures variation in the effective treatment for college j and $k_{ij,1998}/k_{j,1998}$ captures j's dependence on students from i. As appropriations in i decrease, the demand for private options increases, allowing those colleges to raise prices. The importance of a spending shock in i to college j depends on how many students from that state tend to enroll. Contemporaneous measures of the share would lead to an upward bias since enrollments are a function of the sticker prices. We therefore use 1998 as a base year. This strategy exploits both across state variation in appropriations and within state, between college variation based on where they historically draw their students.

As an example, consider Bentley and Northeastern Universities, two private colleges in Massachusetts with upper-middle quartile SAT scores. Bentley draws 8 percent of its students from New York, while Northeastern draws 15. If NY decreases its public college spending, Northeastern will face a larger positive demand shock because a larger share of its potential student population is affected, and it should increase its sticker price by more. The extent to which the changes in spending affects each private college also depends on how close substitutes it is to the publics. Although Northeastern and Boston College both draw 15 percent of their student population from NY, they may not be equally affected. Boston College students have higher SAT scores on average, and likely different college options.

We estimate Equation 2 using a balanced panel of private colleges from 2000 to 2017. For each institution, the Integrated Postsecondary Education Data System (IPEDS) reports the college's sticker price, as well as the number of students from each US state who attend. Grapevine and the State Higher Education Executive Officers report the state-level average appropriations per student at public colleges. We allow κ_p to vary by SAT score quartile since the elasticity may depend on

how close substitutes the public and privates colleges are.[7]

Our identification strategy is similar to Deming and Walters (2018) and Bound et al. (2020) who both look at the impacts of changes in state appropriations on public colleges. Both papers rely on state level variation in average state appropriations over time, as we do here. It is plausible in our setting that private colleges treat average spending at public colleges as exogenous since they are not the recipients. Our strategy is additionally able to leverage spending changes across all states, not just the institution's state, in part because private colleges draw their students from a more national market. This allow us to include more flexible time-varying controls.

The results from our preferred specification are presented in Column (3) of Table 1 with institution and state-by-year fixed effects. Our identification strategy compares private colleges in the same state who face different demand shocks based on where they historically draw their students, netting out other state specific shocks, for example, from the Great Recession. We also present specifications with year fixed effects, and both year fixed effects and state linear time trends to show the importance of capturing business cycle fluctuations. When the economy is doing well, states have more resources to spend on appropriations, but so do households to spend on education, which would lead κ_p to be biased upwards. State-by-year fixed effects also control for other factors that may be important for public college demand, like the size of the 18 year old population in a state (Bound et al. 2020).

The results suggest that private colleges adjust minimally their maximum prices to further increase market power when state appropriations fall. A 10 percent decrease in appropriations leads to less than a 1.3 percent increase in private college sticker prices. The effect is concentrated in the upper-middle quartile of selectivity, at institutions like Northeastern University. Colleges at this level of selectivity are likely close substitutes for the publics. The student-weighted average SAT scores at public colleges is at the boundary of the lower-middle and upper-middle quartiles and well within the upper-middle for flagships. The results may understate the effects at less selective institutions since many draw students locally, which makes it difficult to detect a response with

[7] IPEDS reports the 25th and 75th percentiles of the math and verbal SAT sections. We measure SAT scores as the average of all four components in Fall 2001, the first year available.

Table 1: The Effect of State Appropriations on Private College Sticker Prices

	(1)	(2)	(3)
	Log Price	Log Price	Log Price
Lower quartile	-0.003	-0.015	-0.042
	(0.035)	(0.035)	(0.054)
Lower-middle quartile	0.020	-0.002	-0.031
	(0.025)	(0.026)	(0.049)
Upper-middle quartile	-0.069	-0.093	-0.126
	(0.038)	(0.036)	(0.057)
Upper quartile	0.033	0.011	-0.024
	(0.028)	(0.025)	(0.052)
Year FE	Yes	Yes	No
State Linear Time Trend	No	Yes	No
State-by-Year FE	No	No	Yes

Note: Each column presents the coefficients from a regression of log relevant appropriations interacted with SAT quartile on log sticker price using a panel of private colleges from 2000 to 2017 with college FE. Each regression has 14705 obs. Standard errors are clustered by college.

state-by-year fixed effects. Some institutions are also horizontally differentiated, religious colleges for example, and therefore may also not directly compete with publics. Highly selective institutions compete less with the public sector and respond less as well, based on our estimates.

Our preferred specification estimates the contemporaneous effect of state appropriations on sticker prices, but private colleges may not respond immediately. Admissions and aid offices may not know how prospective students will respond to changes in the quality of their public colleges. However, most of the variation in appropriations are low frequency and the fixed effect estimates can therefore be interpreted as reflecting the long run behavior of private colleges in response to persistent appropriation changes (Baker et al. 1999, Bound et al. 2020). In addition, we estimate a distributed lag model with four lags plus the contemporaneous shock and find similar results, although the magnitudes are slightly larger. Summing the five coefficients for each SAT quartile, we estimate elasticities of -0.05 (0.07) , -0.05 (0.07), -0.20 (0.07), and -0.06 (0.07), moving from lowest to highest.[8]

[8]We also estimate a similar specification, but additionally include and leads of private college j's relevant state appropriations interacted with selectivity quartile following Deming and Walters (2018). We estimate a similar elasticity of -0.081 (p-value of 0.088) for contemporaneous relevant appropriations for the upper-middle quartile. None of the

The subtle response may be consistent with quality-maximizing private colleges, as in our model, if high-ability-low-income students' application decisions are sensitive to the sticker price, as has been well-documented (e.g. Bettinger et al. (2012), Hoxby and Avery (2013), Hoxby and Turner (2015), and Dynarski et al. (2021)). Some private colleges have lowered their sticker prices in hopes of attracting more students (Anderson 2019). Colleges may also have a different objective function for setting their maximum prices. Epple et al. (2006) suggest that low sticker prices can reduce the number of low-ability students who harm the college's reputation, limit the private incentives of administrators to admit students of wealthy households for personal gain, and lead to higher alumni giving.

Since many students receive financial aid from private colleges, changes in sticker prices do not fully capture the distributional implications of state divestment. We next consider the effect on net tuition, or the sticker price minus financial aid. Beginning in the 2008-2009 academic year, IPEDS has collected data on the average net tuition paid for several income-bins[9]. We estimate the effect of a change in private college j's relevant state appropriations on net tuition by income bin b:

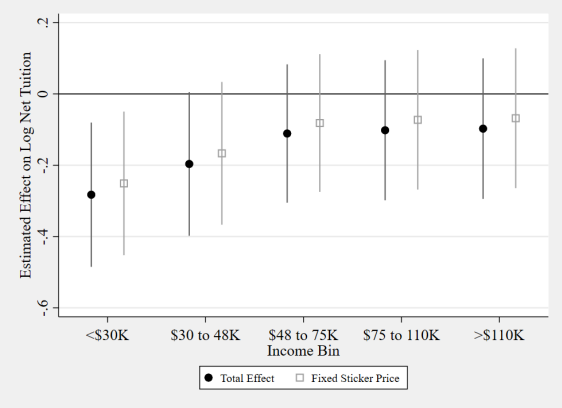
$$\log(p_{jbt}) = \sum_{b=1}^{5} \kappa_b \mathbb{1}_b \log(z_{j(s)t}) + \pi_{j(s)b} + \psi_{st} + u_{jbt} \tag{3}$$

where p_{jbt} is the average net tuition for students in college j in income bin b in year t, $\mathbb{1}_b$ is an indicator for income bin b, $\pi_{j(s),b}$ are institution-by-income bin fixed effects, and ψ_{st} are state-by-year fixed effects. We also estimate a specification where we control for the log of the sticker price. The unconditional specification estimates the total effect, while controlling for the log of the sticker price estimates a partial equilibrium effect where private college market power does not fully adjust.

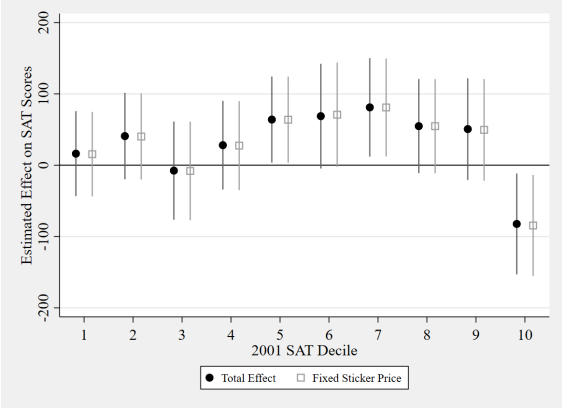
Panel (a) of Figure 2 provides three implications of state divestment: (1) tuition increases for all; (2) tuition increases the most for lower-income households; and (3) tuition increases by less when the sticker prices are held fixed, and market power does not fully increase. Our results are

leads were statistically significant at conventional levels, nor were the sum of the leads for any of the SAT quartiles.

[9]Less than \$30K; \$30K to \$48K; \$48K to \$75K; \$75K to \$110K; and more than \$110K.



(a) Net Tuition by Income



(b) SAT Scores by 2001 Decile

Figure 2: Private College Responses to Public Investment

Note: Panel (a) presents estimates and 95 percent confidence intervals of the effect of changes in college j's relevant appropriations on net tuition by income bin. The sample size is 38027. Panel (b) presents the effect of changes in college j's relevant appropriations on SAT scores by decile. The sample size is 7549. Standard errors are clustered by institution. In both panels, the solid circles show the total effect, while the open squares control for log sticker price.

consistent with Fillmore (2016). He finds that colleges offer lower prices to students when they believes they face stiffer competition. Every additional school listed on a student's FAFSA is associated with a $373 increase in institutional aid. This effect is driven by private colleges and the estimated effect for very selective privates is more than $900.

2.2 Private College Selectivity and Public Investment

Changes in the relative demand for private colleges may also affect which types of students are admitted and enroll. We now investigate the effect of changes in appropriations on private college selectivity, measured by average SAT scores:

$$SAT_{jt} = \sum_{d=1}^{10} \kappa_d \mathbb{1}_{dj} \log(z_{j(s)t}) + \pi_{j(s)} + \psi_{st} + u_{jt} \tag{4}$$

where SAT_{jt} is the average SAT score for students enrolled in college j in year t, $\mathbb{1}_d j$ is an indicator that is 1 if college j is in decile d of private college Fall 2001 SAT scores, $\pi_{j(s)}$ are institution fixed effects, and ψ_{st} are state-by-year fixed effects. We also estimate this specification controlling for the log of the sticker price. Estimated elasticities are plotted in Panel (b) of Figure 2.

After a decrease in state appropriations, SAT scores at the highest quality private colleges,

decile 10, rise. This has two implications for incidence. First, the increase in average SAT scores benefits students who attend the high quality private colleges, and so the accounting approach overstates the benefits of public investment for these students. However, the results also imply that marginal peer costs rise, especially for low-SAT score students. With higher EMC, they may no longer be admitted. In that case, the accounting approach understates the benefits of public investment. The sign of the bias from ignoring these equilibrium effects is therefore ambiguous, and varies by student SAT scores.

Our point estimates also suggest that the magnitude of this effect is larger when sticker prices are fixed. If colleges trade-off tuition revenue to improve expenditure with peer quality, as in our model, then an increase in EMC must also lead to an increase in tuition. However, with fixed sticker prices, fewer students will be able to sufficiently compensate the college for their negative peer externalities. These students are then no longer admitted, which drives up the average SAT score.

McDuff (2006) provides empirical that students respond to changes in public investment. He finds that a 1 standard deviation increase in public college quality, a combination of mean SAT scores, freshman retention, and spending per student at the flagship, increases the percentage of scores sent to in-state publics by 6 percentage points and the likelihood of enrolling in an in-state public by 5 percentage points. Increased demand in one sector implies relative decreases in others, the private market or no college. He also finds that lower income households are more price sensitive, while the higher income are more quality sensitive, which is consistent with the calibrated model. Bound et al. (2009) provide additional suggestive evidence that students responded to the decrease in public college quality over time.

3. The Higher Education Market

We now turn to a general equilibrium model of higher education based Epple et al. (2017) to study the welfare implications of public investment. We consider two main extensions that highlight the importance of private college market power, as well as the labor market returns to college. First, we endogenize sticker prices. In doing so, private colleges are better able to adjust their prices

and admissions decisions with changes in state policy to affect their market power. Second, we model the value of college as a function of the size of the college-educated workforce. Changes in aggregate enrollment affect an individual's demand for higher education through its impact on the college wage premium.[10] We additionally specify a more flexible parameterization that is better able to match attendance patterns.

The market consists of three private colleges, one public college in each of two states, households, and state and federal governments. The college market is stylized, but allows us to highlight the mechanisms in Figure 1 and replicates our findings from Section 2. At a minimum, the model must include at least one public and two private colleges to investigate the spillovers of public investment on the private market power. We include an additional private college to build on Epple et al. (2017), but a version with two private colleges yields the same qualitative results. Including an in-state and an out-of-state public college allows us to compare our results to the accounting exercise since wealthy households who attend the out-of-state public colleges help subsidize less wealthy in-state students.

3.1 Households

There is a unit mass of households living in two identical states. Households are characterized by their state of residence, s, parental income, y_p, and student ability, b, which are drawn from a joint distribution $f(b, y_p)$. Mapping the model to the data and our previous empirical results, we assume ability is measured by SAT scores. Students make college enrollment decisions based on the wage adjusted value of human capital, y_{sj}, from enrolling in j with quality q_j and the household's income net of college cost, y_{pj}. College j costs $p_{sj}(b, y_p)$ in tuition, and L in living expenses. Federal financial aid of A_{sj} is available to offset costs. Households attend the option that maximizes their utility $U_j(s, b, y_p, \varepsilon_j) = \ln(y_{pj}^{\alpha_p} y_{sj}^{\alpha_s}) + \varepsilon_j$, where

[10] George Johnson (1984) shows that this effect can be so strong that non-college enrollees prefer more government investment in public colleges than those who directly benefit.

$$y_{pj} = (1 - t_s - t_f)y_p - p_{sj} - L_j + A_{sj} \tag{5}$$

$$\text{and} \quad y_{sj} = \begin{cases} w_c \beta_1^c \left(\beta_2^c b^{\beta_3^c} + (1-\beta_2^c) q_j^{\beta_3^c}\right)^{1/\beta_3^c} & \text{if attends college j} \\ w_h \beta_1^h b^{\beta_2^h} y_p^{\beta_3^h} & \text{if does not attend college} \end{cases} \tag{6}$$

where α_p and α_s are weighting parameters, t_s and t_f are state and federal tax rates, w is the wage adjusted value of college or non-college human capital, and the disturbances ε_j are i.i.d. Type I Extreme Value preference shocks for j. The value of attending college depends on a student's ability and college quality, while the relative value of the outside option of no college depends on ability and parental income. Under standard regularity conditions on ε_j, as in McFadden (1974), we can recover the probability that a student of type (b, y_p) attends college j, r_{sj}, given the set J of admitted colleges and the outside option of not attending college, O.[11]

The labor market value of college, w_c, and non-college human capital, w_h, are determined by a CES production function in aggregate college and non-college educated labor. The college wage premium for a unit of human capital is:

$$\frac{w_c}{w_h} = \frac{s}{(1-s)} \left(\frac{C}{H}\right)^{\rho - 1} \tag{7}$$

where s is the share on college human capital, ρ determines the elasticity of substitution, C and H are aggregate college and high school human capital, respectively.

3.2 Private Colleges

Private colleges admit students and set individual prices to maximize quality, q_j, subject to a budget constraint and sticker price P_j^c. Quality is a function of mean student ability, θ_j, and instructional expenditure per student, I_j: $q_j = \phi_j \theta_j^\gamma I_j^\omega$, with $\gamma, \omega > 0$. These components are important inputs to the education production function and common proxies for quality (Black and Smith 2006).

All colleges, public and private, have the same cost function, $C(k, I) = F + v_1 k + v_2 k^2 + kI$, where F are fixed costs, k is the number of enrolled students, and v are parameters that capture the

[11] $r_{sj} = y_{pj}^{\alpha_p} y_{sj}^{\alpha_s} / \sum_{k \in J \cup O} y_{pk}^{\alpha_p} y_{sk}^{\alpha_s}$. If a student does not attend college, L, A and p are 0.

marginal cost of enrolling more students. College j has exogenous endowment E_j. A student with ability b and income y faces price p_{sj} that depends on her effective marginal cost,

$$EMC_j = v_1 + 2v_2k + I_j + \frac{\partial q_j/\partial \theta}{\partial q_j/\partial I}(\theta_j - b) \tag{8}$$

and the probability r_{sj} that a student of her type (b, y_p) attends college j

$$p_{sj}(b,y_p) + \frac{r_{sj}(b,y_p)}{\partial r_{sj}(b,y_p)/\partial p_{sj}(b,y_p)} = EMC_j(b) \tag{9}$$

but must not exceed sticker price, $P_j^c(z_s)$, which is a function of state appropriations, z_s. EMC depends on ability through peer effects. Private colleges want to charge high ability students lower prices so that they are more likely to attend and raise θ. A student is admitted if her marginal revenue (the minimum of the left hand side of (9) and the sticker price) is greater than effective marginal cost. They spend tuition and endowment income to cover custodial and instructional costs.

3.3 Public Colleges

Each state operates a public college. The public college in state s maximizes expected future human capital of its state's residents, y_{sj}, subject to a budget constraint. Given z_s, the public college in state s charges T_s to residents and T_{so} to non-residents. In order to raise sufficient funds for instruction, colleges adjust tuition based on z_s. Colleges may also change the relative proportion of residents and non-residents admitted. We assume tuition is a function of appropriations such that

$$T_s = \left[1 + \kappa_s\left(\frac{z_s - \bar{z}_s}{\bar{z}_s}\right)\right]\overline{T}_s; \quad T_{so} = \left[1 + \kappa_{so}\left(\frac{z_s - \bar{z}_s}{\bar{z}_s}\right)\right]\overline{T}_{so} \tag{10}$$

where κ is the elasticity of tuition with respect to appropriations, and $\overline{T}$ represents baseline tuition. This equation is only locally valid and is only used to understand tuition setting under small changes. All students of the same residency type at a public college face the same sticker price, although students with different incomes pay different amounts due to differences in federal aid. Tuition and appropriations fund instructional expenditure per student and custodial costs.

Epple at al. (2017) show that the public college j admits all students with ability above a

threshold for residents, b^s_{min}, and non-residents, b^o_{min} implicitly defined by:

$$y_{sj}(q_j, b^s_{min})/\lambda + T_s + z_s - EMC_j(b^s_{min}) = 0; \qquad (11)$$
$$T_{so} + z_s - EMC_j(b^o_{min}) = 0$$

where λ is the multiplier on the budget constraint. The non-resident threshold is a function of tuition and the appropriations level, while the resident threshold accounts for the effect on the total stock of in-state human capital.

3.4 Federal and State Governments

The federal government distributes aid, A_{sj} through a Pell Grant type program, that takes into account expected family contribution, $EFC(y_p)$. A student can receive at most $\bar{A}$ in aid: $A_{sj} = \min\{\max[0, P^c_j + L - EFC(y_p)], \bar{A}\}$

The state and federal governments must balance their budgets. Let Y_s be pre-tax aggregate parental income in state s.

$$t_s Y_s = z_s k_s, \quad s = \{1,2\}; \quad t_f \sum_s Y_s = \sum_s \int \sum_j r_{sj} A_{sj} f_s(b, y_p) dbdy$$

where k_s is the number of students who attend the public college in state s, regardless of each student's state of residence. State colleges can give admission and tuition preference to residents but do not treat students differently after enrolling.

3.5 Equilibrium Definition

An equilibrium consists of a price and quality vector with college characteristics (θ_j, I_j, k_j); state admission criteria for all states for residents and non-residents; state of residence s for all households and $f(b, y_p)$; a set of student choices for all (s, b, y) and $j \in J$, choice probabilities $r_{sj}(b, y_p)$; and wages w_c, w_h such that:

1. Private colleges choose who to admit and what prices to charge to maximize quality, taking the prices and qualities of the other colleges, the student choice probability functions, public policies, and wages as given.

2. Public colleges choose who to admit to maximizes in-state achievement, taking the prices

and qualities of the other colleges, the student characteristics, public policies, and wages as given.

3. Household (b, y_p, ε_j) picks where to attend to maximize utility, taking prices and qualities, public policies, and wages, as given.

4. State and federal budgets are balanced.

3.6 Brief Discussion of Model Limitations

While the model is stylized, the general equilibrium structure allows us to study the importance of private college market power and the labor market for measuring incidence. However, it is important to understand some of the key simplifications.

First, the public sector only consists of one college per state while states have several colleges of varying quality. Including additional public colleges would provide more competitive pressure on the private sector and therefore strengthen the mechanisms we highlight. Similarly, public colleges do not offer institutional aid in the model, which also understates the competitive pressure they provide. Cook and Turner (2021) show that public research universities have progressive pricing policies, although that is not the case for non-research universities. If the public universities could attract more high-ability students away from the privates with subsidies, then the privates would have less market power. However, the opposite is true for the size of private sector– including more privates would increase the competitiveness of the market and therefore lower the value of public competition.[12]

Our simplifications on the household side are also important for incidence. Households are only able to pay for college out of current income and so some low-income households may be financially rationed out of the private market, especially when the returns to college are high. We may therefore overstate the value of public colleges to the modest-income-high-ability students who are always admitted to the privates but can only afford to attend in our model with public

[12] We additionally assume, for simplicity, that the public colleges are the same quality. This implies that students only attend the out-of-state public if they have a high idiosyncratic preference for that school. This is likely the case for some students who care about non-educational amenities (e.g. sports) or if they want to move to that state after graduating.

competitive pressure.[13] However, a loan market weakly increases households' willingness-to-pay for college and therefore also increases private college prices and market power. Overall, we find that changes in private market power from decreases in public investment mainly affect high-income-modest-ability students who are always able to afford college without loans. A loan market would give greater college access to low-income-higher-ability students, exacerbating the main mechanisms we study.

Despite being stylized, we show in Section 5 that the calibrated model matches both the observed enrollment and variation in tuition by income and test scores we target as well as our empirical estimates of private college net tuition and selectivity spillovers from changes to state spending that we do not target.

4. Private Colleges and Incidence

To understand the role private colleges play for the incidence of public investment, first consider how appropriations, z_s, affect their prices in the model. For the purposes of this illustration, we hold wages fixed. Given the model's parametrization and Equation 9, private college j net tuition after institutional aid is

$$p_{sj} = \frac{(1-r_{sj})\alpha_p}{1+(1-r_{sj})\alpha_p} EMC_j(b) + \frac{y_p - L_j + A_{sj}}{1+(1-r_{sj})\alpha_p} \quad \text{and therefore} \tag{12}$$

$$\frac{\partial p_{sj}}{\partial z_s} = \underbrace{\frac{\alpha_p(y_p - L_j + A_{sj} - EMC_j(b))}{(1+(1-r_{sj})\alpha_p)^2}\left(\frac{\partial r_{sj}}{\partial z_s}\right)}_{\text{relative value of private college}} + \underbrace{\frac{(1-r_{sj})\alpha_p}{1+(1-r_{sj})\alpha_p}\left(\frac{\partial EMC_j(b)}{\partial z_s}\right)}_{\text{cost to college of enrolling}} \tag{13}$$

$$\text{where } \frac{\partial EMC_j(b)}{\partial z_s} = \underbrace{2\nu_2 \frac{\partial k_j}{\partial z_s}}_{\text{custodial costs}} + \underbrace{\left(1+\frac{\gamma}{\omega}\left(1-\frac{b}{\theta_j}\right)\right)\frac{\partial I_j}{\partial z_s}}_{\text{expenditure costs}} + \underbrace{\frac{\gamma I_j b}{\omega \theta_j^2}\frac{\partial \theta_j}{\partial z_s}}_{\text{peer externality}} \tag{14}$$

and $\partial r_{sj}/\partial z_s$ is determined by the household's utility function.[14] When appropriations fall, instructional expenditure at the public colleges falls as well and tuition increases. Households are more likely to enroll in the privates as a result. This implies $\partial r_{sj}/\partial z_s < 0$ and $\partial k_j/\partial z_s < 0$, con-

[13] Our framework does not capture the impact of liquidity constraints and household borrowing, which are likely important (Lochner and Monge-Naranjo 2012) and vary with income.

[14] The derivate is defined for students who attend j in the baseline. $y - L + A_{sj} - EMC_j(b) > 0$ since price is greater than or equal to $EMC_j(b)$ and students only attend if they can afford to.

sistent with McDuff (2006). The first term in Equation 13 captures the first order effect of changes in the value of a student's other options on private college prices. When the value of the public colleges decreases and they provide less competitive pressure, the privates gain market power.

The market level changes also create general equilibrium effects from student sorting, reflected in the second term of Equation 13 and broken down into its components in Equation 14. First, decreases in public college appropriations increase custodial or operating costs as long as the college has increasing marginal costs, or when $v_2 > 0$. The middle term reflects changes in instructional costs. If decreases in appropriations allow the college to charge higher prices because $\partial r_{sj}/\partial z_s < 0$, it will have more revenue to increase instructional expenditure. The direct financial cost of enrolling students increases. The impact of changes in expenditure on prices is weighted by a function of student ability since instruction and average ability are linked through the quality function. Since expenditure and average ability are complements, the value to the college of enrolling high-ability students or cost of enrolling low-ability students is larger when expenditure is higher.

The final term in Equation 14 captures how student sorting affects college quality from changes in peer effects. The sign of $\partial\theta_j/\partial z_s$ and the final term therefore depends on the marginal students to private colleges. When the public colleges become lower quality, low-income-high-ability students may then find it worthwhile to pay for the more expensive privates. In that case, θ_j will increase. The opposite is true if high-income-modest-ability students are on the margin. When θ_j is larger, $\theta_j - b$ is also larger and low-ability students produce more negative peer externalities. They must pay higher prices to compensate, although colleges are unable to charge above P_j^c. This implies that the sign of $\partial p_{sj}/\partial z_s$ is theoretically ambiguous and potentially varies across the income and ability distribution. However, in our calibrated model, we find that both $\partial p_{sj}/\partial z_s$ and $\partial EMC_j(b)/\partial z_s$ are negative for all. This is also consistent with our previous empirical findings.

State investment additionally affects who the privates admit. Each private admits a student if $\min(P_j^c, p_{sj}(b,y)) \geq EMC_j(b)$. Students who pay more than their EMC but less than the sticker price before a small appropriations decrease will still be admitted afterwards. The spending shock

has an ambiguous welfare effect for them since they now face higher prices, but also benefit from higher quality privates.

The students most impacted by decreases in state spending are those who are no longer admitted to the privates. The sticker price and EMC together imply a minimum ability threshold at each college defined by $EMC_j(b) = P_j^c$. Who is still admitted after the state spending change depends on how both pieces respond. Holding the sticker prices fixed, a decrease in appropriations increases the minimum ability threshold if $\partial EMC_j(b)/\partial z_s < 0$ for the marginal ability student. Students who can no longer attend their best option face a potentially large welfare loss. How many students are affected depends on the private college sticker price responses. If the privates also raise their maximum prices when appropriations fall, $\partial P_j^c/\partial z_s < 0$, then more low-ability students can offset their high EMC.

The extent to which EMC changes with appropriations depends on our parameterization for college quality. For our qualitative findings to hold, we need that peer effects matter. Otherwise, modest ability students would not be crowded out when the low-income-high-ability enroll in the high quality privates. The functional form also implies that peer effects and expenditure are strategic complements. While stronger complementarity means that modest-ability students have larger EMC increases with appropriation decreases, the effect in our calibrated model is small. Without this complementarity, fewer, but a positive number of, students would be crowded out after an appropriations decrease.

5. Calibration and Equilibrium Description

We calibrate the model to match the college going behavior across the income distribution and previous estimates from the literature that describe how students and institutions respond to higher education policies. The estimates are presented in Table 2. First, using information on the joint income-ability distribution from the High School Longitudinal Study of 2009 (HSLS), we estimate the income-ability distribution, assuming that they are jointly log-normally distributed.[15] Following Epple et al. (2017), we assume that the ability distribution has a mean of 1 and a standard

[15] All dollar amounts are measured in tens of thousands.

deviation of 0.15.[16] We truncate the income distribution at the lowest bin we observe in the data ($15K) so that all households can afford the in-state college option as well as $300K.

The calibration uses the 2013-2014 academic year to align with the HSLS. The Delta Cost Project has data on institution tuition, and appropriations. We compute the enrollment-weighted average for public and private not-for-profit four-year colleges, divided into three groups by SAT scores. Living Expenses are from the National Center for Education Statistics. Federal aid policies and private college endowments follow Epple et al. (2017)[17].

We calibrate the remaining parameters, αs ,$w\beta$s, ϕs, γ, ω, F, and vs, to minimize the sum of squared percent deviations of: (1) average private college tuition of $27220 (National Postsecondary Student Aid Study 2012, Epple et al. 2019 scaled to 2013-2014 dollars); (2) private school enrollment as percent of total enrollment of 28.5 (HSLS); (3) enrollment elasticity of institutional aid of 0.7 (Van der Klaauw 2002); (4-5) the elasticity of aid with respect to ability and income from Epple et al. (2019) that inform how colleges price discriminate; (6) the 20 percent earnings increase for the marginal-ability student from attending a public college (Hoesktra 2009 and Zimmerman 2014)[18]; (7) public college instructional expenditure per student of $10463 (Delta Cost Project); (8-13) the percent of students from each of 6 income bins who enroll in any 4 year college weighted by the percent of students in each bin[19]; and (14-18) the percent of students from each ability quintile who enroll in any 4 year college weighted by the percent of students. We set v_1 to 0, based on Epple et al. (2006, 2017). Appendix A presents the model fit.

From the calibrated equilibrium, the returns to college quality and ability, βs, and wages, ws, are not separately identified. While βs are structural parameters, ws are equilibrium parameters

[16] Using the PowerStat tool from the National Center for Education Statistics, data is available by the following income bins: less than $15K; in increments of $20K up to $235K; more than $235K. We measure ability using the math quintile score. Income is scaled to 2013-2014 using the CPI.

[17] The maximum federal aid is set to $4K to match estimates from the 2011-12 National Postsecondary Student Aid Study for those who applied for federal aid.

[18] The model implies a minimum-ability threshold at public colleges. This creates a regression-discontinuity, where students just above the threshold have access to the public colleges, but those below do not. We match the model implied earnings gain from college attendance for these students, based on β, to the RD estimates.

[19] We combine the highest income bins to create $95K to $135K and more than $135K so that all bins have at least 10 percent of the population. We exclude the lowest income bin of less than $15K since we truncate the income distribution at that point.

and functions of public investment. Assuming that the labor market value of human capital is determined by a CES production function in college and non-college educated labor, we set ρ to 1.7 (Autor 2014). We then recover the share parameter, s, assuming that the entire baseline earnings difference between workers is because of human capital differences or that $w_c/w_h = 1$.[20]

Finally, we calibrate how public and private college tuition respond to changes in public investment. We set $\kappa_s = -0.263$ and $\kappa_{so} = -0.066$ (Bound et al. 2020).[21]

Using the results from Table 1, we consider a 10 percent national appropriations shock. When appropriations fall in all states to $0.9z_{it}$, $z_{j(s)t}$ similarly falls to $0.9z_{j(s)t}$ for all private colleges. For a national shock, heterogeneity in the shares does not affect the magnitude of the response. This implies that all private colleges decrease their sticker prices by $10\kappa_p$ percent. Although our identification strategy relies on heterogeneous colleges within states and across states in spending over time, the elasticity provides a clear implication for private college responses. We select the largest value in magnitude, $\kappa_p = -0.126$, from our preferred specification to highlight the importance of the sticker price elasticity. We present results with this elasticity and with fixed sticker prices, $\kappa_p = 0$, to understand how the magnitude affects our results, similar to our analyses in Section 2 where we control for the sticker price. Our simulations in Section 5.2 show that the qualitative conclusions would be unchanged if we used the larger elasticity of -0.20 from the dynamic specification. We do not use our other results on net tuition and average SAT scores for calibration. Instead, we use those results for model validation.

5.1 State Investment and The Higher Education Market

From the baseline calibrated model, we simulate the effects of a 10 percent decrease in public support with and without endogenous sticker prices. Table 3 includes key features of the equilibria to highlight the general equilibrium consequences of state divestment. Appendix B additionally

[20] We cannot recover both s and the college wage (per unit of human capital) gap. However, since college educated labor is a scarce resource, we expect $w_c \geq w_h$. From calibration moment (6), the marginal student's earnings gains also imply that $w_c \leq 1.2w_h$. We choose $w_c/w_h = 1$ as a normalization. For a small policy change, the equilibrium ratio is mainly determined by ρ.

[21] Rizzo and Ehrenberg (2004) find that for a \$1000 increase in appropriations, resident tuition decreases by \$60, and non-resident decreases by \$222. Webber (2017) finds larger elasticities, especially for recent years, but does not differentiate between resident and non-resident tuition.

Table 2: Calibration Parameters

Parameter	Name	Value
Households:		
α_p^*	Parent Utility Shifter	20.832
α_s^*	Student Utility Shifter	25.320
$w\beta_1^{c*}$	College Wage Shifter	2.614
$w\beta_2^{c*}$	College Wage Ability Share	0.505
$w\beta_3^{c*}$	College Wage Substitution Parameter	-0.936
$w\beta_1^{h*}$	Non-college Wage Shifter	2.359
$w\beta_2^{h*}$	Non-college Return to Ability	0.111
$w\beta_3^{h*}$	Non-college Return to Parental Income	0.138
L	Living expenses	\$5479
b^*	Ability Distribution	$ln(b) \sim N(1.0, 0.0225)$
y_p^*	Parental Income Distribution	$ln(y_p + 42470) \sim N(11.500, 0.298)$
$corr(b, y_p)^*$		0.359
Governments:		
$\overline{T}_s$	Resident; Non-Resident Tuition	\$7113; 19345
$\bar{z}_s$	Per Student Subsidy	\$7062
EFC	Effective Family Contribution	$\max\{0, .48y_p - 10300, .69y_p - 22500\}$
$\bar{A}$	Maximum federal aid	\$4000
$\kappa_s; \kappa_{so}$	In-state; Out-of-state Tuition Elasticity	-0.263; -.066
Colleges:		
ϕ^*	Private Productivities	1.089;1.118;1.182
γ^*	Return on Peer Quality	0.049
ω^*	Return on Instruction	0.065
E_j/k_j	Baseline Endowments Per Student	\$221, 603, 3850
P_j^c	Baseline Sticker Prices	\$24082; 31724; 34118
κ_p^*	Sticker Price Elasticity	-0.126
Costs:		
$F*$	Fixed Cost	\$231
$v_1; v_2^*$	Custodial cost parameters	\$0; 18057
Labor Market:		
ρ^*	CES Substitution Parameter	0.412
s^*	CES College Share	0.461

* denotes the parameter was calibrated or estimated, rather than directly set.

shows the distributional enrollment changes.

Based on our calibration (column 1), the market consists of an open-access public college in each state, two nearly open-access private colleges, and one selective private college. We refer to the privates as LP, MP, and HP for low-quality, middle-quality, and high-quality private colleges. When state appropriations fall to $0.9\bar{z}$ (column 2), the public colleges charge higher tuition to recover lost revenue, and spend less on instruction. These two changes depress aggregate public college demand and have two implications for private market. First, the privates charge higher prices to increase instructional expenditure, further driving up their own demand for most. However, prices increase too much for the low-income, leading some to substitute to the in-state public where prices did not increase as much, raising its average student ability.[22] The general equilibrium effects of state investment on the private market therefore feedback onto the public colleges.

Second, some baseline public college students now enroll in the privates. In particular, modest-income-very high-ability students, who receive substantial private institutional aid, switch sectors. The enrollment changes increase the average student ability at HP, which raises its minimum ability threshold. Those between the 60th and 62nd percentiles of the ability distribution can no longer sufficiently compensate HP at the baseline sticker price, and are crowded out.

Increased selectivity at HP creates negative spillovers on the other privates. Students just above the 60th percentile are no longer admitted after the state funding decrease are now likely to enroll in LP or MP, lowering their average student ability. This effect outweighs the increased demand from the modest-income-high-ability students who attend the public colleges when state support is high. Overall quality at LP and MP still increases because they enroll more high-income students and can charge higher prices from the change in demand.

Based on the implications for student sorting, state divestment decreases total college human capital. The implied college wage gap increase induces some baseline non-college workers to enroll. Even though enrollment goes up, most attend the now lower quality publics. Although more students would want to enroll in the private sector, since the returns to any college and

[22]The shift of more lower income households to the the less expensive public sector or to no college also decreases total federal financial aid.

Table 3: State Investment and the Higher Education Market

	(1) $\bar{z}_s$ with P_j^c	(2) $0.9\bar{z}_s$ with P_j^c	(3) $0.9\bar{z}_s$ with $(1-0.1\kappa_p)P_j^c$
Enrollment:			
Publics	0.131	0.129	0.130
LP	0.041	0.041	0.040
MP	0.032	0.032	0.032
HP	0.031	0.032	0.031
Expenditure per Student I_j ($10K):			
Publics	1.044	0.993	0.993
LP	1.551	1.619	1.630
MP	2.023	2.086	2.098
HP	2.988	2.995	3.032
Mean Student Ability θ_j (percentile):			
Publics	65.017	65.099	65.147
LP	79.838	79.560	79.765
MP	83.184	83.012	83.182
HP	89.965	90.139	90.007
Quality q_j:			
Publics	1.056	1.052	1.052
LP	1.181	1.184	1.185
MP	1.237	1.240	1.240
HP	1.346	1.346	1.347
Minimum Ability Enrolled (percentile):			
Public Resident	0	0	0
Public Non-resident	0	0	0
LP	0.008	0.008	0.008
MP	0.008	0.008	0.016
HP	60.061	62.331	61.443
Average Tuition ($10K):			
Publics	0.751	0.769	0.769
LP	2.153	2.233	2.251
MP	2.728	2.799	2.817
HP	3.393	3.400	3.443
Percent Increase in Baseline Wages Per Unit Human Capital			
w_c	-	0.239	0.253
w_h	-	-0.178	-0.188
Tax rates			
t_s	0.025	0.022	0.022
t_f	0.005	0.005	0.005

Each column presents equilibrium summary statistics for the two public colleges and the three privates of varying quality. (1) describes the baseline calibrated equilibrium, (2) simulates the new equilibrium holding private college sticker prices fixes, and (3) allows the sticker prices to endogenously adjust.

college quality increased, the privates limit access through admissions decisions and prices.

When private colleges increase their sticker prices slightly after the decrease in state funding (column 3), more modest-ability students can sufficiently compensate HP for their effect on θ_{HP}, and are now admitted. The minimum ability threshold falls slightly but is still above the baseline. The threshold also falls because, at higher prices, low-income-high-ability students are less likely to enroll. Fewer students are crowded out from the policy change, but more choose not to attend because it is not worth the cost.[23] From the enrollment and price changes, the college raises more revenue for instruction, improving quality and thereby increasing demand and the entire distribution of prices further. Moreover, with less crowd out of high-income-low-ability students, the spillovers on the other privates are smaller.

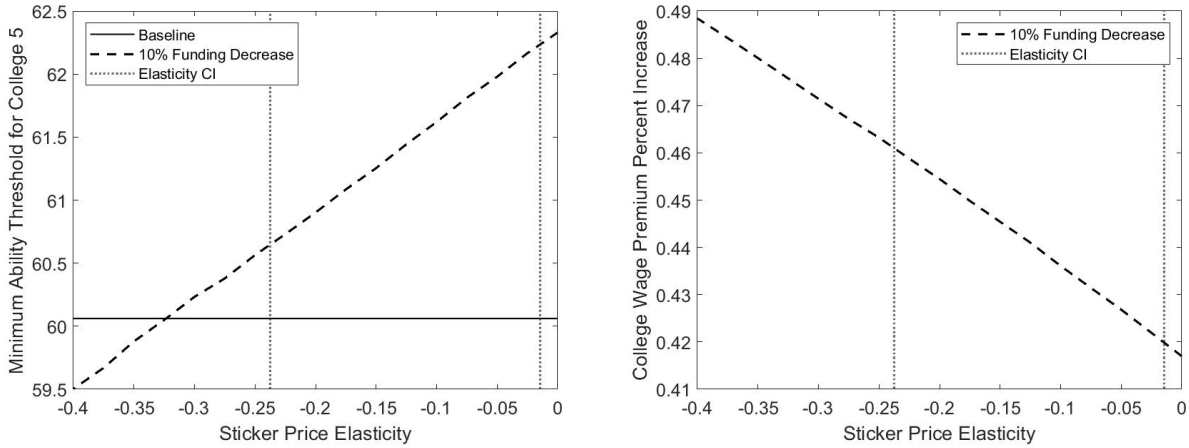
The change in attendance patterns and quality from increases in private sticker prices has an ambiguous effect on the labor market. More students are admitted to HP and the privates collect more tuition revenue but fewer choose to enroll at higher prices. We find that increases in private sticker prices decrease total human capital in the economy. The college wage premium rises with private market power.

Our results from Section 2 help validate the model. We find that the magnitude of the model and estimated net tuition elasticities by income bin are very similar. Our simulations imply an elasticity of -0.30 for those with income less than \$30K and -0.17 for those with income more than \$110K, while we estimate elasticities of -0.28 and -0.10 respectively from Equation 3. Both results also show that net tuition increases by less when sticker prices are fixed. The model also replicates the findings that average student SAT scores increase at the most selective private college, and decreases at the less selective institutions, when state appropriations decrease and that the magnitude of the effect is larger when sticker prices are fixed.

[23] Panel (b) of Figure 7 shows that when sticker prices increase after a decrease in funding, the net impact for the middle-income on HP enrollment is negative for even the top ability decile. The net impact is positive but small for these households when sticker prices are fixed (Appendix B).

5.2 Equilibrium Impacts of Sticker Price Increases

As highlighted in Sections 2 and 4, the sticker price elasticity has important implications for who benefits from public investment. The more the sticker prices increase, the more the privates can increase their market power and modest-ability students can compensate for their negative peer costs. Panel (a) of Figure 3 plots the change in HP's minimum ability threshold as a function of the sticker price elasticity. As it increases in magnitude, the minimum ability threshold falls. However, the elasticity would need to be less than -0.325 for the threshold to be lower than the baseline, which is outside the confidence interval of our estimates. After the decrease in public investment, HP becomes more selective and some modest-ability students are crowded out, although the number depends on the sticker price elasticity.



(a) High-Quality Private College Admission

(b) College Wage Premium Increase

Figure 3: Equilibrium Impacts of Sticker Price Increases

Note: Panel (a) plots the relationship between the sticker price elasticity and HP college's minimum ability threshold for a 10 percent decrease in appropriations per student. The horizontal solid line shows the baseline admission's threshold for reference. Panel (b) plots the college wage premium, w_c/w_h, for the same decrease in funding as a function of the elasticity. In both panels, the vertical dotted lines show the upper and lower bounds of the elasticity's confidence interval from Table 1.

Sticker price increases also affect attendance by pricing lower income households out of the market. They either choose to enroll in the lower quality public colleges or do not attend any. Increased private college market power leads to higher prices for all students, regardless of income

and ability, rather than increased price discrimination where some students receive more aid. Although the privates use the extra revenue to increase their students' human capital, Panel (b) of Figure 3 shows aggregate college human capital decreases after the cut to state spending and is decreasing with the magnitude of elasticity. Higher private college prices exacerbate the college wage premium. Increases in the college wage premium also allow them to charge higher tuition, but they are limited by their sticker prices. These two effects build on one another, but the extent that they do depends on the elasticity.

6. The Incidence of Public Investment

We consider several methods of measuring who benefits from public investment in higher education. We begin by showing that the model replicates the accounting approach. We then present the model implied CV measure in two steps to illustrate the general equilibrium mechanisms. First, the private college sticker prices are held fixed. Then, sticker prices adjust to better understand the role of private college market power. In both exercises, wages endogenously adjust.[24]

6.1 The Model Implied Accounting Approach

The model replicates Pechman and William Johnson's findings that spending is weakly progressive. Panel (a) of Figure 4 presents the distribution of net benefits by parental income, that is, instructional expenditure plus capital costs minus tuition and taxes paid. Open circles represent the average net benefits for a household of type (b, y_p).[25] Based on the model implied accounting approach, the very low income do not benefit since they are unlikely to attend given the costs even with the maximum amount of federal aid. Slightly higher income households still receive the maximum federal aid at both public colleges but tuition is less of a financial burden, leading to large attendance rates and a positive mass around \$40K. As income increases, aid for the in-state public falls while households still receive the maximum amount at the out-of-state option and the privates.

[24] Appendix E additionally presents comparative statics to further illustrate the key mechanisms of how changes in the college market affect incidence.

[25] The figures show the benefits by income and ability, averaging over 20 idiosyncratic preference draws, to emphasize the distributional effects of public investment. Appendix D additionally presents the results for each household-enrollment decision (b, y_p, ε).

Net benefits decrease sharply since they are less likely to attend their in-state public college. High income households have large negative net benefits since they are much more likely to attend the private colleges but pay high income taxes.

Panel (b) of Figure 4 shows a weak negative association between ability and net benefits. The in-state public is the best option for lower ability students since they are not admitted to HP, and face relatively high effective prices at the LP and MP. Higher ability students receive merit aid at the privates, which makes those colleges more affordable. Since income and ability are positively correlated, average taxes paid are also increasing in ability.

We additionally calculate the accounting measure for a 10 percent decrease in state appropriations as the change in instructional expenditure minus the change in tuition and taxes paid to support the public colleges, holding enrollment fixed:[26]

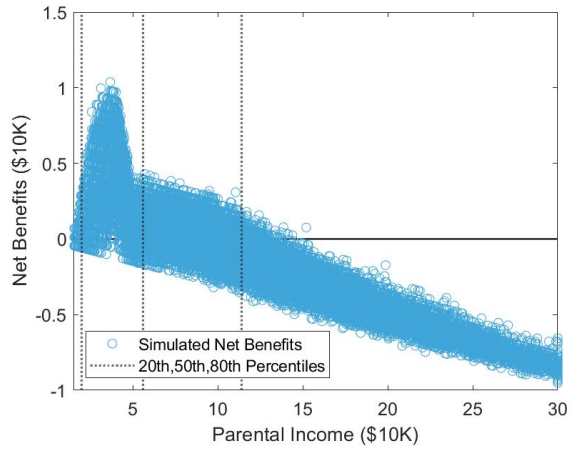
$$(I(z) - I(0.9z)) - (t(z) - t(0.9z))y_p - (T(z) - T(0.9z)) \tag{15}$$

The decrease in appropriations has a direct effect on both instructional expenditure and tax rates. Public colleges also increase tuition to recover some of the lost revenue. Some lower income households also receive additional federal financial to offset the tuition increase. This equation is analogous to Equation 1, which allows us to compare the two approaches for measure incidence and understand the bias from ignoring the general equilibrium effects of public investment. The distributional effects for a 10 percent decrease shown in Panels (c) and (d) are qualitatively similar to the total net benefits.

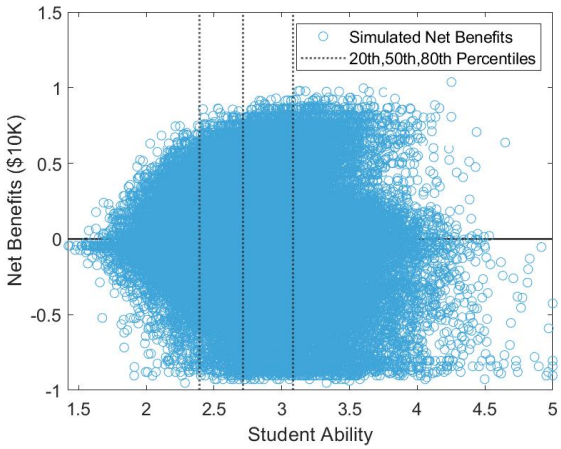
6.2 The General Equilibrium Incidence of Public Investment

We now reexamine incidence using our CV framework. We first decrease state appropriations per student by 10 percent, or about $700, holding private college sticker prices fixed. This corresponds to the equilibrium presented in Column (2) of Table 3. Panels (a) and (b) of Figure 5 present the distribution of CV by income and ability, respectively. A positive number indicates that a household is better off when state spending is high; she would need to be given a positive amount

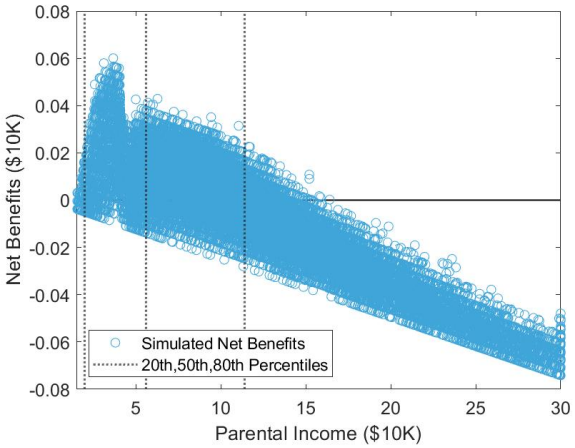
[26] Note that since attendance decisions are fixed, so are capital costs.



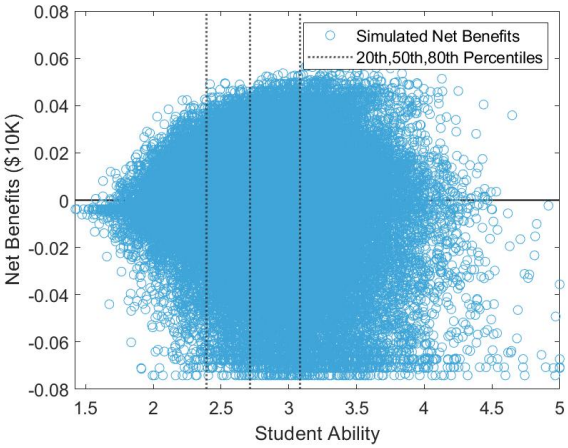
(a) Total net benefits by income



(b) Total net benefits by ability



(c) 10% decrease net benefits by income



(d) 10% decrease net benefits by ability

Figure 4: Net Benefits for Public Higher Education Investment

Note: Each open circle represents average net benefits for one draw from the joint distribution of income and ability using the accounting approach. For each household, we take 20 draws from the preference distribution, find the implied college enrollment decision, and then average over the corresponding net benefits. Panels (a) and (b) present the distribution for public colleges, while (c) and (d) for a 10 percent decrease in appropriations. The dotted vertical lines represent the 20th, 50th and 80th percentiles of the income and ability distribution. A positive value implies that the average household of type (b, y_p) receives more in college expenditure than it pays in tuition and taxes.

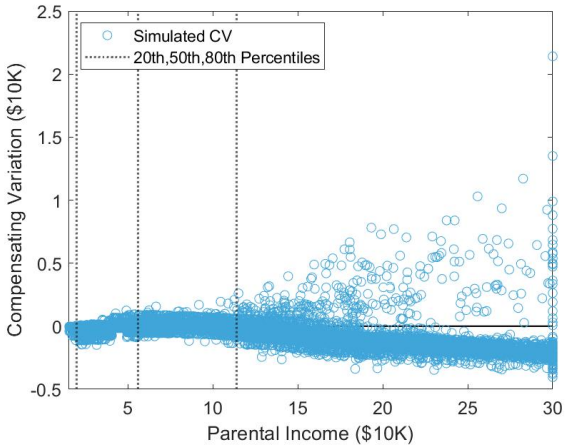
of money to be just as well off after the decrease. Each open circle represents the average CV for a household of type (b, y_p) based on 20 draws from the preference distribution. We focus on the average CV to highlight the distributional effects.[27]

Public investment in higher education is weakly progressive, but high-income-modest-ability students benefit the most. They are crowded out of HP since more low-income-high-ability students now enroll. The implied change in the minimum ability threshold generates the large positive spike in CVs in panel (b) near the 60th percentile of ability. Many of these students lose access to their preferred college and face a large cost to move to their next best option. The negative welfare effects are especially concentrated among the high-income because low-income-modest-ability households are less likely to enroll in the high price privates where they are charged the full sticker price. Even those that do are not as harmed when moving to the lower price public colleges. Given relative prices and qualities, the publics and privates are closer substitutes for lower income households.

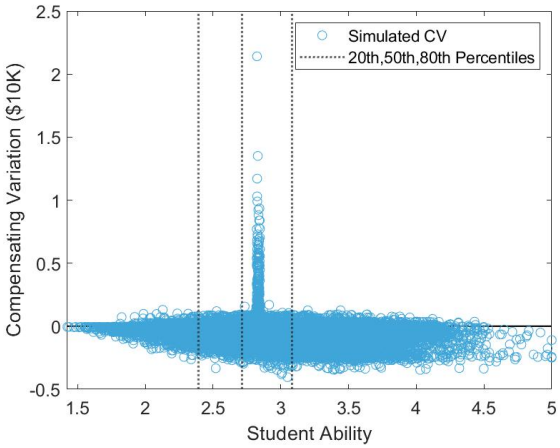
Most students who enroll in public colleges when state support is high are also negatively affected by the appropriations decrease, but the welfare effects are smaller in magnitude than those on the high-income-modest-ability. This mainly affects above median income households who are the most likely to enroll in the in-state public, as seen in the small hump in panel (a) from \$50K to \$100K. Their preferred baseline, $(\bar{z})$, college option becomes lower quality and more expensive, implying a positive CV, especially for those that still enroll. They are not very mobile across sectors because the privates are too expensive and the returns to any college are high. However, some lower ability students who still enroll in the public colleges after the appropriations decrease are better off because the value of the increased returns to college outweighs the decrease in quality. By missing the general equilibrium labor market effects, the accounting approach overstates the negative effects on these students. Slightly lower income households are less affected because their federal aid increases with prices.

Baseline public college students can partially avoid the effects of higher public tuition and

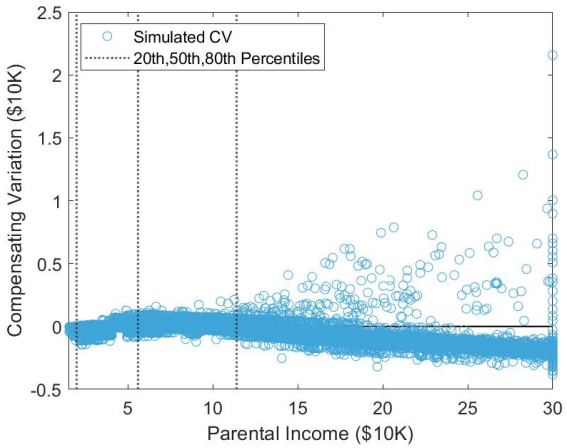
[27] Appendix D presents results conditional on a (b, y_p, ε)'s attendance decision.



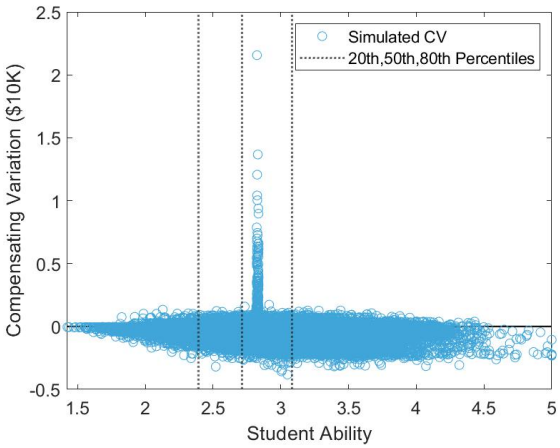
(a) CV by income with fixed sticker prices



(b) CV by ability with fixed sticker prices



(c) CV by income with endogenous sticker prices



(d) CV by ability with endogenous sticker prices

Figure 5: Compensating Variation for Public Higher Education Investment

Note: Each open circle represents average compensating variation (CV) for one draw from the joint distribution of income and ability. For each household, we take 20 sets of draws from the preference distribution, compute the corresponding CV based on equilibrium changes and the enrollment decisions, and then average over the 20 estimates. The dotted vertical lines represent the 20th, 50th and 80th percentiles of the income and ability distribution. A positive value in panels (a) and (b) denotes that the household is better off under the baseline than when appropriations decrease by 10 percent, holding private college sticker prices fixed. Panels (c) and (d) allow private colleges' sticker prices to endogenously adjust.

lower college quality by enrolling in the privates or not enrolling in any college. However, when they leave the public sector, they still face the private and labor market general equilibrium effects. College choice, as a function of state funding, is important for assessing who benefits. The low income are especially harmed because the price increases push some of them out of the college market, and they see their wages fall from the decreases in both human capital and the returns to human capital as non-college workers. The higher income, who are less burdened by the private price increases, are more likely to shift to the higher quality colleges where they benefit from the increased returns to college. The overall welfare effect is ambiguous in sign for these students, but since they no longer pay public college tuition, CV is often negative.

High-income-high-ability students benefit the most from state divestment. As more high-ability students shift to HP and all privates collect more tuition revenue, the colleges become higher quality. However, these households always pay the full sticker price. They receive a higher quality education, when the returns to quality are higher, while paying the same tuition and lower taxes. Although missed by the accounting approach, the general equilibrium consequences of public investment have large and varied effects on the high-income. Excluding these effects creates biases in both directions.

The equilibrium changes in the private college and labor markets have an ambiguous welfare effect on lower income baseline private college students. The moderate income households value the increased quality and returns to college more than the added tuition costs, while the reverse is true for lowest income. The higher prices lead some students to enroll in the less expensive and lower quality public colleges or not enroll in any college– increased private market power crowds out some low-income students.[28] For those who switch to the public sector from the privates, the welfare effect could be positive or negative, depending on the individual's benefits from the increased returns to college. However, CV is shifted up because they only pay public college tuition when spending is low.

Finally, the equilibrium labor market changes have a negative welfare effect on baseline non-

[28] Very few students are no longer able to afford college from the price change. However, price increases enough that the privates are no longer their best option.

college workers, especially the low income. Their wages decrease as college human capital becomes more scarce from the increased private college market power and decrease in public college value. The changes in the college market spill over to non-college workers since the two are linked through the economy's production function. With more public investment, non-college workers benefit from less competition in the labor market. Although the accounting approach implies that these students have negative net benefits from paying taxes, it understates progressivity by ignoring these general equilibrium effects.

Inframarginal college attendees in the baseline enroll in college after the shock because of the decrease in relative earnings. The welfare effect is ambiguous in sign, similar to what we describe for several other cases, because both price and the returns to college increase. This trade-off is more likely to be a net benefit for the high-income baseline non-college workers, who enroll in LP or MP. Lower income, modest ability students switch to the publics to avoid the low non-college wages and are worse off but often have positive CVs because the policy change leads them to pay public college tuition.

With increased demand after the negative shock to appropriations, the privates increase their sticker prices. Panels (c) and (d) of Figure 5 present the distribution of CV allowing the maximum prices to adjust, as in Column (3) of Table 3. Since the sticker prices minimally increase, the results are qualitatively similar to the previous case. However, the mass of positive points for households in the top of the income distribution in Panel (c) is slightly smaller than in Panel (a).[29] With higher sticker prices, more students are able to compensate HP for their modest ability. Public investment is still weakly progressive, but the largest benefits go to modest ability students who only have access to HP when state spending is high.

Sticker price increases also create other equilibrium changes in college price and quality, the wage premium, and taxes that matter for incidence. Overall, these effects are much smaller in magnitude than changes in admission, but impact all households. The sign of these effects on welfare varies with income and ability, but the implications for incidence are analogous to the fixed

[29]For example, in panel (c), 1.03 percent of households in the top 10 percent of the income distribution have positive average CV. In panel (a), the corresponding percent in 1.21.

sticker price case because they all move in the same direction from the baseline. Compared with the fixed sticker price case, high-income-high-ability students receive much of the new benefits because HP's quality increases along with the returns to quality. Since they are high income, they always pay (nearly) the full sticker price so tuition only increases modestly. Most of the new burden from the sticker price increases falls on the lower income, who are more harmed by the increase in prices than benefit from the increase in private college quality.

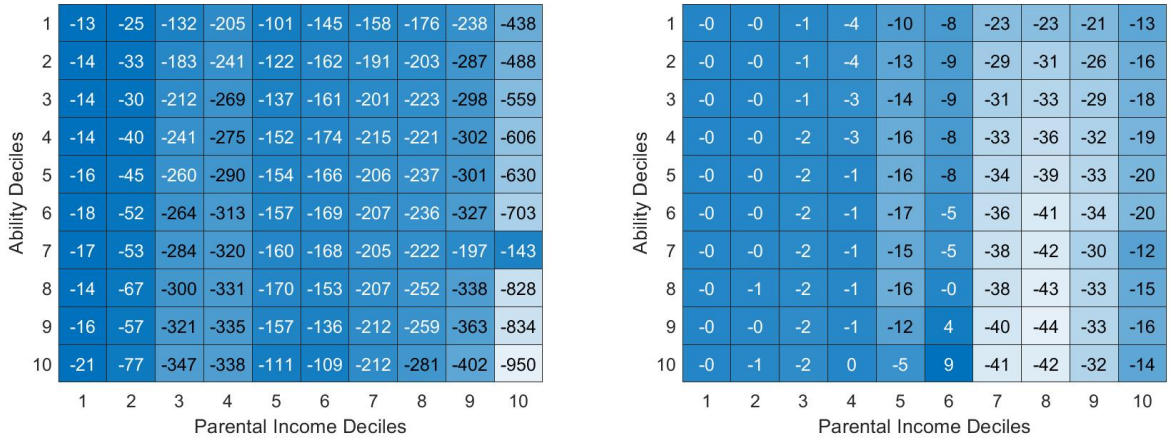
Our results suggest that high-income-modest-ability students benefit the most from public investment in higher education because the general equilibrium effects are large. Since these households are very likely to attend the privates under the current level of state appropriations, the accounting approach would instead say that they do not benefit but pay high taxes. However, these households only have access to the highest quality private college when state spending is high. By ignoring the spillover effects, the accounting approach mischaracterizes incidence.

6.3 The Bias from Ignoring Equilibrium Effects

We consider two policy relevant measures of the bias from ignoring equilibrium effects. First, in Panel (a) of Figure 6, for each income-ability decile, we present average CV with endogenous sticker prices and wages minus the accounting approach for a 10 percent decrease in state appropriations (Equation 1 - Equation 15). In Panel (b) we define the bias as the percent of households with positive CV minus the percent with positive accounting measures. More negative values are shaded lighter and indicate that the accounting approach overstates the benefits by more.

Overall, the accounting approach overstates both the average benefits and the number of households that benefit from public investment, but the magnitude varies by income and ability because the general equilibrium effects are large but varied in sign. The largest differences in magnitude in Panel (a) are for the highest income decile. They benefit from the implications on private college quality and the labor market. Ignoring these effects leads to substantial bias for measuring who benefits. The bias is large enough that the accounting approach also gets the sign of the welfare effect wrong for about 16 percent of the highest income decile households.

The average net benefits and CV for the very high income households in the seventh ability



(a) Average Benefits

(b) Percent Positive Benefits

Figure 6: Difference Between CV and Accounting Approaches

Note: Panel (a) shows the difference between CV and 10 percent of net benefits from the accounting approach in dollars by income-ability deciles. Panel (b) shows the difference in the percent of households with positive compensating variation minus percent with positive net benefits by income-ability deciles.

decile are much closer in magnitude but only because the welfare effects from changes in private college market power vary in sign. High-income-modest-ability students between the 60th and 61st ability percentiles are crowded out of HP when state funding decreases and are much worse off, while those above the 61st benefit from the increases in private quality and the returns to college.

Slightly lower income households in the seventh, eighth, and ninth deciles, are similarly affected, although to a lesser extent, from the increase in private market power and the returns to college. Increased market power leads to price increases for these students since they are less likely to pay the full sticker price. These households additionally have more negative CV, on average, because they are especially likely to switch to the private colleges after the public funding decrease. They avoid the negative effects of divestment on the public colleges, and they no longer pay public college tuition. Those who remain at the public colleges also benefit from the increased returns to college human capital.

The difference between CV and the accounting measure is nearly uniformly decreasing in ability for the relatively high income, except for the high-income-modest ability who are crowded out of HP. Both the human capital returns to college quality and the labor market returns to college

are higher for higher ability students. However, the same pattern does not hold for the percent with positive benefits because public college enrollment and the likelihood of moving from a public to private college after state divestment are non-linear functions of ability, conditional on income.

The interaction between college choice, private college market power and the labor market are especially important for households in the fifth and sixth income deciles. Many only enroll in public colleges when state spending is low. The private colleges become too expensive, and non-college wages fall. The changes in tuition from changes in enrollment not captured by the accounting approach have a large impact on CV. These interaction effects are also important for households in the third and fourth income deciles. Since college imposes a large financial burden, the public college price increases lead some to no longer enroll. They are made worse-off from the decrease in relatively wages and loss of human capital. However, they only pay public college tuition when state spending is high, which pushes CV down.

Finally, although the difference between the two approaches is small for households in the bottom two income deciles, the composition of the total effects are different. These households are mainly affected by the tax changes, which both approaches capture, and the labor market effects. Since fewer students enroll in the public colleges after the spending decrease, governments need less tax revenue. The accounting approach understates the decrease in equilibrium tax rates because enrollments are fixed. This alone would lead CV to be larger than the accounting measure. However, for these students, the accounting approach overstates the total benefits because it does not include the negative labor market externalities.

7. Conclusion

Previous measures of the incidence of public investment in higher education implicitly ignore general equilibrium effects. We use a CV framework in a general equilibrium model to understand how responses in the private college and labor markets affect the distribution of benefits. We show that public investment puts competitive pressure on the privates and reduces the college wage premium, which creates benefits for students who do not attend public colleges. Unlike the previous approaches, our measures capture the spillover effect on private college prices and

admissions, student enrollment, and the aggregate implications for relative wages.

We find that these general equilibrium effects are large in magnitude and vary with both income and ability. This makes signing the bias from the previous approaches difficult. Students who look similar based on their income and college attendance decisions face different consequences of state divestment. For example, high-income-modest-ability students benefit the most because they are only admitted to the privates when when state support is high. However, the high-income, slightly higher ability students are not crowded out after divestment. They retain access to the highest quality private colleges when increased private market power improves quality and raises their wages.

Our framework for measuring incidence builds on, and helps validate, stylized general equilibrium models of higher education, but the qualitative findings and mechanisms we highlight hold as long as peer effects are important for the production of college human capital. In that case, "modest-ability" students benefit the most from public investment, but exactly which students are crowded out and the magnitude of the effect is sensitive to model specification.

8. References

Anderson, Nick, "Attention, college shoppers. These schools are slashing their prices," The Washington Post, January 21, 2019

Autor, David H. "Skills, education, and the rise of earnings inequality among the "other 99 percent"." Science 344, no. 6186 (2014): 843-851.

Baker, Michael, Dwayne Benjamin, and Shuchita Stanger. "The highs and lows of the minimum wage effect: A time-series cross-section study of the Canadian law." *Journal of Labor Economics* 17, no. 2 (1999): 318-350.

Bettinger, Eric P., Bridget Terry Long, Philip Oreopoulos, and Lisa Sanbonmatsu. "The role of application assistance and information in college decisions: Results from the H&R Block FAFSA experiment." *The Quarterly Journal of Economics* 127, no. 3 (2012): 1205-1242.

Black, Dan A., and Jeffrey A. Smith. "Estimating the returns to college quality with multiple proxies for quality." *Journal of Labor Economics* 24, no. 3 (2006): 701-728.

Bound, John, Breno Braga, Gaurav Khanna, and Sarah Turner. "A Passage to America: University Funding and International Students." American Economic Journal: Economic Policy 12, no. 1 (2020): 97-126.

Bound, John, Breno Braga, Gaurav Khanna, and Sarah Turner. "Public universities: The supply side of building a skilled workforce." RSF: The Russell Sage Foundation Journal of the Social Sciences 5, no. 5 (2019): 43-66.

Bound, John, Brad Hershbein, and Bridget Terry Long. "Playing the admissions game: Student reactions to increasing college competition." *Journal of Economic Perspectives* 23, no. 4 (2009):

119-46.

Bound, John, Michael F. Lovenheim, and Sarah Turner. "Why have college completion rates declined? An analysis of changing student preparation and collegiate resources." *American Economic Journal: Applied Economics* 2, no. 3 (2010): 129-57.

Bound, John, and Sarah Turner. "Cohort crowding: How resources affect collegiate attainment." *Journal of Public Economics* 91, no. 5-6 (2007): 877-899.

Chade, Hector, Gregory Lewis, and Lones Smith. "Student portfolios and the college admissions problem." *Review of Economic Studies* 81, no. 3 (2014): 971-1002.

Conlisk, John. "A Further Look at the Hansen-Weisbrod-Pechman Debate." The Journal of Human Resources 12, no. 2 (1977): 147-63. Accessed June 23, 2021.

Cook, Emily E., and Sarah Turner. "Progressivity of Pricing at US Public Universities." Tulane Economics Working Paper Series, (2021).

Deming, David J., and Christopher R. Walters. "The impact of state budget cuts on US postsecondary attainment." 2018.

Dynarski, Susan, C. J. Libassi, Katherine Michelmore, and Stephanie Owen. "Closing the gap: The effect of reducing complexity and uncertainty in college pricing on the choices of low-income students." *American Economic Review* 111, no. 6 (2021): 1721-56.

Epple, Dennis, and Richard E. Romano and Holger Sieg. "Admission, tuition, and financial aid policies in the market for higher education." *Econometrica* 74, no. 4 (2006): 885-928.

Epple, Dennis, Richard Romano, Sinan Sarpça, and Holger Sieg. "A general equilibrium analysis of state and private colleges and access to higher education in the US." *Journal of Public Economics* 155 (2017): 164-178.

Epple, Dennis, Richard Romano, Sinan Sarpça, and Holger Sieg, and Melanie Zaber. "Market Power and Price Discrimination in the US Market for Higher Education." *Rand Journal of Economics* (2019)

Fillmore, Ian. "Price Discrimination and Public Policy in the US College Market. Employment Research Newsletter. Volume 23, Number 2." *WE Upjohn Institute for Employment Research* (2016).

Fu, Chao. "Equilibrium Tuition, Applications, Admissions, and Enrollment in the College Market." *Journal of Political Economy* 122, no. 2 (2014): 225-81.

Fu, Chao, Junjie Guo, Adam J. Smith, and Alan T. Sorensen. "Students' Heterogeneous Preferences and the Uneven Spatial Distribution of Colleges." No. w28343. National Bureau of Economic Research, 2021.

Fu, Chao, Shoya Ishimaru, and John Kennan. "Government Expenditure on the Public Education System." No. w26425. National Bureau of Economic Research, 2019.

Gordon, Grey, and Aaron Hedlund. "Accounting for the Rise in College Tuition." Education, Skills, and Technical Change: Implications for Future US GDP Growth (2018): 357-394.

Hansen, W. Lee, and Burton A. Weisbrod. "The distribution of costs and direct benefits of public higher education: the case of California." *Journal of Human Resources* (1969): 176-191.

Hoekstra, Mark. "The effect of attending the flagship state university on earnings: A discontinuity-based approach." *The Review of Economics and Statistics* 91, no. 4 (2009): 717-724.

Hoxby, Caroline, and Christopher Avery. "The missing" one-offs": The hidden supply of high-achieving, low-income students." *Brookings Papers on Economic Activity* 2013.1 (2013): 1-65.

Hoxby, Caroline, and Sarah Turner. "What high-achieving low-income students know about college." *American Economic Review* 105.5 (2015): 514-17.

Johnson, George E. "Subsidies for Higher Education." *Journal of Labor Economics* 2, no. 3 (1984): 303-18.

Johnson, William R. "Are public subsidies to higher education regressive?" *Education Finance and Policy* 1.3 (2006): 288-315.

Kasman, Matt, and Katherine Guyot. "Predicting the Impact of College Subsidy Programs on College Enrollment." Brookings. October 21, 2019.

Lochner, Lance, and Alexander Monge-Naranjo. "Credit constraints in education." *Annual Review of Economics* 4, no. 1 (2012): 225-256.

McDuff, DeForest. "Quality, tuition, and applications to in-state public colleges." *Economics of Education Review* 26, no. 4 (2007): 433-449.

McFadden, Daniel. "The measurement of urban travel demand." *Journal of Public Economics* 3, no. 4 (1974): 303-328.

Pechman, Joseph A. "The Distributional Effects of Public Higher Education in California". *Journal of Human Resources* 5 (1971): 361-370.

Pechman, Joseph A. "The Distribution of Costs and Benefits of Public Higher Education: Further Comments". *Journal of Human Resources* 6 (1971): 375-3

Peltzman, Sam. "The effect of government subsidies-in-kind on private expenditures: The case of higher education." *Journal of Political Economy* 81, no. 1 (1973): 1-27.

Rothschild, Michael, and Lawrence J. White. "The analytics of the pricing of higher education and other services in which the customers are inputs." *Journal of Political Economy* 103, no. 3 (1995): 573-586.

Rizzo, Michael, and Ronald G. Ehrenberg. "Resident and nonresident tuition and enrollment at flagship state universities." College choices: The economics of where to go, when to go, and how to pay for it. University of Chicago Press, 2004. 303-354.

Van Der Klaauw, Wilbert. "Estimating the Effect of Financial Aid Offers on College Enrollment: A Regression-Discontinuity Approach." *International Economic Review* 43, no. 4 (2002): 1249-287.

Webber, Douglas A. "State divestment and tuition at public institutions." *Economics of Education Review* 60 (2017): 1-4.

Winston, Gordon C. "Subsidies, hierarchy and peers: The awkward economics of higher education." *Journal of economic perspectives* 13, no. 1 (1999): 13-36.

Zimmerman, Seth D. "The returns to college admission for academically marginal students." *Journal of Labor Economics* 32, no. 4 (2014): 711-754.

A. Calibration Results

Table 4 shows that the model matches our target moments well. The college market moments are close to the data, although the private aid elasticities are just outside the boundary of the targeted ranges. The model also approximates the distribution of college attendance by income and ability. Our approach builds on Epple et al. (2017), but can better match these patterns. This is mostly because we allow the no 4-year college option to be a function of both income and ability, rather than fixed across the population. However, our parametrization is highly stylized[30] and the model understates enrollment for the high-income and high-ability. This likely biases our findings against the mechanisms we highlight because it implies that the model understates the value of college quality for the high-ability (weakens the general equilibrium sorting effects), while overstates the value of no college for the high-income (weakens the negative consequences of no longer being admitted to the privates).

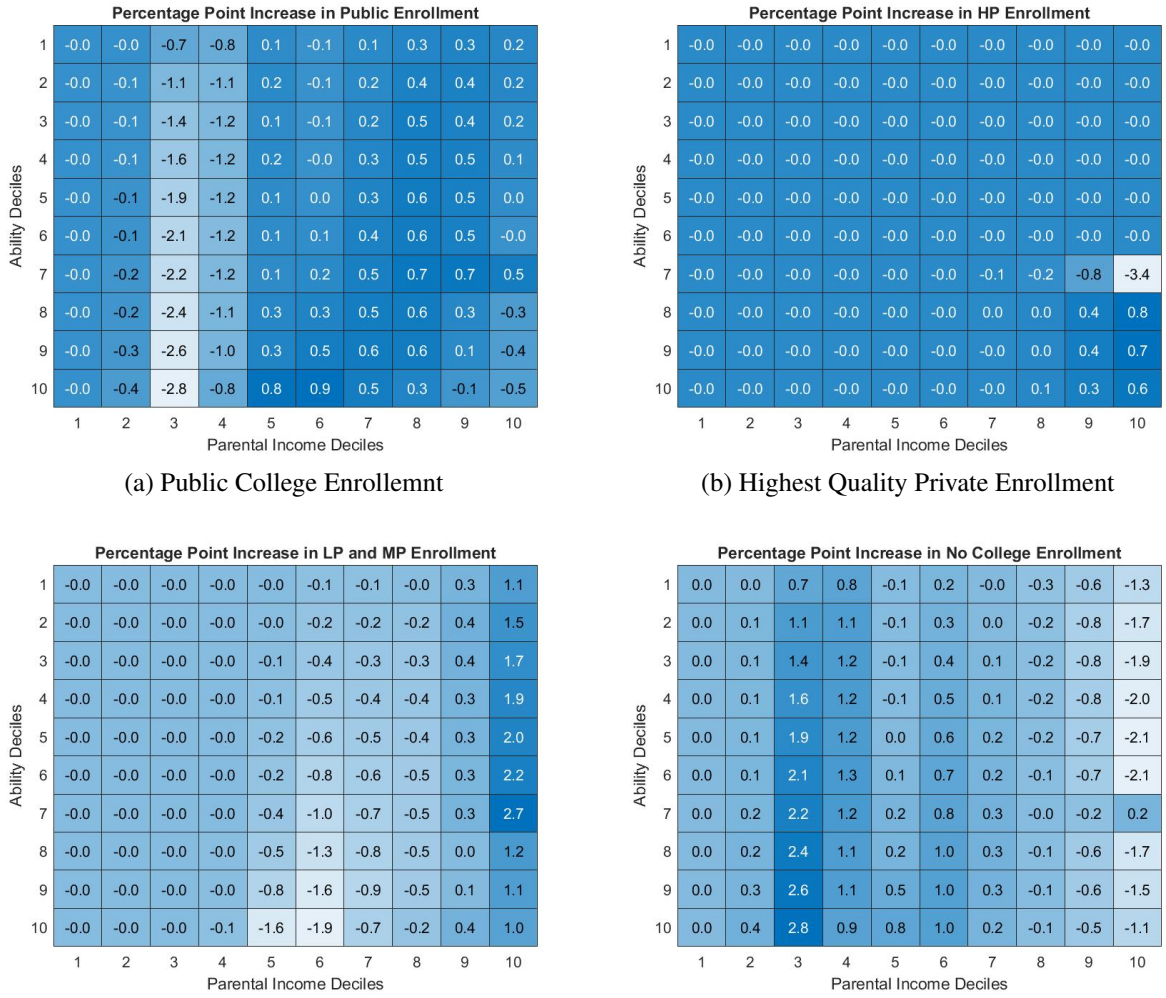
[30]For tractability, the value of college and utility are continuously differentiable in income and ability, where all households have the same preference parameters (e.g. αs).

Table 4: Calibration Results

Moment	Data	Model
College Market Moments:		
Average Private Tuition	$27220	$26978
Private Enrollment as Percent of Total	28.5	28.6
Enrollment Elasticity of Aid	0.700	0.700
Additional Private Aid for 1 Std Increase in Ability	(920,1960)	918
Additional Private Aid for $10000 Decrease in Income	(210, 510)	516
Earnings Percent Increase for Marginal-Ability Student	20.0	21.9
Public College Instructional Expenditure	$10463	$10436
Percent Enrolled in College with 2011 Income between:		
$15k and $35k	25.6	21.9
$35k and $55k	32.6	40.2
$55k and $75k	41.2	42.2
$75k and $95k	47.8	49.8
$95k and $135k	54.2	54.9
more than $135k	65.5	62.9
Percent Enrolled in College by Ability quintile:		
First (Lowest)	13.7	12.4
Second	23.4	24.3
Third	32.2	34.2
Fourth	53.9	47.1
Fifth (Highest)	75.9	64.8

B. Investment and Enrollment

Figure 7 shows how attendance changes by student income and ability after a 10 percent decrease in state appropriations per student, allowing private college sticker prices to adjust based on our empirical estimates.



(a) Public College Enrollemnt

(b) Highest Quality Private Enrollment

(c) Low and Middle Quality Private Enrollment

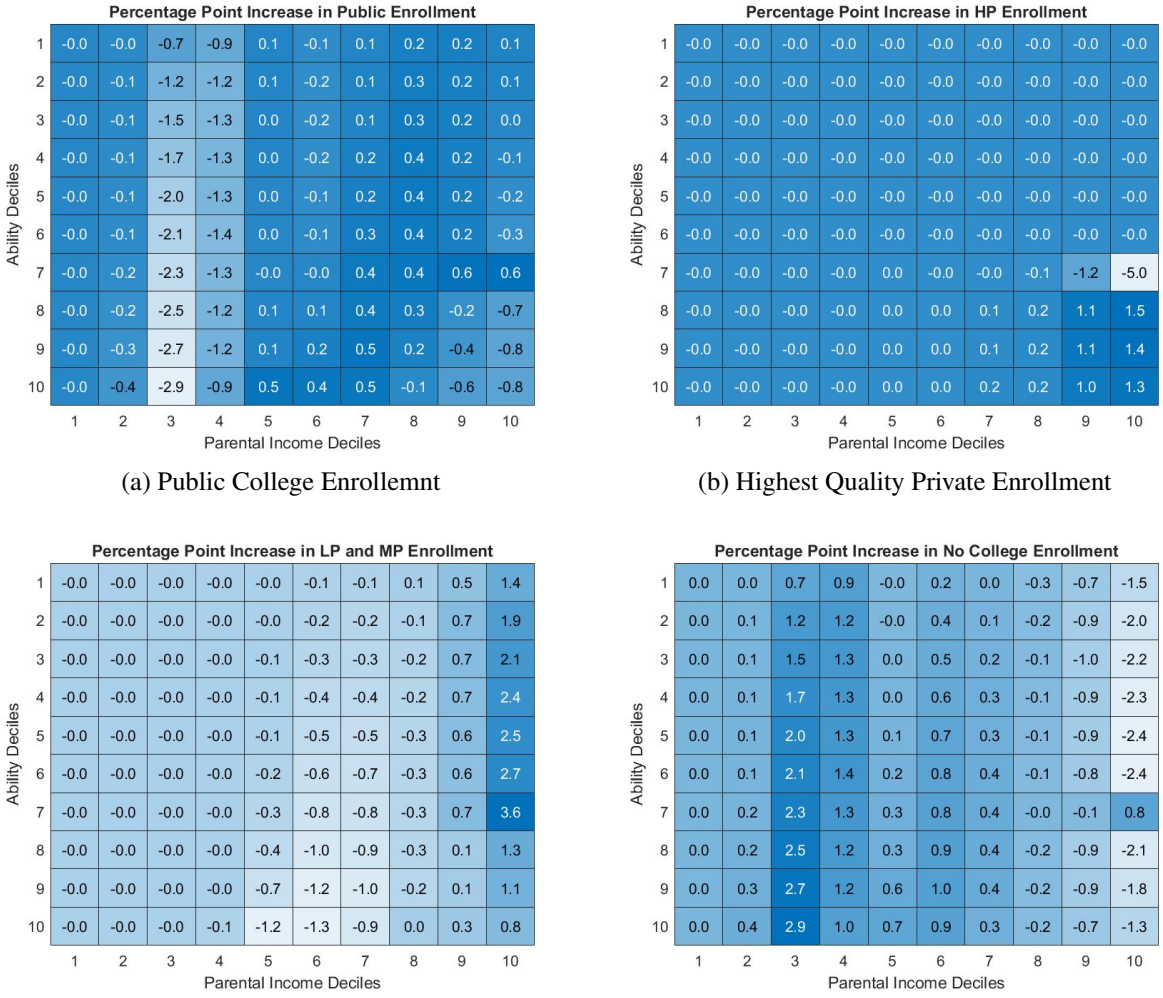
(d) No College Enrollment

Figure 7: Public Investment and Enrollment with Endogenous Sticker Prices

Note: Each panel is a heat map of the percentage point increase in enrollment after a 10 percent decrease in state spending per student, when allowing private college sticker prices to endogenously adjust. A darker shade denotes that enrollment increases by more after appropriations decrease.

Figure 8 shows how attendance changes by student income and ability after a 10 percent decrease in state appropriations per student, holding private college sticker prices fixed to their base-

line levels.



(a) Public College Enrollemnt

(b) Highest Quality Private Enrollment

(c) Low and Middle Quality Private Enrollment

(d) No College Enrollment

Figure 8: Public Investment and Enrollment with Fixed Sticker Prices

Note: Each panel of the figure is a heat map showing the percentage point increase in student enrollment after a 10 percent decrease in state appropriations per student, when allowing private college sticker prices are fixed to their baseline levels. A darker shade denotes that enrollment increases by more after appropriations decrease.

C. Public College Responses to State Appropriations

Following the empirical strategy of Sections 2 and **??**, we estimate the following specifications on four year public colleges to test the model's prediction about the change in student ability after a decrease in the college's own state's spending per student, z_{st}:

$$SAT_{jt} = \sum_{d=1}^{10} \kappa_d \mathbb{1}_{dj} \log(z_{st}) + \pi_j + \psi_t^1 + \psi_s^2 t \mathbb{1}_s + u_{jt} \tag{16}$$

where SAT_{jt} is the average of the 25th and 75th math and verbal SAT score percentiles for students enrolled in public college j in year t, $\mathbb{1}_d j$ is an indicator that is 1 if college j is in decile d of public college Fall 2001 SAT scores, π_j are institution fixed effects, ψ_t^1 are year fixed effects, and $\psi_s^2 t \mathbb{1}_s$ are state linear time trends. Since the treatment here is at the state level, we cannot include state-by-year fixed effects like in the other specifications on the private colleges. The unconditional specification estimates the general equilibrium effect. We additionally estimate a specification where we control for the log of the average private college sticker price in college j's state in a given year to approximate our fixed sticker price simulations. The coefficients are plotted in Figure 9.

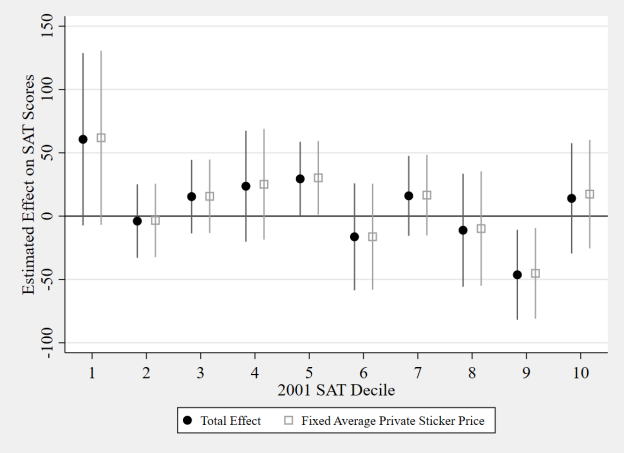


Figure 9: State Appropriations and Public College SAT Scores

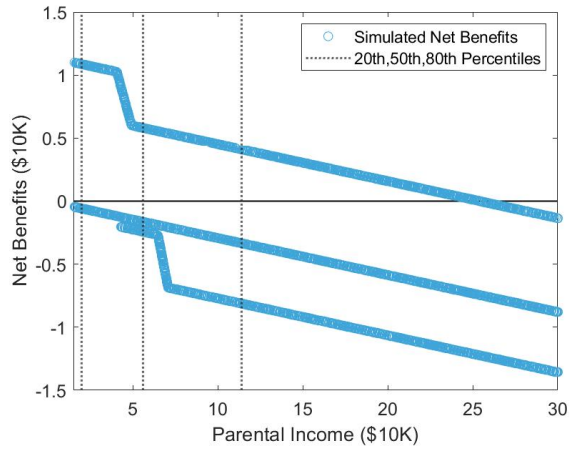
Note: The figure presents elasiticity estimates and 95 percent confidence intervals of the effect of changes in public college j's own state's appropriations per student on SAT scores by 2001 SAT decile using data from IPEDS 2002 to 2017. The sample size is 3480 and standard errors are clustered by institution. The solid circles show the total effect, while the open squares control for the log of the average private college sticker price in j's state in a given year.

The results provide some mixed evidence for the model predictions. From the model, we would expect that the higher quality public colleges (deciles six through ten) that compete with the privates would see an increase in student SAT scores after a decrease in state funding per student. Only the point estimates for three of the five deciles have the predicted sign, but the estimated effect is negative and significant for the ninth decile. The model also predicts that the general equilibrium elasticity should be more negative when holding private college sticker prices fixed. We find this to be the case in the data for all ten deciles, which supports the main mechanism we highlight in the model about the importance of private college market power and sticker prices.

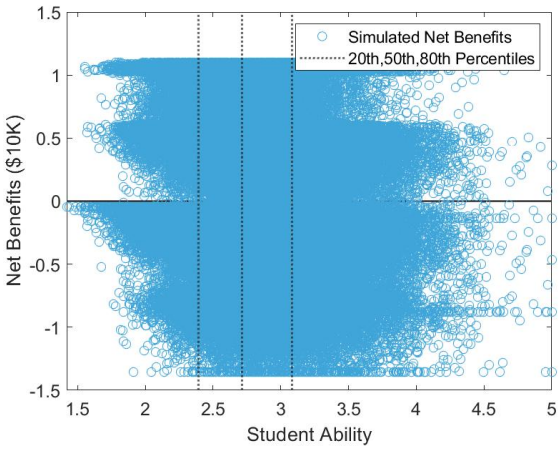
D. Incidence by Attendance Decision

We present our model implied net benefits and compensating variation for each household of type (b, y_p, ε). Figure 10 presents the net benefits from the model implied accounting approach conditional on students' enrollment decisions. In panel (a) shows that there are three possible values for net benefits based on a household's income. For the very low income who cannot afford the out-of-state public, there are only two possible values. This is because public tuition, net of federal aid, and taxes are determined by income alone. The top line represents those who attend the publics and pay low tuition but receive instructional and capital expenditure, the middle line represents those who attend the privates or do not attend college and therefore only pay taxes, and the bottom line represents those who pay high out-of-state tuition plus taxes in exchange for the public college's services. Panels (c) and (d) show how the accounting measure changes after a 10 percent decrease in appropriations. Although these illustrations are helpful for seeing the magnitude of net benefits based on enrollment, it does not show the likelihood of taking up the services by income or ability, which are important for incidence.

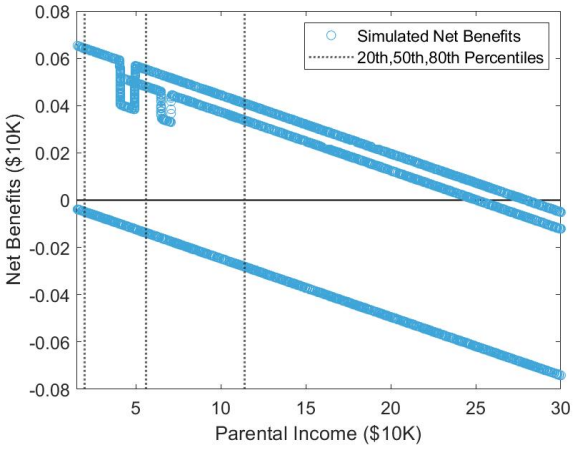
Figure 11 conducts a similar exercise conditional on students' enrollment decisions in both the baseline and counterfactuals using the general equilibrium model and our CV framework. Conditional on college enrollment decisions, CV is mostly linear in income and ability which generates the horizontal lines in the figure. For example, the bottommost line in all panels corresponds to students who attend the out-of-state public in the baseline, but then enroll in the privates when state spending is lower. They are better off because the returns to college quality increased while taxes decreased, and were nearly indifferent between those two options in the baseline. CV for these students is especially low because they no longer help finance public expenditure with high out-of-state tuition. Students who lose access to the highest quality college have much larger CVs and are located above the horizontal lines.



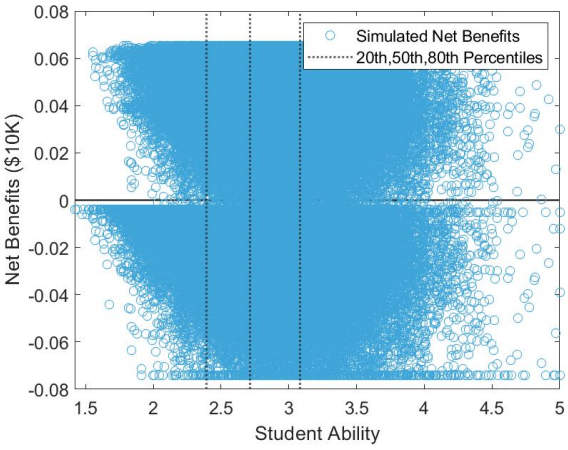
(a) Total net benefits by income



(b) Total net benefits by ability



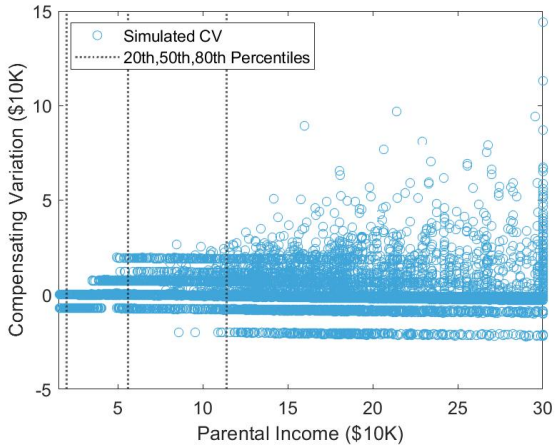
(c) 10% decrease net benefits by income



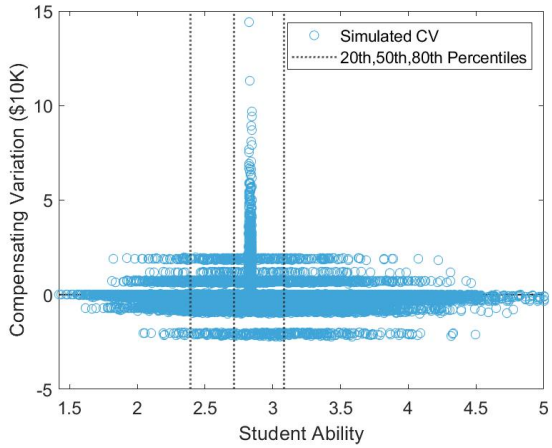
(d) 10% Decrease net benefits by ability

Figure 10: Net Benefits by Attendance Decisions

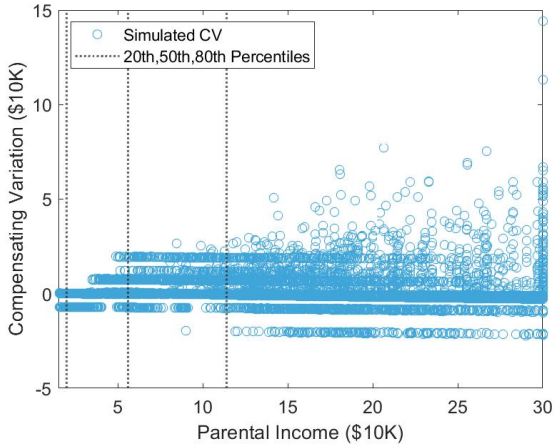
Note: Each open circle represents average net benefits for one draw from the joint distribution of income and ability using the accounting approach based on the household's preference shocks and corresponding enrollment decision. For each of 100,000 households, we take 20 draws from the preference distribution. Panels (a) and (b) present the distribution for public colleges, while (c) and (d) for a 10 percent decrease in appropriations. The dotted vertical lines represent the 20th, 50th and 80th percentiles of the income and ability distribution. A positive value implies that the household of type (b, y_p, ε) receives more in college expenditure than it pays in tuition and taxes.



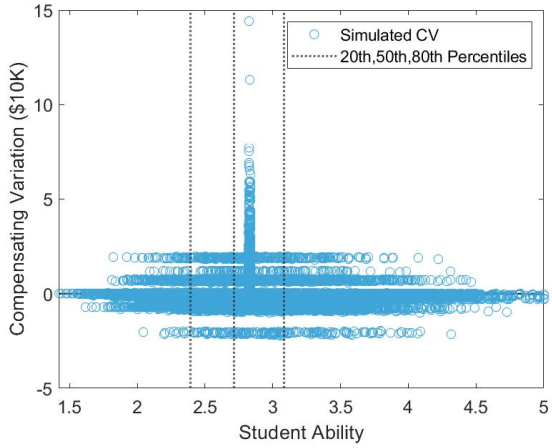
(a) CV by income with fixed sticker prices



(b) CV by ability with fixed sticker prices



(c) CV by income with endogenous sticker prices



(d) CV by ability with endogenous sticker prices

Figure 11: Incidence by Attendance Decisions

Note: Each open circle represents average compensating variation (CV) for one draw from the joint distribution of income and ability. For each household, we take 20 sets of draws from the preference distribution, compute the corresponding CV, and then average over the draws. The dotted vertical lines represent the 20th, 50th and 80th percentiles of the income and ability distribution. A positive value in panels (a) and (b) denotes that the household is better off under the baseline than when appropriations decrease by 10 percent, holding private college sticker prices fixed. Panels (c) and (d) compute average CV when private college's sticker prices endogenous adjust.

E. Incidence Comparative Statics

To further highlight how changes in the private college market affect the incidence of public investment in higher education, we simulate the effect of a 1 percent increase in γ and ω with endogenous sticker prices. Changes in these parameters affect student sorting through the returns to attending a higher quality institution as well as private college admissions decisions and pricing (Equations 8 and 9). In aggregate, these decisions affect the labor market returns to college as well but the effect is very small for only a 1 percent increase.

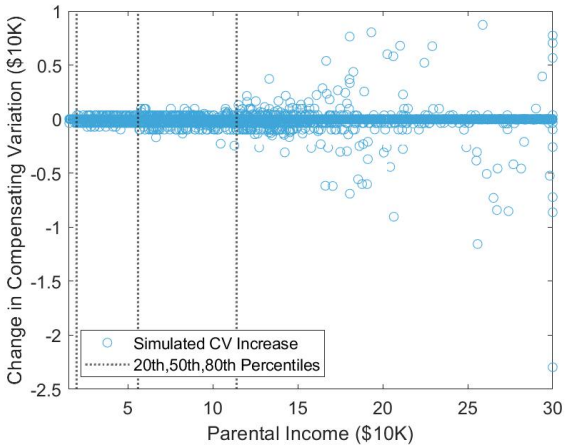
For each change in the structural parameters, we simulate the corresponding changes in compensating variation (CV) for a 10 percent decrease in appropriations per student:

$$\begin{aligned} \Delta CV(\gamma) &= CV(1.01\gamma) - CV(\gamma) \\ \Delta CV(\omega) &= CV(1.01\omega) - CV(\omega) \end{aligned} \tag{17}$$

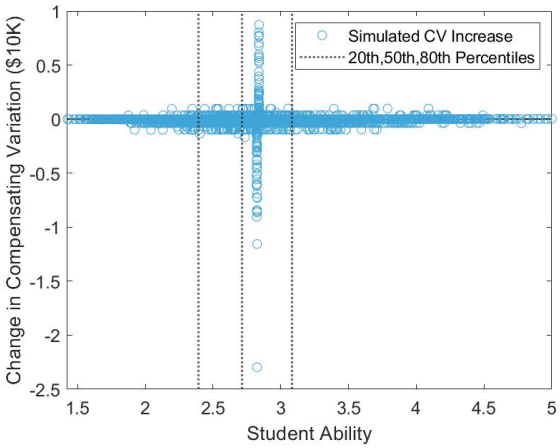
and plot the results in Figure 12. A positive value implies that a household has larger benefits from public investment in higher education when the structural parameter, γ or ω, is high.

Panels (a) and (b) show how CV changes for a 1 percent increase in γ, or the returns to peer quality, by income and ability respectively. When γ is higher, there is an ambiguous effect on private college access. The implied increase in demand for the highest quality private, because the returns to quality are now higher, lead it to increase prices. Low-income students are less likely to attend and θ_5 falls slightly. At the same time, effective marginal costs are increasing in γ for all students with ability less than the college's average, θ_5. We find that the baseline ($z = \bar{z}$) minimum ability threshold is lower, and the counterfactual threshold rises more after the state spending decrease. Based on these two changes, Panel (b) shows both a large negative and positive spike in $\Delta CV(\gamma)$. When γ is higher, additional students near the 60th percentile of ability are crowded out from decreases in public investment, while fewer are near the 62nd percentile.

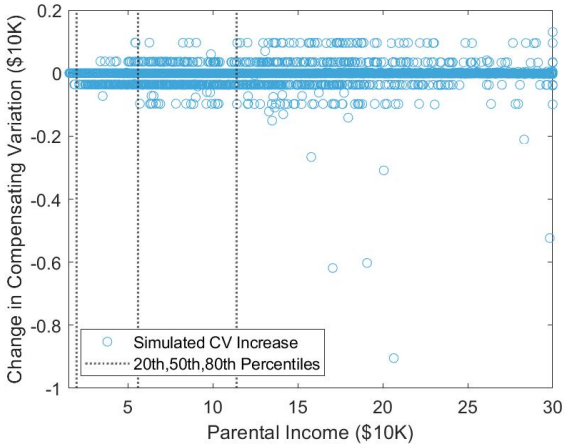
Panels (c) and (d) present the effect of a 1 percent increase in ω, or the returns to instructional



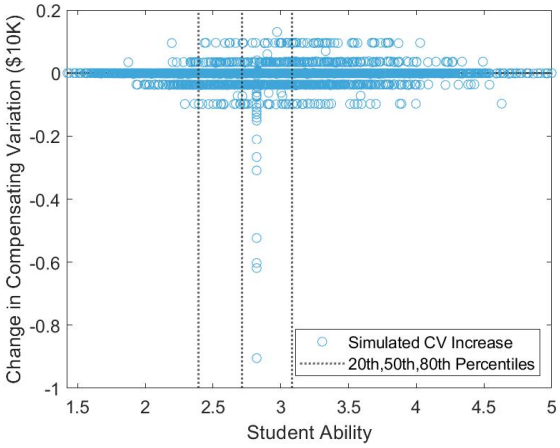
(a) 1 Percent Increase in γ by Income



(b) 1 Percent Increase in γ by Ability



(c) 1 Percent Increase in ω by Income



(d) 1 Percent Increase in ω by Ability

Figure 12: Compensating Variation Comparative Statics

Note: Each open circle represents the difference in average compensating variation for one draw from the joint income and ability distribution. For each household, we take 20 sets of draws from the preference distribution, compute the corresponding CV based on the equilibrium changes for the structural parameter and a 1 percent increase in the parameter, and average over the 20 estimates. The dotted vertical lines represent the 20th, 50th, and 80th percentiles of the distributions. A positive value implies that a household has larger benefits from public investments when the parameter (γ or ω) is high.

expenditure, on CV. When the privates value collecting tuition revenue more, additional students with lower ability are admitted to the highest quality private in the baseline with state spending is high. The minimum ability threshold falls, allowing more high-income-modest-ability students to enroll. However, these students are crowded out of the market when state spending falls. More baseline private college students are affected by the decrease in public investment in higher education when the returns to instructional expenditure are high.

In both comparative statics, others students have a non-zero change in CV largely because the increase in the structural parameters affects the likelihood they enroll in the publics. This creates relatively large changes in public college tuition and relatively small changes in the individual household's value of public spending, ν. Since increases in the structural parameters affect the returns to any college, the returns to college quality, and prices, some students are induced into the publics while others into the private market, generating the horizontal lines in all panels.