Accounting for Tuition Increases across U.S. Colleges*

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Abstract

College tuition has skyrocketed over the past few decades, yet agreement on the underlying causes remains elusive. This paper provides quantitative insights into the drivers of tuition inflation using a micro-consistent, macro-IO model of the higher education sector that features imperfect competition, price discrimination, and defaultable student loans. The model environment gives rise to equilibrium sorting between heterogeneous households and colleges as well as within-school and between-school tuition dispersion. The quantitative analysis fully accounts for the persistent rise in tuition over time and across institutions. Multiple factors—rather than one single culprit—explain these patterns, but financial aid expansions and lagging state support emerge as salient forces.

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1 Introduction

The stubborn upward march of college tuition over the past several decades continues to fuel growing alarm about access, affordability, and mounting student debt as well as resounding calls for reform. Not limited to any one segment of the market, these trends have proven remarkably broad-based across all types of four-year, nonprofit institutions—the focus of this paper. Restricting attention to the period from 1987 to 2010 before the full fallout of the Great Recession era reached higher education, real net tuition—that is, sticker tuition minus institutional need-based and merit aid—increased by 50% at selective, private research institutions (from \$15,500 to \$23,700 in constant 2010 dollars) and by an astonishing 140% (from \$2,700 to \$6,400) at nonselective public teaching colleges.[1] Figure 1 shows these trends for colleges grouped by source of control (public G vs. private P), focus (research-intensive R vs. teaching-oriented T), and selectivity (selective S vs. nonselective N). Several explanations have been offered to explain the rise in net tuition, some of which highlight economy-wide forces—such as lagging service-sector productivity growth—while others focus on college-specific factors such as state appropriations cuts, the increasing returns to a college degree, or the unintended consequences of federal student aid.

This paper quantitatively evaluates several prominent theories of college tuition inflation using detailed micro-data and a rich equilibrium macro-IO framework that incorporates several key features of the higher education landscape. To organize thinking, we group the tuition theories into those that directly affect college supply and those that shift demand. On the supply side, Baumol's cost disease emphasizes the commonality between higher education and other service sectors, with cost pressure coming from the combination of rising economy-wide wages and stagnant sectoral productivity growth. Another common supply-side explanation focuses on the role of declining state appropriations for public institutions. We analyze this theory on its own and within the broader context of changes to other sources of nontuition revenue, including endowment growth and federal funding. On the demand side, we examine the frequently mentioned Bennett hypothesis, which attributes higher tuition to the same federal student aid programs that are meant to help with college affordability. Specifically, we quantify the contribution of Federal Student Loan Program changes

[1] Athreya, Herrington, Ionescu, and Neelakantan (2021) describe in greater detail the numerous sources of disruption to higher education created by the Great Recession itself and associated policy changes during that era. We plan to quantitatively assess the impact of these forces in future work.

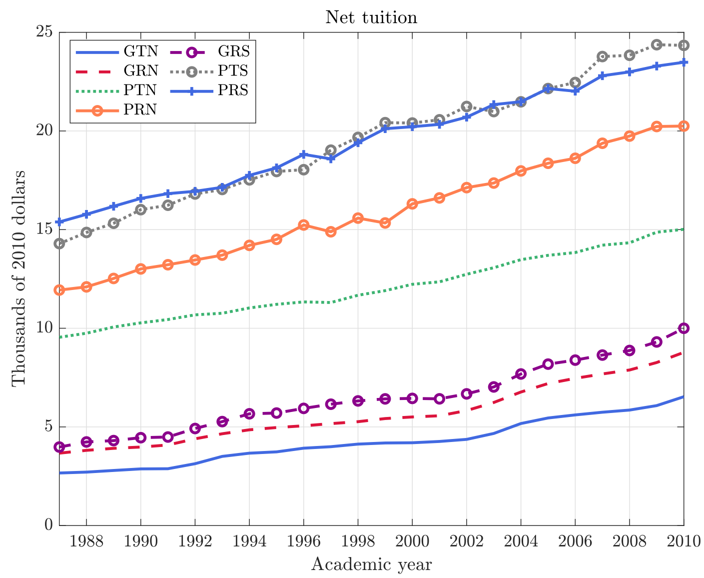


Figure 1: Net Tuition Weighted by Full-Time Equivalent (FTE) Enrollment

(such as the addition of unsubsidized student loans in 1993) as well as the evolution of loan limits, interest rates, and Pell Grant amounts. Lastly, we also examine the role of parental income growth and dynamics of the ex-ante returns to college enrollment.

Given the presence of complicated financial aid rules, extensive public subsidies, market power, and widespread price discrimination, higher education functions quite differently from most other markets. Furthermore, nonprofit institutions—the focus of this paper—face different objectives and incentives than profit-maximizing firms. To capture these features, we extend the seminal work of Epple, Romano, and Sieg (2006) to a dynamic environment that incorporates lifecycle behavior, borrowing constraints, equilibrium default, and time-varying policy and macroeconomic conditions. In their framework and ours, colleges are quality-maximizers, where quality is a function of per-student investment and average student ability. The dependence of quality on student ability makes students both consumers of, and inputs to, the production of education quality (as in Rothschild and White, 1995), which gives rise to peer effects that influence student sorting and provides colleges a rationale to charge differential tuition based on academic ability that rewards higher-achieving students with price discounts. However, to fund desired quality-enhancing student investment, colleges balance their efforts to recruit high ability students through tuition discounts with the need to raise revenue from students with a higher willingness to pay and at times lower ability. The model also features a directed search environment to capture further sources of price dispersion and frictions in the sorting between students and colleges.

Taking into account the market structure of the college sector is but one piece of the puzzle necessary to properly study the aforementioned tuition inflation theories. A rich, dynamic household component is also needed to account for important forward-looking behavior, expectations, and intertemporal decision-making, particularly as it pertains to student loan borrowing, repayment, and default choices. These channels prove relevant because of the wide gap in time and circumstances between when students make college decisions, when they must incur the cost, and when the benefits materialize. For example, the sensitivity of college demand to federal financial aid changes depends on the resource constraints students face in the present along with the economic and policy environment they expect to encounter in the future come repayment time, such as the riskiness of earnings and bankruptcy regime.

The household side of the model features heterogeneous students who differ in terms of their academic and family financial backgrounds. When deciding whether and where to go to college, students direct their search by weighing cost and college quality. The latter enters their utility directly while attending and indirectly by affecting the return to college enrollment, which depends both on the likelihood of successful graduation and the subsequent labor market premium—factors which also depend on individual student ability relative to that of peers. Upon entering the workforce, households progress through their life cycle by making decisions related to loan repayment vs. default, consumption, and savings subject to idiosyncratic earnings risk followed eventually by retirement.

Combining both sides of the market, equilibrium college quality affects the endogenous sorting of students across colleges, which in turn influences college quality, thus creating a computationally challenging fixed point problem. As a result, methodologically, this paper is the first that we are aware of that develops a macro-IO model of the higher education market which integrates a heterogeneous, imperfectly competitive college sector into a dynamic, incomplete markets, overlapping generations environment with equilibrium default. These features, in turn, allow this paper to also be the first to quantitatively evaluate several prominent tuition inflation hypotheses through a unified framework disciplined both by theory and data.

The quantitative analysis finds that the aforementioned tuition inflation theories can together explain the entire increase in average college net tuition during the 1987–2010 time period (while not our focus, the model also explains the entire increase in sticker prices, expenditures, and enrollment.) Thus, through the lens of the model, there is no apparent need for an entirely new hypothesis for rising tuition. However, the critical task that remains is understanding the relative importance of each driving force. To that end, a series of decomposition exercises reveal that some forces exert much larger pressure on the higher education market than others but without a singular smoking gun emerging to explain the upward march in net tuition.

Beginning with supply-side factors, the role of public appropriations in shaping the dynamics of net tuition depends on the source of appropriations and the choice of counterfactual. Combined public appropriations from all levels of government have actually risen modestly in real absolute terms, contributing to a slight decline in net tuition relative to if appropriations had remained fixed. However, state-level appropriations as a share of equilibrium college revenues have fallen considerably. Had this share instead remained stable—which we find would have required real appropriations to grow 2% per year on average—tuition inflation would have been markedly lower over the past few decades. Specifically, the model indicates that public, teaching-focused, nonselective (GTN) colleges would have experienced $4,000 less cumulative growth in annual net tuition, and net tuition at public, research-intensive, selective colleges (GRS) would have actually fallen in absolute terms. Surprisingly, tuition and enrollment at private colleges prove mostly unresponsive to these price declines at public colleges because of a high degree of market segmentation.

Also on the supply side, the quantitative analysis finds that Baumol's cost disease is responsible for anywhere from 13% to 31% of the observed rise in net tuition depending on the decomposition method. This wide range signifies the importance of interactive effects between Baumol's cost disease and other forces. While Baumol's cost disease on its own causes net tuition to increase by $700–$1,600 in the aggregate, the effects vary by school type, with public colleges proving more sensitive.

Shifting attention to the demand side of the ledger, expansions in federal financial aid account for 46% to 57% of the aggregate rise in annual net tuition, or $2,900–$3,600 in real terms. These results translate to a 50% to 60% pass-through rate from grant aid to net tuition—in line with some of the empirical literature—and smaller, state-dependent pass-through rates from loan limit expansions that are stronger when borrowing constraints are tight relative to prevailing college prices. The analysis also uncovers the importance of both the extensive and intensive borrowing margins. Interestingly, because of looser eligibility requirements allowing a greater number of borrowers to respond to loan limit expansions, unsubsidized loans can at times exhibit higher tuition pass-through rates compared to subsidized loans.

After aid, the strongest demand-inducing effects come from family income growth and the accompanying parental transfers, which account for between 35% and 48% of the total increase in net tuition according to the model.[2] This result mirrors recent findings about the importance of rising income dispersion for net tuition from Cai and Heathcote (2022). Lastly, the rising returns to college enrollment coming from increasing graduation rates, earnings premia, and flow utility while in college ("amenities") can jointly explain around 18% of total observed tuition inflation.

In summary, a confluence of factors contribute to the persistent rise in college prices, with financial aid expansion and lagging state appropriations as a share of college revenues emerging as particularly salient forces. However, the effects of each of the examined theories varies by institution type, which highlights the importance of heterogeneity and market structure for understanding the dynamics of tuition.

1.1 Related Literature

This paper contributes to a growing literature that employs general equilibrium models to analyze higher education. At present, nearly all of these models focus on the demand-side while taking college pricing as given. Recent work includes the analysis by Abbott, Gallipoli, Meghir, and Violante (2019) of financial aid policies on college attendance, and work by Athreya and Eberly (2021), Hendricks and Leukhina (2018a), and Chatterjee and Ionescu (2012) that studies the connection between college returns—taking into account drop-out risk—for college attainment. Garriga and Keightley (2007), Lochner and Monge-Naranjo (2011), Belley and Lochner (2007), and Keane and Wolpin (2001) also develop equilibrium models to study the macroeconomic effects of higher education. Recently, Kennan (2020) develops and estimates a college model with migration to study the role of cross-state differences in college costs in determining the state-by-state supply of college graduates.

Relative to this literature, our paper endogenizes tuition and the response of colleges to evolving market conditions and policies. In this vein, work by Jones and Yang (2016) closely mirrors the objectives here. They explore the role of skill-biased technical change in explaining the rise in college costs from 1961 to 2009. However, their study differs from this paper in several ways. First, this paper takes a unified look at

[2] Because of interaction effects, the decomposition shares need not add to 100%.

both supply-side and demand-side factors that influence tuition, whereas they focus on the role of cost disease. Second, the object of interest in Jones and Yang (2016) is college costs, which increased by 35% in real terms between 1987 and 2010, whereas this paper addresses the much larger near-doubling of net tuition. Also, whereas they use a competitive, representative college framework, this paper employs a model with heterogeneous, imperfectly competitive colleges, peer effects, and student loan borrowing with default. Fillmore (2016) and Fu (2014) also develop frameworks with heterogeneous colleges, but in both cases, students have static, reduced-form utility functions. Furthermore, peer effects are exogenous in Fillmore (2016), and Fu (2014) does not allow price discrimination based on ability and income. More recently, Cai and Heathcote (2022) develop a tractable static framework with competitive, profit-maximizing colleges and heterogeneous students to evaluate the impact of rising income inequality on college tuition. Although the colleges lack monopoly pricing power, the perfect segmentation of the market by student type and presence of peer effects gives rise to student-specific tuition schedules. The authors are able to characterize the equilibrium in closed-form for a simplified version of the model, and in a richer model they are able to show quantitatively that a general increase in income dispersion and fattening of the right tail are significant driving forces of higher net tuition. These results mirror our findings on the importance of parental income for tuition.

The most closely related papers to ours are Epple et al. (2006), Epple, Romano, Sarpca, and Sieg (2017), and our earlier paper, Gordon and Hedlund (2019). The first two papers pioneered a static, quantitative model of heterogeneous, quality-maximizing colleges that operate in an environment of imperfect competition and engage in price discrimination. Gordon and Hedlund (2019) adapt and situate this framework in a broader macroeconomic model but consider only the case of a single, monopolistic college. Such a case greatly simplifies computation but implies exaggerated market power with colleges facing no competitive pressure other than from the outside option of skipping college entirely. This paper extends the environment to a richer setting of heterogeneous, imperfectly competitive colleges that gives rise to equilibrium sorting as well as within-school and between-school tuition dispersion.

The results in this paper are also consistent with a large empirical literature that estimates the effects of macroeconomic factors and policy changes on tuition and enrollment. The origins of cost disease emerge from seminal works by Baumol and Bowen (1966) and Baumol (1967). They lay out a clear mechanism: productivity increases in the macroeconomy drive up wages, which service sectors with lagging productivity growth pass along via relative price increases. Archibald and Feldman (2008) emphasize this dynamic in the higher education market. Baumol's cost disease also plays an important role according to our quantitative analysis.

Our model is also consistent with several empirical papers that establish a link between sluggish state appropriations and rising net tuition at public colleges. For example, Heller (1999) suggests such a negative relationship, and a large study commissioned by Congress in the 1998 reauthorization of the Higher Education Act of 1965, Cunningham, Wellman, Clinedinst, Merisotis, and Carroll (2001), emphasizes this relationship. Empirical work by Chakrabarty, Mabutas, and Zafar (2012), Koshal and Koshal (2000), and Webber (2017) find further support for this link and also deliver similar tuition pass-through rates from appropriations as in this paper.

Shifting to demand-side factors, we find aggregate and cross-sectional tuition pass-through rates of Pell Grant and loan limit expansions that are in line with several papers in the literature, including Rizzo and Ehrenberg (2004), Singell and Stone (2007), and more recently, Lucca, Nadauld, and Shen (2019). Other papers also find evidence in support of the Bennett hypothesis, such as McPherson and Shapiro (1991), Turner (2012), Turner (2017), Long (2004a), and Long (2004b), though they disagree on magnitudes and whether public or private institutions are more responsive to financial aid expansions.

2 The Model

The model consists of an imperfectly competitive higher education sector, a continuum of heterogeneous households, and a government that administers a student loan program and social security system.

2.1 Colleges

The higher education sector consists of K college types with each type $k \in \{1, \ldots, K\}$ containing a positive measure $g(k)$ of identical nonprofit colleges. Colleges are not profit-maximizers but instead seek to maximize quality, which is a function of the average academic ability X_k of the student body, investment per student I_k, and enrollment N_k.[3] Higher academic ability and investment per student improve quality, whereas schools may differ on whether they prefer to have larger or smaller enrollment.

[3] This objective follows Epple et al. (2006, 2017) and was used in Gordon and Hedlund (2019).

Thus, quality $q_k(X_k, I_k, N_k)$ also depends directly on k.

Besides differing in the weights they place on each of the components of quality, colleges are ex-ante heterogeneous with respect to their sources of nontuition funding, their operating costs, and expected student outcomes. Beginning with the revenues side of the balance sheet, colleges receive type-specific government appropriations $G_k(N_k)$ and private endowment funding $E_k(N_k)$, which may depend on enrollment. On the spending side, colleges face operating costs $pC_k(N_k)$ that are distinct from the cost of investment pI_kN_k—where p is the relative price of college expenditures—and do not enter the college's quality function. Turning to student outcomes, colleges offer different student-specific dropout risks and labor market prospects. Specifically, a student of type $s = (x, y)$ that consists of academic ability x (an amalgum of innate ability and human capital at age 18) and parental income y drops out with annual probability $\delta_k(s)$. Students graduate after J_Y years and receive earnings premium $\lambda_k(s)$, which is pro-rated for dropouts. Besides these sources of ex-ante heterogeneity, colleges differ endogenously as a result of equilibrium sorting and investment.

The admissions and matriculation process takes place through directed search with a constant returns to scale matching function $M(n, v)$ between student applications n and college vacancies v. As is customary in the search literature, the probability that a vacancy "finds" an application in a given submarket is $M(n, v)/v = M(1/\theta, 1)$, and the probability that an application finds a vacancy is $M(n, v)/n = M(1, \theta)$, where $\theta = v/a$ is the tightness. Define $\rho^{match}(\theta) \equiv M(1/\theta, 1)$ and $\eta(\theta) \equiv M(1, \theta) = \theta\rho^{match}(\theta)$.

To reflect the multi-stage nature of the college admissions process, the model incorporates $\overline{R}$ rounds of matching. In the quantitative section, $\overline{R} = 3$, corresponding to an "early action" round ($R = 1$), a "regular decision" round ($R = 2$), and a "backup" round ($R = 3$). In each round, colleges post vacancies in submarkets $m \equiv (k, T, s)$ indexed by college type k, net tuition T, and student characteristics s, while prospective students choose a submarket m to which they submit their applications *in any given round*. For example, a student may choose to submit a few applications to private, research-intensive, selective institutions in the first round (e.g. Harvard, Yale, Princeton—which the model treats as identical because they fall within the same type k), and conditional on not receiving any offers of admission, the student may then choose to apply to several state flagship universities in the second round. All matches result in an offer of admission, but not all offers of admission result in a matriculation, because students may receive multiple offers of admission from distinct (but identical) type-k institutions in a given round. In this case, the student commits to attending a type-k college but randomizes over the specific (identical) institutions that extended admissions offers.

From the perspective of the college, the probability $\rho^{match}(\theta_R(m))$—where the market tightness $\theta_R(m)$ may depend both on the submarket m and the round R—that a vacancy matches with an application is only the first step to filling the vacancy, because the college then faces a yield rate $\rho^{yield}(n_R(s(m)), \theta_R(m))$ owing to the fact that students may receive multiple offers of admission within a round and go elsewhere. The more schools within type k that students get into—which depends on the number $n_R(s)$ of applications they submit and the market tightness θ_R—the lower the yield rate for any given college of that type in that round. Taking into account both the matching probability and the yield rate, the overall vacancy fill rate is given by $\rho_R(m) \equiv \rho^{match}(\theta_R(m))\rho^{yield}(n_R(s(m)), \theta_R(m))$, which the college takes as given. Note that colleges can post vacancies in multiple submarkets simultaneously, which gives rise to within-school tuition dispersion and a heterogeneous student body.

To avoid complications from strategic investment and dynamic market power, the model adopts some assumptions from Gordon and Hedlund (2019) that render the college's decision problem independent across cohorts. In particular, we assume additive separability of q, C, E, and G across cohorts as well as a cohort-by-cohort balanced budget requirement. Moreover, colleges have access to perfect capital markets where they can borrow interest-free against the future revenue streams of a given cohort. Therefore, upon matriculation, colleges value the cohort-specific sequence of tuition payments $T(m)$, $(1-\delta(m))T(m)$, $(1-\delta(m))^2T(m)$, etc. at $T(m)\omega(m)$, where $\omega(m) = \sum_{j=1}^{J_Y}(1-\delta(m))^{j-1}$.

The within-cohort optimization problem for college type k is

$$
\begin{aligned}
&\max_{\substack{v_R(m)\geq 0,\\ X_k, I_k, N_k}} q_k(X_k, I_k, N_k) \\
\text{s.t. } & pI_kN_k + pC_k(N_k) + \kappa_k \sum_R \int v_R(m)dm = \sum_R \int T(m)\omega(m)v_R(m)\rho_R(m)dm + G_k(N_k) + E_k(N_k) \\
& X_k = \sum_R \int x(m)\omega(m)v_R(m)\rho_R(m)dm/N_k \\
& N_k = \sum_R \int \omega(m)v_R(m)\rho_R(m)dm.
\end{aligned}
\tag{1}
$$

In active submarkets, the equilibrium tightness $\theta_R(m)$ (implicit in $\rho_R(m)$) satisfies

$$T(m) = \underbrace{\frac{\kappa_k}{\omega(m)\rho_R(m)}}_{\text{Markup}} + \overbrace{\underbrace{pI_k + pC_k'(N_k) - [G_k'(N_k) + E_k'(N_k)]}_{\text{Marginal resource cost}} - \underbrace{p\frac{q_N}{q_I}N_k}_{\text{Size discount}} - \underbrace{p\frac{q_X}{q_I}(x(m) - X_k)}_{\text{Ability discount}}}^{EMC_k(s(m))} \tag{2}$$

Intuitively, for each unit mass of vacancies in submarket m, the college pays cost κ_k, successfully enrolls a measure $\rho_R(m)$ of type-$s(m)$ students, and receives net payoff $T(m) - EMC_k(s(m))$ equal to the difference between net tuition T and the effective marginal cost $EMC_k(s)$ of a type-s student—a term coined by Epple et al. (2006). This term includes the marginal resources spent on a student—equal to the difference between the sum of marginal investment and operating costs, $pI_k + pC_k'(N_k)$, and the sum of marginal government appropriations and private endowment funding, $G_k'(N_k) + E_k'(N_k)$. In addition, unlike with canonical production firms, $EMC_k(s)$ takes into account the marginal contribution of type-s students to college quality. For example, colleges provide greater tuition discounts to students of high relative academic ability, $x > X_k$, who create positive peer effects by raising the school's average. Besides the effective marginal cost, net tuition also includes a markup that arises from search frictions but will represent market power more generally when taking the model to the data.

Note that no term in equation 2 besides $\rho_R(m)$ depends on R, which implies that $\rho_R(M)$ must itself be invariant to R. For this condition to hold, any dependence of an individual college's yield rate on R through the number of applications $n_R(s(m)$ must be unwound by changes to $\theta_R(m)$ that equalize the college's payoff to creating a vacancy across submarkets. Re-casting equation 2 by unpacking $m = (k, T, s)$ makes it clear how the vacancy fill rate varies inversely with net tuition T:

$$T = \frac{\kappa_k}{\omega(k, T, s)\rho(k, T, s)} + EMC_k(s). \tag{3}$$

Combining this equation with the relationship

$$\rho(k, T, s) = \rho^{match}(\theta_R(k, T, s))\rho^{yield}(n_R(s), \theta_R(k, T, s)) \tag{4}$$

pins down equilibrium market tightnesses $\theta_R(k, T, s)$.

Given a generic (n_R, θ_R), the expression for the yield rate is

$$\rho^{yield}(n_R, \theta_R) = \sum_{j=0}^{n_R-1} \underbrace{\binom{n_R-1}{j} \eta(\theta_R)^j (1-\eta(\theta_R))^{n_R-1-j}}_{\text{Prob the student gets into } j \text{ other schools}} \times \underbrace{\frac{1}{1+j}}_{\text{Prob enrolls here}}, \tag{5}$$

where $\eta(\theta_R)$ is the aforementioned student admissions probability.

This equation can be written in closed form as

$$\rho^{yield}(n_R, \theta_R) = \frac{1-(1-\eta(\theta_R))^{n_R}}{n_R \eta(\theta_R)}, \tag{6}$$

which is decreasing both in n_R and θ_R.

Combining equations 4 and 6 and substituting $\rho^{match}(\theta) = \eta(\theta)/\theta$ from the definition of these functions gives the following equilibrium condition for $\theta_R(k, T, s)$:

$$\rho(k, T, s) = \frac{1-(1-\eta(\theta_R(k,T,s)))^{n_R(s)}}{n_R(s)\theta_R(k,T,s)}. \tag{7}$$

2.2 Households

Households go through three phases of life: youth, working age, and retirement. The opportunities and risks they encounter, the public policies they face, and the resulting decisions they make depend on their stage in the life cycle.

2.2.1 Youth and College Students

Each cohort has a fixed mass of heterogeneous youth with characteristics $s = (x, y)$ drawn from the distribution $\Gamma(s)$ enter the economy at high school graduation age $j = 1$ and receive a vector of taste shocks $\{\epsilon_k\}$ that impact the utility they receive from deciding whether and where to attend college. After receiving these taste shocks, youth either enter the workforce, $k = 0$, or they commence the college search process introduced in section 2.1. Specifically, in each round they choose the quantity n of applications to submit and where to submit them, $m = (k, T, s)$, facing a search disutility of ψn and an admissions probability of $\eta(\theta(m))$ per application.[4] If students do not receive any admission offers in a round, they can re-optimize their search in subsequent rounds—for example, by changing the school type they target or the

[4] As is standard in the search literature, youth only enter one submarket.

number of applications to submit. Within a given college type k, students face more competition when searching in submarkets characterized by a lower net tuition $T(m)$.

Youth who pursue higher education receive two distinct benefits. First, they enjoy additive flow utility $\varphi_k(I_k)$ while in college, which is increasing in college investment. Second, they earn higher future labor income. Students who avoid the annual dropout probability $\delta_k(s)$ for all J_Y years and graduate receive log earnings premium $\lambda_k(s)$. Students who drop out after j years receive a premium of $\lambda_k(s)j/(J_Y+1)$, which implies a sheepskin effect from diploma receipt equal to $1/(J_Y+1)$.

Students face total cost of attendance $COA(T)=T+\phi$, where ϕ represents nontuition expenses. Need-based government grants $\zeta(COA(T), EFC(s))$ defray some of this cost, with eligibility based on $COA(T)$ and the expected family contribution $EFC(s)$, which is set by policymakers. Students must then decide how to finance the remaining net cost of attendance between out-of-pocket family resources and borrowing with student loans, $NCOA(T,s) = [COA(T) - \zeta(COA(T), EFC(s))]^+$, where $x^+ \equiv \max\{0,x\}$.

Students finance consumption spending c (which includes living expenses such as meals, shelter, etc., but can be less than listed nontuition expenses ϕ) and net tuition T using endowment income e_Y, parental transfers ξEFC—which they receive in proportion ξ to their expected family contribution—government grants ζ, and borrowing through subsidized student loans b_{sub} and unsubsidized loans b_{unsub}, as described below. Defining $\zeta(m) \equiv \zeta(COA(T(m), EFC(s(m))))$, a college student who enters submarket m has budget constraint

$$c + T(m) \leq e_Y + \xi EFC(s(m)) + \zeta(m) + b_{sub} + b_{unsub}. \tag{8}$$

The Federal Student Loan Program offers students two complementary loan options. For those with financial need—that is, a net cost of attendance that exceeds their expected family contribution, $NCOA(T,s) > EFC(s)$—subsidized loans represent the first line of borrowing because they do not accrue interest while students are enrolled in college. Besides the eligibility requirement, students are subject to an annual subsidized borrowing limit of $\bar{b}_j^{sub}$ in year $j=1,\ldots,J_Y$ of college and an aggregate subsidized limit of $\bar{l}^{sub}$. Together, the statutory ceilings and need-based eligibility yield an annual subsidized limit for students with net cost of attendance $NCOA$ and expected financial contribution EFC of $\min\{\bar{b}_j^{sub}, (NCOA - EFC)^+\}$.

Define the maximum subsidized balance that a student can accrue by year j as $\widetilde{l}_j^{sub}(NCOA, EFC) \equiv \min\{\bar{l}^{sub}, \sum_{i=1}^{j} \min\{\bar{b}_i^{sub}, (NCOA - EFC)^+\}\}$.

Since their advent in 1993, unsubsidized loans—which accrue interest at the rate i—have allowed students regardless of need to finance their remaining net cost of attendance up to an annual combined (subsidized plus unsubsidized) borrowing limit of $\bar{b}_j$ and an aggregate combined limit of $\bar{l}$. To capture this change in loan regime, we introduce an annual *unsubsidized* loan limit $\bar{b}_j^{unsub}$ for notational convenience that equals 0 before 1993 and $\bar{b}_j$ after 1993. The post-1993 unsubsidized limit is nonbinding after taking into account the constraint on annual combined borrowing of $b_{sub} + b_{unsub} \leq \min\{\bar{b}_j, NCOA\}$. Analogously, we define $\bar{l}^{unsub}$ to be 0 before 1993 and $\bar{l}$ after 1993. This constraint is nonbinding after taking into account the cumulative combined borrowing limit of $l'_{sub} + \frac{l'_{unsub}}{1+r_l} \leq \bar{l}$.[5]

Under the maintained assumption that students first exhaust subsidized borrowing before taking out any unsubsidized loans, the total balance l acts as a sufficient statistic for the student debt portfolio (l_{sub}, l_{unsub}). Specifically, l is decomposed as

$$(l_{sub}, l_{unsub}) = \begin{cases} (l, 0) & \text{if } l \leq \widetilde{l}_{j-1}^{sub}(NCOA, EFC) \\ (\widetilde{l}_{j-1}^{sub}(NCOA, EFC), l - \widetilde{l}_{j-1}^{sub}(NCOA, EFC)) & \text{otherwise,} \end{cases} \tag{9}$$

where the $j-1$ refers to the constraint faced last period, and first-year students begin with zero debt. A corresponding decomposition exists for any new l' chosen in year j of college, where $(l'_{sub}, l'_{unsub}) \equiv (l_{sub} + b_{sub}, (1 + r_l)(l_{unsub} + b_{unsub}))$. To summarize, the annual and aggregate *subsidized* borrowing limits are encoded into the definition of $\widetilde{l}_j^{sub}(NCOA, EFC)$ and the decomposition of total debt. What remain are the annual and aggregate combined borrowing limits, $b_{sub} + b_{unsub} \leq \min\{\bar{b}_j, NCOA\}$ and $l'_{sub} + \frac{l'_{unsub}}{1+r_l} \leq \bar{l}$, respectively.

2.2.2 Workers and Retirees

Workers (retirees) receive labor income (retirement benefits) $\mu_j e^z$, where μ_j is a deterministic age-dependent profile and z follows a random walk with innovations $\varepsilon \sim \mathcal{N}(0, \mathbf{1}_{[j<J_{retire}]}\sigma_\varepsilon^2)$—implying that workers, but not retirees, face income risk.[6] Workers draw their initial education-dependent z_0 upon entering the labor market,

[5] Equivalently, current balances plus new borrowing must satisfy $l_{sub} + b_{sub} + l_{unsub} + b_{unsub} \leq \bar{l}$.

[6] The random walk assumption saves on the need to keep track of the college premium as a separate state variable.

whether at $j = 1$ as a high school graduate or upon leaving college. The government then taxes this income at rate τ. All households (including college students) value consumption according to the utility function $u(c)$ and discount at rate β.

Workers and retirees can save using risk-free bonds a with exogenous interest rate r, but student loans are the only source of borrowing in the model. Borrowers with outstanding loan balance l and remaining duration $t \leq t_{max}$ face repayment obligations of $p(l,t) = l\frac{i(1+r_l)^{t-1}}{(1+r_l)^t - 1}$, where $p(l,t)$ is the standard amortization amount. The evolution of t and l follows $t' = t-1$ and $l' = (l - p(l,t))(1+r_l)$, respectively.

We also include the option to default on student loans, since "the demand for credit can be much higher with explicit insurance mechanisms or implicit ones such as bankruptcy [and] default..." (Lochner and Monge-Naranjo, 2016, p. 423). We model student default to be consistent with current law. In particular, unlike other forms of consumer debt, student loan debt is generally not dischargeable through bankruptcy. Instead, when borrowers default by skipping a payment, they enter a state of delinquency where they suffer two consequences. First, one-time collections penalties add a fraction ι to their outstanding balance. Second, borrowers face proportional wage garnishment χ for earnings above a minimum threshold $\underline{e}$ as long as they remain delinquent. Borrowers can rehabilitate their loan and leave delinquency by making a regular payment, which resets the loan clock to t_{max}.

2.3 Household Decision Problems

This section discusses the household decision problems, moving backward from workers/retirees to college students and, lastly, to youth.

2.3.1 Consumption, Savings, and Student Loan Repayment

At the beginning of each period, workers in good standing on their student loans, $f = 0$, make a student loan payment or default, causing them to suffer the balance penalty ι. They solve

$$V_j(a,l,t,z,f=0) = \max\{V_j^P(a,l,t,z), V_j^D(a,l(1+\iota),z)\}, \tag{10}$$

where V^P is the value of making a payment, and V^D is the value of default.

Workers with delinquent debt, $f = 1$, decide whether to remain delinquent or rehabilitate the loan by making a payment, resetting the duration to t_{max}. They solve

$$V_j(a, l, z, f = 1) = \max\{V_j^P(a, l, t_{\max}, z), V_j^D(a, l, z)\}. \tag{11}$$

Workers who make a payment choose how much to consume and save,

$$\begin{gathered} V_j^P(a, l, t, z) = \max_{c, a' \geq 0} u(c) + \beta \mathbb{E}_{\varepsilon'} V_{j+1}(a', l', t', z + \varepsilon', f' = 0) \\ \text{such that } c + a'/(1 + r) + p(l, t) \leq (1 - \tau)\mu_j e^z + a \\ l' = (l - p(l, t))(1 + r_l), \quad t' = \max\{t - 1, 0\}. \end{gathered} \tag{12}$$

The value function associated with choosing to remain in default is

$$\begin{gathered} V_j^D(a, l, z) = \max_{c, a' \geq 0} u(c) + \beta \mathbb{E}_{\varepsilon'} V_{j+1}(a', l', z + \varepsilon', f' = 1) \\ \text{such that } c + a'/(1 + r) \leq (1 - \tau)\mu_j e^z - \chi \max\{0, (1 - \tau)\mu_j e^z - \underline{e}\} + a \\ l' = \max\{0, (l - \chi \max\{0, (1 - \tau)\mu_j e^z - \underline{e}\})(1 + r_l)\}, \end{gathered} \tag{13}$$

where $\chi \max\{0, (1 - \tau)\mu_j e^z - \underline{e}\}$ is garnished wages applied to the loan balance.

2.3.2 Financing College

Students with debt l who originally matched in college submarket $m = (k, T, s)$ choose consumption and borrowing. Their value function is

$$\begin{aligned} Y_j(m, l) = \max_{c, b_{sub}, b_{unsub} \geq 0} u(c) + \varphi_{k(m)}(I_{k(m)}) + \beta \Bigg\{ & \overbrace{[1 - \delta(m)]\mathbf{1}_{[j < J_Y]} Y_{j+1}(m, l')}^{\text{stay in college}} \\ & + \overbrace{[1 - \delta(m)]\mathbf{1}_{[j = J_Y]} \mathbb{E}_{\varepsilon'} V_{j+1}\left(a' = 0, l', t_{max}, z' = \lambda(m) + \sqrt{j + 1}\varepsilon', f' = 0\right)}^{\text{graduate}} \\ & + \overbrace{\delta(m) \mathbb{E}_{\varepsilon'} V_{j+1}\left(a' = 0, l', t_{max}, z' = \lambda(m)\frac{j}{J_Y + 1} + \sqrt{j + 1}\varepsilon', f' = 0\right)}^{\text{drop out}} \Bigg\} \end{aligned} \tag{14}$$

subject to

$$
\begin{gathered}
c + T(m) \leq e_Y + \xi EFC(s(m)) + \zeta(m) + b_{sub} + b_{unsub} \\
l' = \overbrace{l_{sub} + b_{sub}}^{l'_{sub}} + \overbrace{(1+i)(l_{unsub} + b_{unsub})}^{l'_{unsub}} \\
b_{sub} \leq \min\{\bar{b}_j^{sub}, (NCOA - EFC)^+\}, \quad b_{unsub} \leq \bar{b}_j^{unsub}, \quad l'_{sub} \leq \bar{l}^{sub}, \quad \frac{l'_{unsub}}{1+r_l} \leq \bar{l}^{unsub} \\
b_{sub} + b_{unsub} \leq \min\{\bar{b}_j, NCOA\}, \quad l'_{sub} + \frac{l'_{unsub}}{1+r_l} \leq \bar{l},
\end{gathered} \tag{15}
$$

where $\delta(m)$ and $\lambda(m)$ denote dropout risk and the post-college earnings premium, respectively, and the decomposition of loan balances into its constituent subsidized and unsubsidized components comes from equation 9. The adjustment term $\sqrt{j+1}\varepsilon'$ holds earnings risk constant across college attainment status, thus preventing artificial college demand from youth looking to avoid early-life earnings risk.

2.3.3 College Choice

Youth entering round R of the college application process have value function $A_R(s, \boldsymbol{\epsilon})$, which depends on their student type s and their draw of preference shocks $\boldsymbol{\epsilon}$ across each of the college types (including skipping college) as follows:

$$
A_R(s, \boldsymbol{\epsilon}) = A_{R+1}(s, \boldsymbol{\epsilon}) + \underbrace{\max_{n,m} -\psi n + \overline{\eta}_R(m,n)\left[Y_1(m,0) + \frac{1}{\sigma_\epsilon}\epsilon_{k(m)} - A_{R+1}(s, \boldsymbol{\epsilon})\right]}_{\text{Optional value of applying}} \tag{16}
$$

where $\overline{\eta}_R(m,n) \equiv 1 - (1 - \eta(\theta_R(m)))^n$ is the probability of receiving an admissions offer in submarket m after submitting n applications. Let

$$
A_{\overline{R}+1}(s, \boldsymbol{\epsilon}) \equiv \mathbb{E}_{\varepsilon'} V_1(a=0, l=0, t=0, z=\varepsilon, f=0) + \frac{1}{\sigma_\epsilon}\epsilon_0 \tag{17}
$$

denote the value of directly entering the workforce. Thus, someone looking to purposely skip college can simply set $n = 0$ for each round.

2.4 Government

The government operates the student loan and social security programs. Outlays include new loans and retirement benefits, while revenues come from the earnings tax, loan payments, and wage garnishment on delinquent borrowers. Because we are not evaluating welfare in the model, we do not impose budget balance. Instead, the earnings tax rate τ is estimated from the data, as discussed in section 3.2.4.

2.5 Equilibrium

An equilibrium consists of market tightnesses $\theta(m)$, vacancy postings $v(m)$, value functions $\widehat{Y}(k;s)$, $Y_j(m,l)$, and $V_j(a,l,t,z,f)$, application rates $A(k;s)$, and tax rate τ such that colleges optimally choose $v(m)$, households maximize utility, and the market tightnesses are consistent with the behavior of colleges and youth applicants.

3 Parametrization of the Model

Some of the model parameters are set from external estimates, others are estimated directly from the data, and the rest are jointly determined to minimize the distance between a set of moments in the model and data. One model unit is normalized to \$1,000 in 2010 dollars, and the risk-free rate is set to 2%, i.e., $r = 0.02$.

3.1 Colleges

This section describes the parametrization of the college quality function $q_k(X_k, I_k, N_k)$; custodial costs $C_k(N_k)$; nontuition revenue for public appropriations, $G_k(N_k)$, and endowment funding, $E_k(N_k)$; the student-college matching function $M(\cdot,\cdot)$ underlying ρ and η (i.e. $\rho(\theta) = M(1/\theta, 1)$ and $\eta = M(1,\theta)$); dropout probabilities $\delta_k(s)$; earnings premia $\lambda_k(s)$; and the remaining college parameters.

3.1.1 College Data

We use National Center for Education Statistics (NCES) Integrated Postsecondary Education Data System (IPEDS) institution-level data curated and harmonized by the Delta Cost Project (DCP).

Categorizing Colleges We classify colleges into $K = 7$ types by their source of control (public G vs. private P), focus (research-intensive R vs. teaching-oriented T according to their Carnegie Classification), and degree of selectivity (selective S vs. nonselective N based on mean SAT scores).[7] There are no GTS colleges. The number of schools within each type $g(k)$ also comes from the data.[8]

[7] Sections B.1 and B.2 in the appendix provide additional details.

[8] There is virtually no school entry or exit in the data over this time period. Thus, we focus on colleges in the sample for all years 1987–2010 and assume that $g(k)$ is time-invariant.

College Balance Sheets We distill college balance sheets into net tuition revenue T, public appropriations G, endowment funding E, custodial costs pC, recruiting costs $\kappa V \equiv \kappa \int vdm$, and investment pIN. The budget constraint can be written as

$$pC + pIN + \kappa V = T + G + E. \tag{18}$$

Section B.3 explains in detail the mapping between college revenue and expenditure categories in the model and the data, and section B.4 explains the mapping between full-time equivalent (FTE) enrollments in the model and data. Summary statistics by school type and year—including the budgetary items discussed above—are given in table 11 in the appendix.

3.1.2 College Quality

We specify a constant elasticity of substitution (CES) quality function,

$$q_k(X_k, I_k, N_k) = \left(\alpha_{X,k} X_k^{\frac{\epsilon-1}{\epsilon}} + \alpha_{I,k} I_k^{\frac{\epsilon-1}{\epsilon}} + \alpha_{N,k} N_k^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\epsilon}{\epsilon-1}}. \tag{19}$$

We estimate type-specific values of α_X and α_N, while normalizing $\alpha_I = 1$ for each college. In addition, the elasticity parameter ϵ is the same across all colleges. Thus, the college-side of the model gives rise to $2K+1 = 15$ parameters to be identified. All of these parameters (plus some others discussed momentarily) are determined jointly using the model, which section 3.4 covers in detail.

3.1.3 Custodial Costs

We parametrize custodial costs using the functional form

$$pC_k(N_{k,t}; t) = \exp(\alpha_k + \beta_k t + \delta_k N_{k,t} + \zeta_k N_{k,t} t), \tag{20}$$

which has its time-varying "efficient scale" at $1/(\delta_k + \zeta_k t)$. We determine the coefficients by estimating separately for each k the following:

$$\log pC_{i,t} = \alpha_k + \beta_k t + \sum_{\tilde{i}} \gamma_{\tilde{i}} \mathbf{1}[\tilde{i} = i] + \delta_k N_{i,t} + \zeta_k N_{i,t} t + \epsilon_{i,t}, \tag{21}$$

where $\gamma_{\tilde{i}}$ are college fixed effects, and $N_{i,t}$ is FTE enrollment at college i in year t.

Figure 20 in the appendix plots the estimated curves for 1987 along with dots representing actual mean enrollment for each school type. Observed enrollments are all on the downward sloping portion of the average total cost (ATC) curve where marginal cost (MC) is below ATC, and the efficient scale has been growing over time for all schools except private, teaching-oriented, selective (PTS) colleges. The implied average fixed cost in 1987 ranges from \$1,200 to \$5,300 in 2010 dollars, and the marginal cost is on the order of one to three thousand dollars.

3.1.4 Nontuition Revenue

We specify the following form for public appropriations and endowment funding as

$$G_k(N_k;t) = \frac{a_{G,t}N_k^{1-\gamma}}{1-\gamma} - a_{G,t}b_G(N_{k,t}^*)^{-\gamma}N_k \text{ and} \tag{22}$$

$$E_k(N_k;t) = \frac{a_{E,t}N_k^{1-\gamma}}{1-\gamma} - a_{E,t}b_E(N_{k,t}^*)^{-\gamma}N_k, \tag{23}$$

where $N_{k,t}^*$ is year-t observed enrollment. The rationale for this functional form is that it ensures that the following properties hold: (1) zero enrollment implies zero revenue, $G_k(0;t) = E_k(0;t) = 0$; (2) the Inada condition holds, i.e., $\lim_{N_k \downarrow 0} G_k'(N_k;t) = \lim_{N_k \downarrow 0} E_k'(N_k;t) = \infty$; (3) nontuition revenue is consistent with the data, $G_k(N_{k,t}^*;t) = G_{k,t}^*$ and $E_k(N_{k,t}^*;t) = E_{k,t}^*$; and (4) the elasticity of nontuition revenue with respect to enrollments equals the value estimated in the data, $G_k'(N_{k,t}^*;t)N_{k,t}^*/G_{k,t}^* = \epsilon_G^*$ and $E_k'(N_{k,t}^*;t)N_{k,t}^*/E_{k,t}^* = \epsilon_E^*$.[9] Given $\gamma \in (0,1)$, b_G is identified from $\epsilon_G^* = \frac{1-b_G}{1/(1-\gamma)-b_G}$, and then $a_{G,t}$ is identified from $a_{G,t}(1/(1-\gamma) - b_G){N_{k,t}^*}^{1-\gamma} = G_{k,t}^*$. The same approach is used to identify b_E and $a_{E,t}$. Any $\gamma \in (0,1)$ can be supported, but $\gamma = 0.75$ works well for computational stability.

3.1.5 Dropout Probabilities and Earnings Premia

We let $J_Y = 5$ to reflect the median time to degree of 52 months.[10] This value implies a sheepskin effect—equal to $1 - J_Y/(J_Y+1)$ in the model—of 17%, which is in the range of estimates provided by Jaeger and Page (1996). We assume graduation rates and earnings premia depend on college type and individual ability according to

$$(1-\delta_k(x))^{J_Y} = \min\left\{\left(1-\overline{\delta}_k\right)^{J_Y}\left(\mu_\delta + (1-\mu_\delta)\frac{x}{X_k}\right), 1\right\} \tag{24}$$

$$\lambda_k(x) = \overline{\lambda}_k\left(\mu_\lambda + (1-\mu_\lambda)\frac{x}{X_k}\right), \tag{25}$$

[9] Appendix section B.6 provides details on the regression specification and estimates.

[10] Completion times can be found here: `https://nces.ed.gov/fastfacts/display.asp?id=569`.

where $(1-\delta_k(x))^{J_Y}$ is the probability of successfully graduating. We choose a value of $\mu_\lambda = \mu_\delta = 2/3$ in line with the literature and also assess robustness by trying values between 0.5 and 0.8.[11] The main model results are extremely robust, with net tuition growth from 1987 to 2010 only changing by 0.2%. To determine $\overline{\lambda}_k$, we first calculate earnings for each college relative to the FTE-weighted average across colleges, then compute the mean of this measure within each college type k, and finally, multiply by the aggregate premium based on Autor, Katz, and Kearney (2008). Table 9 in the appendix lists the premium and dropout rate for each college type.

3.1.6 Matching Function and Vacancy Posting Costs

The matching function is given by $M(u, v) = \min\{u, u^{1-\gamma}v^{\gamma}\}$, yielding a relationship between the vacancy filling probability ρ and college admissions probability η of

$$\eta(\rho^{-1}(y)) = \min\{1, y^{-\gamma/(1-\gamma)}\}, \tag{26}$$

where y denotes vacancy-filling rate.

For use later, we derive a relationship between acceptance probabilities and net tuition to help determine γ and κ_k for each college type. Rearranging the tuition expression in equation 2 implies that the active market tightnesses $\theta^*(m)$ in equilibrium must satisfy

$$\rho(\theta^*(m)) = \frac{\kappa_k}{\omega(m)[T(m) - EMC_k(s(m))]}. \tag{27}$$

The corresponding acceptance probability for students is then

$$\eta(\theta^*(m)) = \min\left\{1, \left(\frac{\omega(m)[T(m) - EMC_k(s(m))]}{\kappa_k}\right)^{\gamma/(1-\gamma)}\right\}, \tag{28}$$

which is strictly increasing in T until $\frac{\kappa}{\omega} + EMC$ before leveling off at 1. Thus, students only apply to submarkets where $T \leq \frac{\kappa}{\omega} + EMC$, and active submarkets must satisfy

$$T(m) = \frac{\kappa_k}{\omega}\eta(\theta^*(m))^{(1-\gamma)/\gamma} + EMC_k(s(m)). \tag{29}$$

[11] For example, ignoring the costs of delayed job entry, table 8 in Hendricks and Leukhina (2018b) reports that lifetime earnings are 88% higher (63 log points) for college graduates, with differences in ability generating 31% (27 log points) higher earnings—accounting for 35% of the premium and implying a value of μ_λ of 0.65.

Vacancy Posting Costs We identify vacancy posting costs κ_k using the parental income gradient in net tuition. If $\kappa_k = 0$, net tuition is degenerate by income (but not ability) at $T = EFC_k(s)$. Higher values of κ_k produce price dispersion by income.[12]

We measure the empirical parental income gradient using College Scorecard data on net tuition and fees across five income bins. Defining $\hat{T}_{ij}$ as the percentage deviation of net tuition for income bin j from average tuition at college i and likewise for $\hat{Y}_{ij}$, our school-specific measure is the coefficient β_k in the regression

$$\hat{T}_{ij} = \alpha_{k(i)} + \beta_{k(i)}\hat{Y}_{ij} + \epsilon_{ij}, \tag{30}$$

where $k(i)$ is the type of college i. The estimates in table 7 in the appendix range from 0.15–0.3 for nonselective colleges to around 0.8 for selective private colleges.

To identify κ_k, we assume that students pay the full sticker price tuition above a parental income cutoff $y \geq Y_k^* + \overline{n}\sigma_{Y,k}$ for some $\overline{n}$, where $\sigma_{Y,k}$ is the standard deviation of parental income. Similarly, we assume that students with low parental income, $y \leq Y_k^* + \underline{n}\sigma_{Y,k}$, pay the least possible net tuition. Substituting these two endpoints into equation 30, differencing, and rearranging yields

$$\kappa_k = T_k^* \omega_k \beta_k \frac{(\overline{n} + \underline{n})\sigma_{Y,k}}{Y_k^*}, \tag{31}$$

where the k subscripts reflect the dependence of posting costs on college type.

We have β_k from the regression in equation 30, dropout rate data (which enter into ω_k), average net tuition T_k^*, average parental income Y_k^*, and the standard deviation of parental income $\sigma_{Y,k}$. Lastly, to match the approximate 40% share of students who pay sticker price, we set $\overline{n}$ such that 40% of students are above this threshold. Similarly, we choose $\underline{n}$ such that 40% of students are below this threshold to account for the flat parental income gradient in the bottom two income brackets of the College Scorecard data. Section B.7 provides additional details and validation.

Matching Function Curvature Treating equation 29 as an empirical identity, γ controls the curvature of the relationship between net tuition T_{ik} and acceptance probabilities η_{ik} for students i with characteristics $s(i)$ at college type k. Taking the

[12] Figure 11 in the appendix shows the model-generated within-school dispersion in net tuition dispersion and markups $T - EMC$.

expectation over enrollments and approximating by treating ω_k as a constant gives

$$T_k^* = \frac{\kappa_k}{\omega_k^*}\mathbb{E}[\eta]^{(1-\gamma)/\gamma} + \mathbb{E}[EMC_k]. \tag{32}$$

If we assume that sticker price tuition $T_k^{sticker}$ is the maximum possible markup (corresponding to $\eta = 1$), then γ_k satisfies

$$\gamma_k = \left(1 + \log(1 - \frac{\omega_k^*}{\kappa_k}(T_k^{sticker} - T_k^*))/\log(\mathbb{E}(\eta))\right)^{-1}. \tag{33}$$

Equation 33 produces γ_k estimates of just over 0.5 for most college types and values a bit lower for a couple others. Thus, we let $\gamma = 1/2$ in the benchmark.

3.1.7 Nontuition College Expenses

As in Gordon and Hedlund (2019), we set the sequence ϕ_t of nontuition expenses that enter into the total cost of attendance, $COA(T_k) = T_k + \phi$, based on NCES data.

3.2 Households

This section describes the parametrization for households—namely, preferences, college-specific taste shocks and additive attendance utilities, college search disutility, parental transfers, earnings, and the distribution of student characteristics.

3.2.1 Preferences

We assume constant relative risk aversion utility with risk aversion $\sigma = 2$ and discount rate $\beta = 0.96$. The additive utility of college attendance is given by

$$\varphi_k(I_k) = a_{0,public}\mathbf{1}_{[k,public]} + a_{0,private}\mathbf{1}_{[k,private]} + a_1 I_k + u_k. \tag{34}$$

Thus, attendance utility is increasing in college investment (assuming $a_1 > 0$) and can vary with college control. The determination of the coefficients, residual terms u_k, and search disutility parameter ψ occurs as part of the joint parametrization in section 3.4. Lastly, for the college taste shocks $\{\epsilon_k\}$, we set the standard deviation at just $\sigma_\epsilon = 0.02$ to ensure continuous (nondegenerate) choice probabilities in **??**.

3.2.2 The Distribution of Student Characteristics

We parametrize the joint distribution $\Gamma(x, y)$ of ability x and parental income y that comprise student characteristics $s = (x, y)$ following Gordon and Hedlund (2019).

3.2.3 Parental Transfers in College

We use NLSY97 data to set the fraction ξ of parental transfers that appear directly in the student budget constraint, i.e., $\xi EFC(s)$. First, we compute parental income and use the simplified formula from Epple et al. (2017) to determine EFC. Next, we use data on family aid for college that is not expected to be paid back and find the annual level of support. Lastly, we regress this transfer measure on interaction terms between EFC and whether a student dropped out or graduated on the sample of students for whom $EFC < T$. The coefficient is 0.419 for dropouts and 0.901 for graduates, leading us to set $\xi = 0.7$ around the midpoint.

3.2.4 Earnings and Taxes

We use data from Heathcote, Perri, and Violante (2010) to estimate the tax τ on earnings, the deterministic life cycle profile, and stochastic earnings innovations. The estimated tax rate is $\tau = 0.184$. A first-stage regression identifies the deterministic age-earnings profile. The second stage uses the residuals to estimate a permanent-transitory decomposition with GMM:

$$\begin{aligned} \nu_{i,t} &= z_{i,t} + \varsigma_{i,t}, & \varsigma_{i,t} &\sim N(0, \sigma_\varsigma^2) \\ z_{i,t} &= z_{i,t-1} + \varepsilon_{i,t}, & \varepsilon_{i,t} &\sim N(0, \sigma_\varepsilon^2). \end{aligned} \tag{35}$$

We use the point estimate $\sigma_\varepsilon^2 = 0.00619$ for the random walk. The transitory component $\varsigma_{i,t}$ is discarded.[13] Section C provides more details on the methodology.

3.3 Federal Financial Aid

This section explains the parametrization of federal aid programs. For student loans, we set the time-varying student loan rate i and loan limits $\bar{b}_j^{sub}$, $\bar{l}^{sub}$, $\bar{b}_j$, and $\bar{l}$ from the data following Gordon and Hedlund (2019). The student loan term is $t_{max} = 10$.

3.3.1 Expected Family Contribution

We use the EFC formula from Epple et al. (2017) of $EFC(y_p) = \max\{\tilde{y}(y_p)/5.5 - \$5{,}000, \tilde{y}(y_p)/3.2 - \$16{,}000, 0\}$ in 2009 dollars, where adjusted gross parental income $\tilde{y}(y_p)$ depends on raw parental income as follows: $\tilde{y}(y_p) = y(1 + 0.07 \cdot \mathbf{1}[y \geq \$50000])$.

[13] The transitory component $\varsigma_{i,t}$ conflates measurement error and any true transitory shock. We do not include a transitory shock in the model as it is unlikely to affect college decisions.

3.3.2 Pell Grants

We rely on tabulations of EFC, COA, and awarded Pell Grants from the Department of Education.[14] Letting the maximum statutory Pell Grant be $\bar{\zeta}$, the functional form

$$\frac{\zeta(COA, EFC)}{\bar{\zeta}} = \min\left\{1, \max\left\{0, \zeta_0 \frac{1}{\bar{\zeta}} + \zeta_{COA}\frac{COA}{\bar{\zeta}} + \zeta_{EFC}\frac{EFC}{\bar{\zeta}}\right\}\right\},$$

fits the data very well. With this specification, we can recover the coefficients ζ_0, ζ_{COA}, and ζ_{EFC} by running a Tobit (censored) regression censoring both at zero and one. The results are stable over time and almost exactly given by $\zeta_{COA} = 1 = -\zeta_{EFC}$ with $\zeta_0 = 0$, which implies that Pell Grants increase by one dollar for every dollar increase in COA or dollar decrease in EFC when not an endpoint.

3.3.3 Consequences of Student Loan Default

Garnishment for student loan applies only to earnings exceeding a threshold corresponding to 30 hours of minimum wage work in the data.[15] To map to the model, we compute the real minimum wage in 2010 dollars (which average $6.32 over 1987-2010) and multiply by 30*52 to arrive at the annual after tax earnings an individual in default keeps. These calculations produce a value of $\underline{e} = 9.867$ in model units ($9,867 in 2010 dollars). For any earnings above this amount, a fraction $\chi = 0.25$ is garnished.

3.4 Joint Parametrization and Model Fit

The remaining parameters to identify are the quality function parameters $\alpha_{X,k}$, $\alpha_{N,k}$ (7 each), and ϵ, the search disutility ψ, and the coefficients of the college attendance utility function $\varphi_k(I_k)$. After first jointly determining the level of utilities φ_k (7 scalars) along with other parameters via a GMM procedure, we project φ_k onto $\varphi_k = a_{0,public}\mathbf{1}_{[k,public]} + a_{0,private}\mathbf{1}_{[k,private]} + a_1 I_k + u_k$ using 1987 data on I_k to determine the coefficients $a_{0,public}$, $a_{0,private}$, and a_1 along with the residuals u_k.

3.4.1 GMM Procedure

The joint parametrization procedure sets out to identify the search disutility ψ, the 7 attendance utility scalars φ_k, and the 15 quality function parameters. All but ϵ (22 parameters in total) are used to minimize the distance between model and data

[14] See here: https://fsapartners.ed.gov/sites/default/files/attachments/dpcletters/p0003TableAFultime.PDF and https://fsapartners.ed.gov/sites/default/files/attachments/dpcletters/GEN1804AttachRevised1819PellPaymntDisbSched.pdf.

[15] See here: https://www.dol.gov/whd/regs/compliance/whdfs30.pdf (retrieved 12/20/2019).

moments in 1987. The quality curvature ϵ cannot be separately identified using just the 1987 equilibrium and is thus set to ensure the model matches aggregate 2010 enrollment from the data (the only 2010 moment we target), as is discussed below.[16]

We target average net tuition T_k, average ability X_k, and FTE enrollment N_k for each type k. In addition, we target the FTE-weighted college acceptance probability $\mathbb{E}[\eta]$, leaving us with 22 parameters and 22 moments to allow for exact identification. However, we use an overidentification strategy that makes the estimation more efficient by targeting the school-specific quality weight on enrollment needed to rationalize the data as an equilibrium. Section B.8 provides more details. Appendix figure 21 establishes the identification. Tables 8 and 9 summarize the joint parametrization. In addition to matching the targeted moments, the model provides a good fit for sticker price and relative parental income by type in 1987, as shown in figure 2.[17]

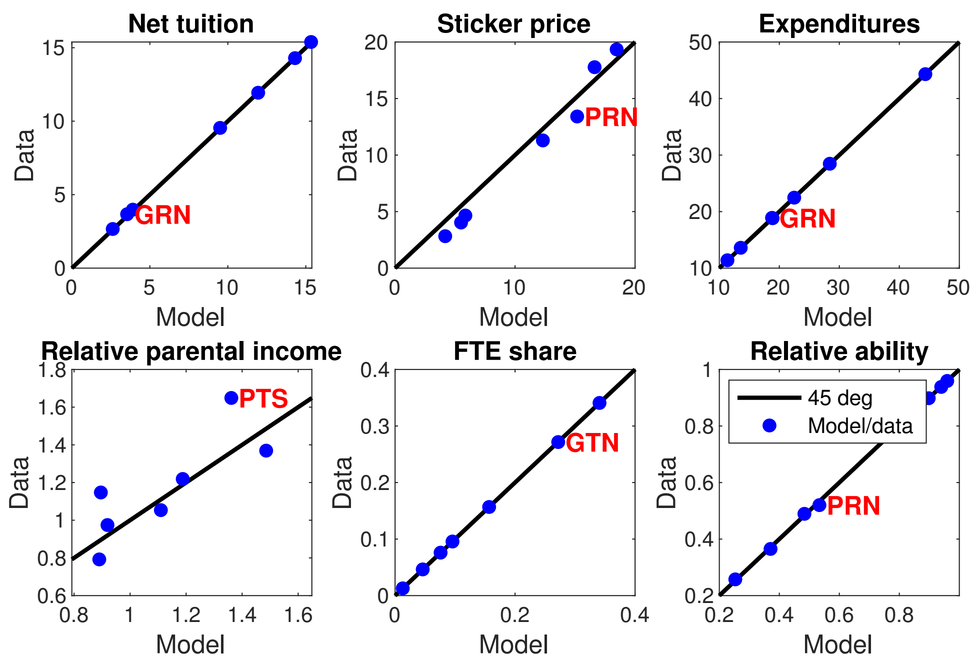


Figure 2: Joint Parametrization Goodness of Fit

[16]Suppose $\kappa = 0$ and one exactly matches X_k, N_k, T_k, which allows a perfect match of I_k for some $\epsilon^1, \{\alpha^1_{X,k}\}, \{\alpha^1_{N,k}\}$. Now consider a different ϵ^2, and adjust $\{\alpha^2_{X,k}\}$ and $\{\alpha^2_{N,k}\}$ to leave q_N/q_I and q_X/q_I at the target moments. In this case, previously-optimal enrollment decisions are still optimal, leaving demand unchanged. Thus, the old X_k, N_k, T_k, I_k still solve the college problem.

[17]We define sticker price in the model as the conditional mean of net tuition for students above the x_k percentile of the k-specific distribution, where x_k is the share in the data paying sticker price.

4 Results

The main objectives of this section are to assess whether the model can successfully replicate the untargeted evolution of higher education outcomes from 1987 to 2010 and, if so, to use the model to understand the main underlying driving forces. To do so, section 4.1 first examines the model's ability to jointly rationalize the observed changes in tuition, enrollment, and expenditures over this time period. Section 4.2 then employs a stylized "toy model" to glean intuition into the mechanisms driving the joint results. From there, section 4.3 delivers a quantitative decomposition that reveals the relative importance of each of the different tuition inflation theories.

4.1 Jointly Accounting for College Tuition Trends

Here, we first formalize the tuition inflation theories from section 1, and then we assess the model's ability to explain higher education trends between 1987 and 2010.

4.1.1 Implementing the Economic and Policy Changes

As outlined in section 1, we incorporate several economic and policy forces that have been proposed as possible theories behind the persistent rise in college tuition. We divide these theories into those that primarily impact the equilibrium of the higher education market through supply and those that have more direct demand-side effects.

Factors Affecting College Supply On the supply side, colleges have been affected both by shifting cost structures and changes to nontuition revenue. With regard to costs, we implement Baumol's cost disease as a rise in the relative price p_t of college inputs by feeding in the observed path of the CPI-adjusted Higher Education Price Index, which increased from 1.08 in 1987 to 1.30 in 2010. In addition, we incorporate the dynamics of the custodial cost function $C_k(N_{k,t}; t)$ discussed in section 3.1.3. With regard to nontuition revenue, we feed in the evolution of government appropriations at the federal, state, and local levels and that of endowment funding.

Factors Affecting College Demand On the demand side, we incorporate a rise in the returns to college enrollment, a rise in average parental income from economic growth, and changes to financial aid, both in the form of loans and grants. The change to college returns incorporates an academic, monetary, and amenity component. Specifically, for the academic dimension, we adjust the probabilities $\overline{\delta}_k$ to reflect the rise in college completion rates over the past two decades. On the monetary side, we proportionately scale the college-specific college premium $\overline{\lambda}_k$ to match the trends in Autor et al. (2008).[18] Lastly, amenities (flow utility φ_k) increase endogenously with investment I. To capture the effects of economic growth on parental income, we adjust $EFC(s)$ to reflect the 44% rise in real GDP per capita from 1987 to 2010. Lastly, to test the Bennett hypothesis—which postulates that colleges seek to capture increases in external financial aid by raising tuition—we model the evolution of the Federal Student Loan Program and the Pell Grant program. Specifically, we incorporate shifts in borrowing limits, interest rates, Pell Grant amounts, and the introduction of supplemental unsubsidized loans in 1993. Lastly, because we seek to explain tuition and not other costs of college attendance, we increase the parameter ϕ for nontuition expenses to reflect NCES estimates.

4.1.2 The Evolution of Higher Education 1987–2010: Model vs. Data

When subjected to all of the previously discussed forces, the equilibrium dynamics of the model resemble quite closely the trends in the data, both in the aggregate and the cross section. Figure 3 visualizes the model's performance in matching changes between 1987—which was targeted in the joint parametrization—and 2010. The base of each segment represents the model (horizontal axis) and data (vertical axis) values for 1987, and the "cannonball" represents the 2010 values. A perfect match coincides with the 45 degree line. Trajectories parallel to the 45 degree line indicate that the model matches the change from 1987 to 2010 while missing the initial level.

The model captures the evolution of higher education between 1987 and 2010 quite well along several dimensions.[19] For the main variable of interest—net tuition—the model generates an FTE-weighted 111% increase between 1987 and 2010 compared to 91% observed in the data, largely because of overshooting among GTN colleges, which comprise 27% of aggregate enrollment. The model somewhat undershoots for GRS colleges but nearly exactly matches the rise in net tuition among the remaining types. Both the model and data report that the largest *absolute* rise in net tuition comes from private colleges, and an even larger increase occurs for sticker price tuition. Thus, while private schools in 2010 are more expensive on average, they have also made institutional aid more generous to attract the most desirable students. On a

[18] We move the college completion rates from their 2002 value (the earliest year in the IPEDS/DCP data for this series) to their 2010 value. The college graduate labor market premium data in Autor et al. (2008) stops in 2005, so we extrapolate to 2010 following Gordon and Hedlund (2019).

[19] The data does not contain the dynamics of ability and parental income.

percentage change basis, however, *public* colleges exhibit the most rapid net tuition inflation both in the model and data. On the spending side, a clear dichotomy emerges by degree of admissions selectivity. Spending per student at selective colleges go up by 30% or more in the data, whereas they only rise by 15% for public research nonselective schools and remain stagnant or even decline for all other types. The model captures this dichotomy but overestimates the total rise in expenditures.

Although the parametrization targeted the aggregate rise in enrollment from 1987 to 2010, figure 3 demonstrates that the model also replicates almost perfectly the untargeted school-specific pattern of enrollment changes. The model is able to reproduce the 13 percentage point rise in the data—from 35% to 48%—along with the fact that two-thirds of the increase accrues to public colleges. Delving into the cross section of students, figure 4 shows heat maps for equilibrium enrollment in the model for both 1987 and 2010. The distributions of student abilities within each college type remain mostly stable, though it is evident from the darkening of the shading in the 2010 plots that the largest enrollment increases occur among GTN and PTN colleges, particularly for students of moderate ability and higher parental income.

While we lack data on the evolution of cross-sectional enrollment patterns, the

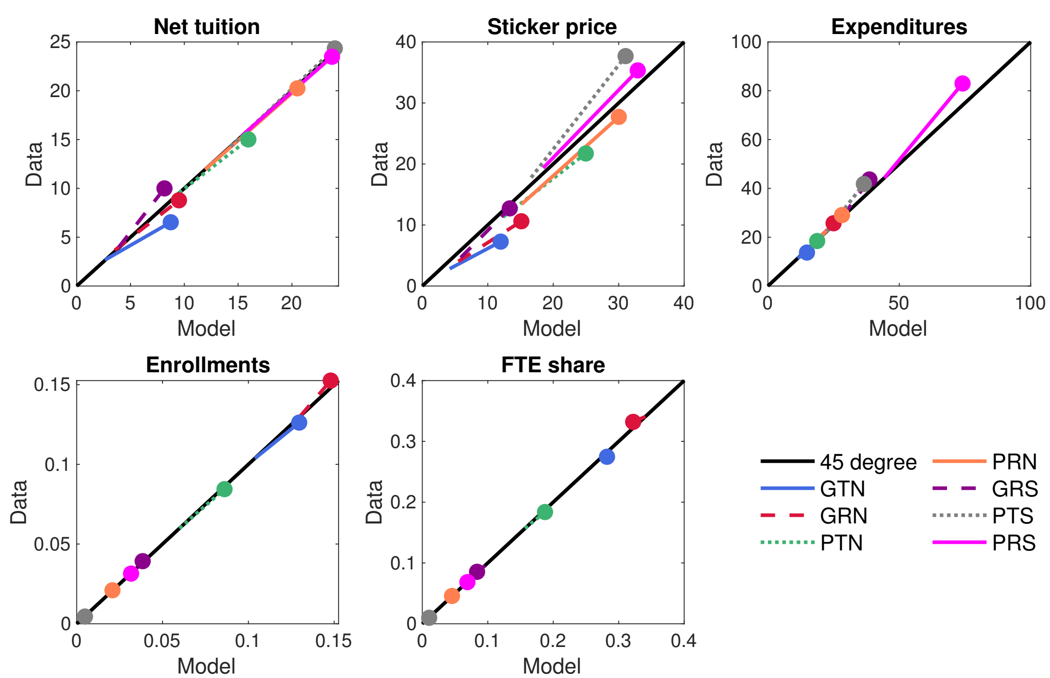


Figure 3: Data vs. Model, 1987 vs. 2010

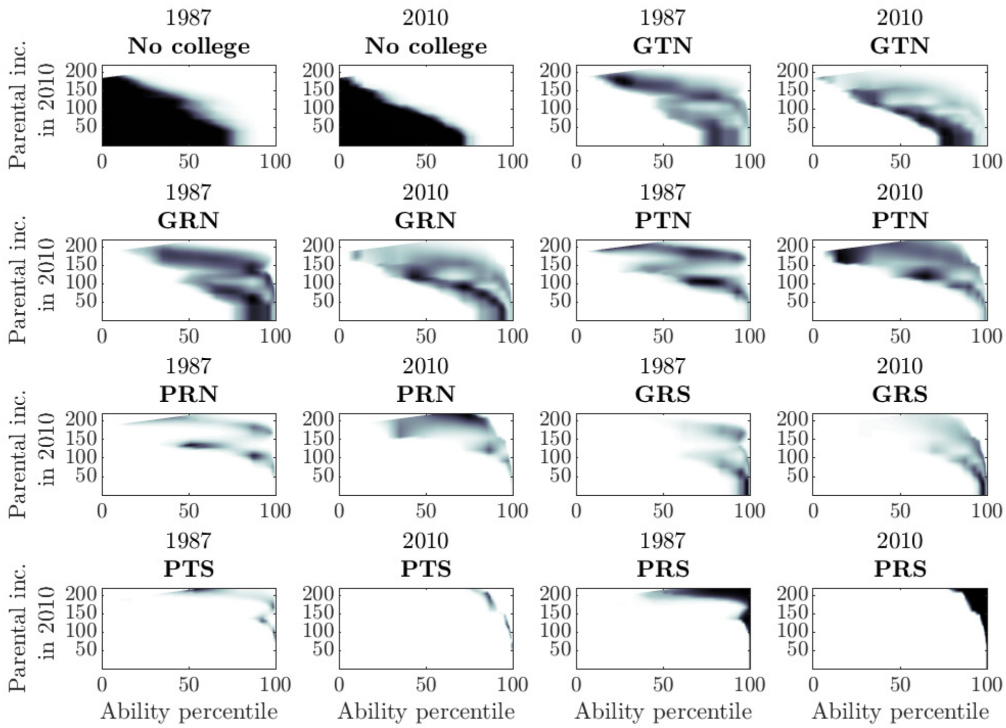


Figure 4: Sorting in 1987 and 2010

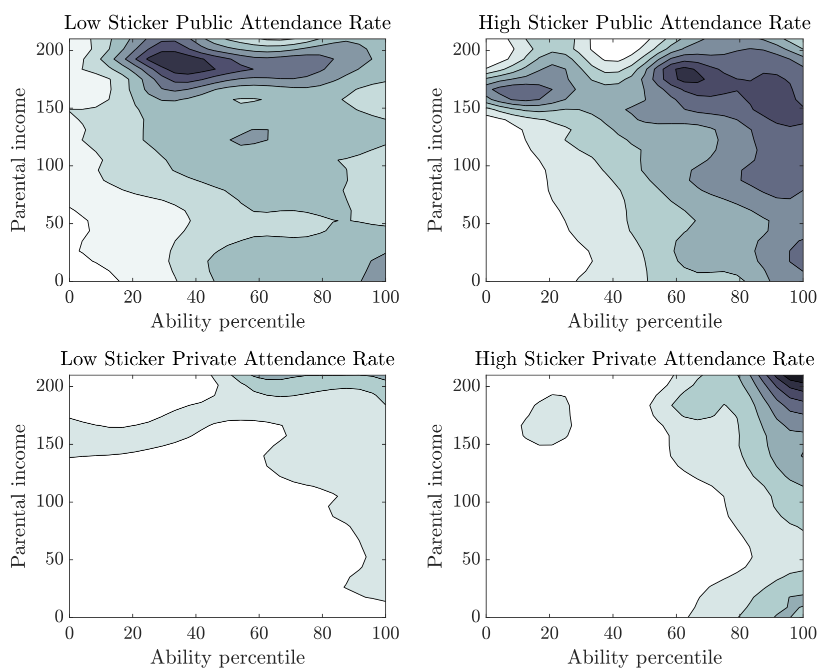
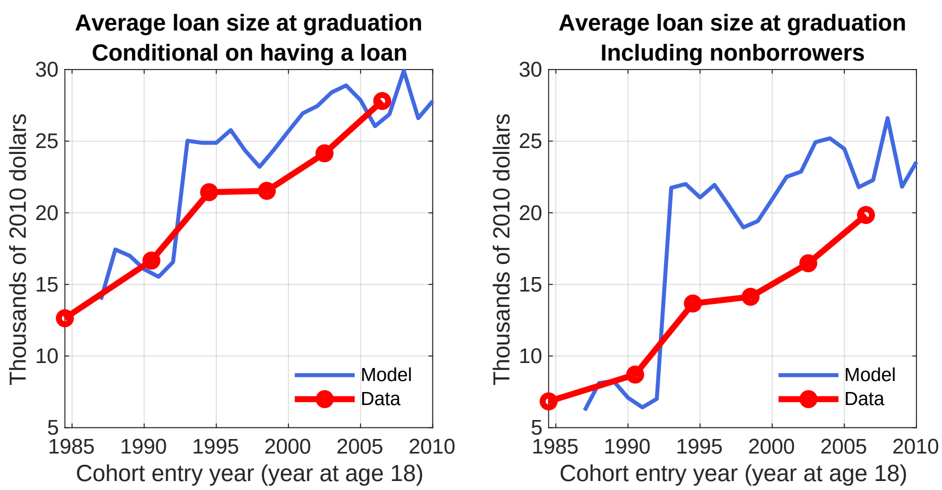


Figure 5: Sorting Patterns for Attendance in the NLSY97

NLSY97 provides insight into enrollment patterns around year 2000. These patterns are displayed in figure 5 broken down into public versus private and high (i.e., above median) sticker price versus low (below median) sticker price colleges. The sorting patterns between the model and data look strikingly similar. In particular, enrollment at high sticker price private schools (e.g., PRS) is concentrated among students that are both high ability and high income. In addition, public colleges exhibit relatively wide variation both in student ability and parental income, whereas low sticker price private schools cater almost exclusively to the more affluent, unless the student is of very high ability. Overall, the sorting of students across schools in the model looks reasonable, both in 1987 and 2010, when compared to this data.



Data Source: Hershbein and Hollenbeck (2015). Their estimates are in 2013 dollars by graduation year. We deflate to 2010 dollars and convert to cohort year by subtracting 5 from the year.

Figure 6: Average Loan Size at Graduation

Student debt and default in the model also mirror their behavior in the data despite being untargeted. For instance, the model closely approximates the path of average student debt at graduation, conditional on having a loan, with figure 6 showing a rise from under $15,000 in 1987 to around $28,000 in 2010. The model overshoots the short-run dynamics of the unconditional average loan size in the early 1990s upon the introduction of unsubsidized loans, but the model and data end up at similar values by the end of the sample period. At the extensive margin, Akers and Chingos (2014) report that 14% of 20- to 40-year-olds had student loans in 1989, with this number rising to 36% by 2010. In the model, the percentage of 20- to 40-year-olds with student loans is 17.2% for the 1987 cohort and increases to 38.2%. Lastly, the Department of Education reports a 17.6% two-year cohort default rate for 1987, which falls to 5.2% in 2006 before the Great Recession.[20] In the model, the two-year cohort default rate declines from 20.6% to 5.5% over the sample period. It turns out that the insurance mechanism of being able to default on student debt is an important determinant of credit demand and, thus, the demand for college. The model predicts that, absent default, the average student loan balance at graduation would be $3,200 lower ($19,500 instead of $22,700), and net tuition would be $300 lower in 2010.

4.1.3 Tuition Dynamics

Before assessing the quantitative contribution of each driving force, figure 7 shows the dynamics (rather than just the endpoints) of net tuition in the model and data.[21] Overall, the model does remarkably well at matching tuition over time across each of the college types, though it overshoots the path of net tuition for PTS colleges, consistent with the discussion earlier. The same overshooting in the model occurs for PRS colleges in the late 1990s, but by 2010, the model and data are more or less in agreement. Net tuition dynamics for the other five college types are quite closely aligned during the entire time period.

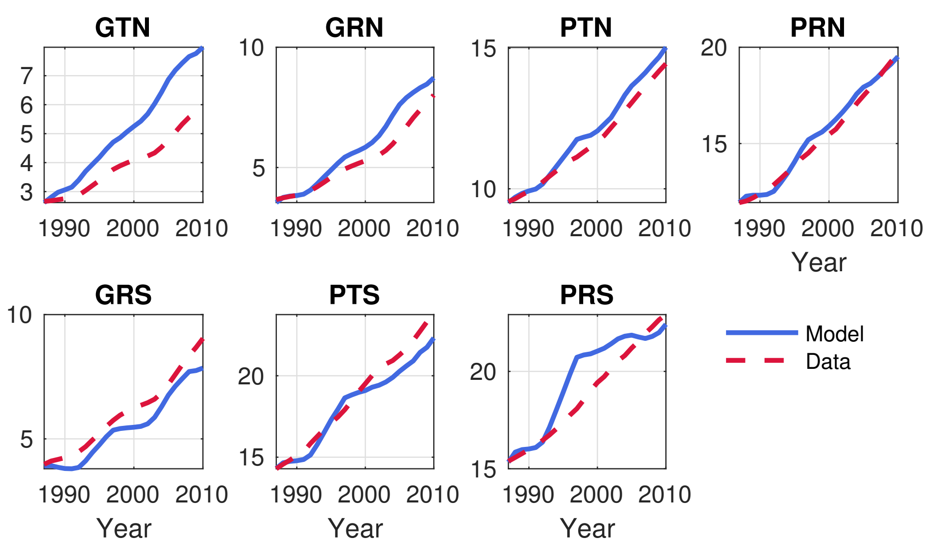


Figure 7: Net Tuition Dynamics: Model vs. Data

[20]https://www2.ed.gov/offices/OSFAP/defaultmanagement/defaultrates.html.

[21]Because colleges in the model set tuition by cohort, we report 5-year rolling averages for the model transition dynamics.

Returning to the earlier institutional aid discussion, the ability premium rises steeply for all college types throughout almost the entire time period (seen in the left panel of appendix figure 16). The only exception is a leveling off starting in the mid-2000s for all types except private selective colleges. Regarding the parental income gradient, $\beta_{k(i)}$ in equation 30, the model reveals an increasing pattern for every college type except GTN in the mid-1990s (seen in the right panel) after the expansion in financial aid following the introduction of unsubsidized loans. This gradient then stabilizes or declines for most colleges except PRS, for which it continues to rise.

4.2 Comparative Statics in a Stylized "Toy" Model

Before undertaking a full quantitative evaluation of the different tuition theories, we turn to a static, stylized version of the model to glean insights into the underlying mechanisms impacting higher education. Although a simplification, the qualitative predictions are consistent with the quantitative evaluation done later in section 4.3.[22]

Consider a representative college with quality function $q(I, N)$ that depends on investment I and enrollment N but not on student ability. Rather than explicitly model the decision of *who* the college admits, assume that the college faces a downward sloping demand curve $T(N)$ and simply chooses I and N to maximize $q(I, N)$ given the budget constraint. In this case, the college solves

$$\begin{aligned} &\max_{I,N} q(I, N) \\ &\text{s.t. } pIN + pC(N) = T(N)N + \overline{G}N + \overline{E}N, \end{aligned} \tag{36}$$

where $\overline{G}$ and $\overline{E}$ are per-pupil appropriations and endowment flows, respectively.

Implicitly, the downward sloping $T(N)$ is akin to saying that, absent dependence of q on academic ability, and conditional on targeting some level of enrollment N, the college designs its admissions strategy to maximize per-pupil resources. The higher the desired enrollment N, the lower net tuition $T(N)$ it must charge to still attract the requisite number of students. Given $T(N)$, the budget constraint implies that

$$I(N) = -\frac{C(N)}{N} + \frac{1}{p}\left(T(N) + \overline{G} + \overline{E}\right). \tag{37}$$

For small N, the fixed cost component of $C(N)$ dominates, causing $I(N)$ to be a large

[22] Appendix section A.6 summarizes this comparison.

negative number. As N increases, $I(N)$ first rises and then falls again given the convex shape of $C(N)$ and the decreasing average net tuition function $T(N)$, as captured by the blue curve in the top left panel of figure 8. The red dashed curve represents an "indifference curve" for the quality function q, and point A is a visual representation of the optimality condition $I'(N^*) = q_N(I(N^*), N^*)/q_I(I(N^*), N^*)$, with the asterisk directly below on the dashed black curve showing the average net tuition $T(N^*)$.

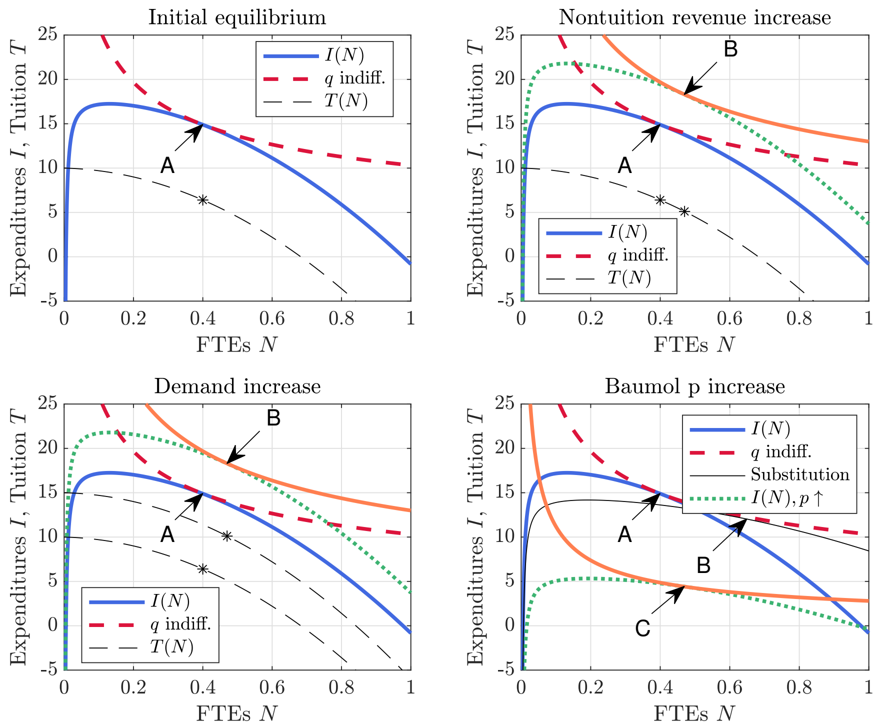


Figure 8: Comparative Statics in a Simple Model

4.2.1 An Increase in Nontuition Revenue

The top right panel depicts the impact of an increase to nontuition revenue $\overline{G}$ or $\overline{E}$, which causes an outward, parallel shift in $I(N)$ from the blue to the green dotted curve. Akin to a pure income effect, we see that the new tangency point B occurs to the northeast of A at both higher enrollment $N_B > N_A$ and investment $I_B > I_A$. With no actual shift in the $T(N)$ curve, the higher level of enrollment is only possible if net tuition declines, i.e., $T(N_B) < T(N_A)$. Thus, net tuition tends to move in the opposite direction of nontuition revenue. This result implies, for instance, that net tuition *increases* and quality-enhancing spending I *falls* if the government cuts its level of direct appropriations to colleges.

4.2.2 An Expansion in Government Financial Aid

The bottom left panel visualizes the impact of a demand increase—for example, from more generous government financial aid—manifested as an outward shift in $T(N)$ and therefore also $I(N)$. In principle, the shift to $\widetilde{T}(N)$ could take a number of different forms, resulting possibly in both income and substitution effects. If net tuition shifts in an approximately parallel fashion, as shown in the figure, then enrollment and investment both increase, i.e., $N_B > N_A$ and $I_B > I_A$, just like they did in response to higher nontuition revenue. However, unlike in the case of nontuition revenue, equilibrium net tuition rises after a positive demand shock as one might expect. The magnitude of the increase in net tuition is less than the demand shock, though, with $T(N_A) < \widetilde{T}(N_B) < \widetilde{T}(N_A)$. These results suggest that tuition absorbs part of the increase in demand, with the rest passed through to higher investment and enrollment.

4.2.3 Baumol's Cost Disease

Unlike the straightforward predictions in the previous two experiments, Baumol's cost disease yields ambiguous effects on net tuition depending on the driving forces of rising costs. For example, if average costs $C(N)/N$ increase uniformly, then the result is the same as what occurs if government cuts appropriations—namely, net tuition rises while enrollment and investment both fall, as discussed at the end of section 4.2.1. By contrast, if it is the relative price of college inputs p that drives rising costs, then there are offsetting income and substitution effects that lead to an ambiguous result. Specifically, from equation 37, the investment curve $I(N; p)$ flattens in response to an increase in p. This rotation creates income and substitution effects. The former induces a response tantamount to a cut in nontuition revenue—namely, lower enrollment and thus higher net tuition. The substitution effect, however—as shown by the black curve in the bottom right panel—tends to reduce investment and increase enrollment, which leads to lower net tuition. The bottom right panel shows the case where the substitution effect dominates, i.e., $N_C > N_A$. In general, though, an increase in the relative price of college inputs has ambiguous effects on net tuition and enrollment, absent a quantitative analysis.

4.3 Explaining the Rise in Net Tuition and Other Trends

Though useful for intuition, the previous stylized model ignored competition between colleges, heterogeneity in net prices across students within a college, and dynamics from forward-looking behavior. Thus, this section undertakes a quantitative approach to measuring the relative contribution of each of the demand and supply factors.

We perform this decomposition from two sides. First, starting with the 1987 cohort-specific equilibrium, we introduce one force at a time by setting the relevant parameters to their 2010 values, such as changing loan limits and grant amounts to quantify just the Bennett hypothesis. Then, we do the opposite by starting with the 2010 equilibrium and *removing* one force at a time, reverting the corresponding parameters to their 1987 values. These two decomposition approaches are necessary given possible interaction effects.

4.3.1 Supply: Changes in Government Appropriations

Beginning with supply factors, table 1 finds that changes to government appropriations between 1987 and 2010 have actually contributed to a *decline* in net tuition of \$100–\$300, depending on whether we start from the 1987 equilibrium and implement the 2010 level of public appropriations (in the "2010 Toggle" column, comparing the value of 5.6 for the public revenues experiment to the 1987 value of 5.7) or whether we start with the 2010 equilibrium and revert government appropriations from 2010 to 1987 levels (in the "1987 toggle" column, comparing the 2010 value of 12 to the value of 12.3 for the public revenues experiment). At first glance, this result may seem surprising in light of the comparative statics of the stylized model and extensive public discourse about government cutbacks fueling higher tuition. The reason for this counterintuitive finding is actually quite simple: total (federal + state/local) government appropriations have actually *gone up* in the aggregate, not declined. Only PTN and GTN colleges have experienced total cutbacks. Thus, consistent with the stylized model, higher nontuition revenue in the form of government appropriations translates to lower net tuition. If we focus only on state appropriations—which have indeed fallen—table 1 finds that cutbacks have fueled a \$500–\$600 rise in real net tuition from 1987 to 2010. Broken down by college type, figure 9 (complemented by figure 17 in the appendix) indicates that declining trends in public appropriations created the largest upward pressure on net tuition at teaching-focused GTN colleges. By contrast, at research-intensive GRS and GRN colleges, the rise in federal appropriations more than offset state cutbacks.

In a sense, the above analysis which focuses on absolute levels of state appropriations may miss some of the narrative, because as a share of college revenues, *relative* state appropriations have indeed declined more noticeably. To evaluate the effects of state appropriations failing to keep up with tuition, we conduct another quantitative experiment in the model that keeps state appropriations stable relative to total college revenues between 1987 and 2010. This exercise is somewhat more complex, because college revenue at each school is an endogenous object that itself depends on the level of state appropriations and the pricing decisions of other colleges. To take into account such equilibrium feedback, this exercise solves for the average annual real growth rate of state appropriations that causes its share of equilibrium revenues in 2010 to remain the same as in 1987. A real growth rate of 2% emerges as the value that stabilizes state appropriations as a share of equilibrium revenues for the three public college types (GTN, GRN, and GRS) for which this exercise is most relevant.

		Net Tuition			
		Model: 1987 Baseline		Model: 2010 Baseline	
Experiment / change	Data	2010 Toggle	% Explained	1987 Toggle	% Explained
1987	5.8	5.7	0.0	5.7	-118.6
Baumol (p, C)	–	6.4	13.0	10.4	-31.0
Relative prices (p)	–	6.1	7.2	11.0	-19.9
Real costs (C)	–	6.1	7.3	11.5	-10.1
Pub. rev. (G)	–	5.6	-1.3	12.3	6.0
Pub. rev. federal (G^{fed})	–	5.0	-13.1	12.9	16.2
Pub. rev. state (G^{state})	–	6.2	10.4	11.4	-11.4
Priv. rev. (E)	–	5.2	-9.4	12.9	15.9
Bennett $(\bar{l}, i, \zeta, \phi)$	–	8.6	54.6	8.4	-67.1
Borrowing limits $(\bar{l})$	–	7.2	29.2	10.4	-30.3
Pell Grants (ζ)	–	6.5	16.0	11.2	-14.6
Returns (λ, δ, q)	–	6.7	18.9	11.1	-17.5
College premium (λ)	–	6.2	10.4	11.6	-8.3
Completion rates $(1-\delta)$	–	5.7	1.1	11.9	-1.7
Amenities (q)	–	6.2	9.1	11.6	-7.1
Parental income / transfers	–	7.6	35.0	9.5	-47.9
2010	11.1	12.0	118.6	12.0	0.0

Note: % explained is the model's change from the base year divided by the data's change from 1987 to 2010; all numbers are FTE weighted.

Table 1: The Contribution of Individual Forces to Average Net Tuition

This counterfactual exercise indicates that maintaining stability in the relative generosity of state appropriations over time would have greatly slowed tuition inflation in the presence of other forces. For GTN colleges, real net tuition in this counterfactual increases by a cumulative 84% between 1987 and 2010 instead of the 234% from the baseline with the actual observed change in state appropriations, translating to a much smaller net tuition increase of \$2,200 versus \$6,100. At GRN colleges, the more generous state appropriations cut cumulative net tuition growth from 168% to 45%, thereby reducing the absolute rise in net tuition from nearly \$6,000 to only \$1,600. Among GRS colleges, maintaining state appropriations as a share of revenues at 1987 levels causes net tuition to *decline* by nearly \$1,700 instead of exhibiting a \$4,200 hike. By contrast, equilibrium net tuition at private colleges is nearly invariant to this change in state appropriations. Interestingly, enrollment shares barely budge despite the larger gap created between public and private colleges, indicating a high degree of segmentation consistent with Hendricks, Herrington, and Schoellman (2021).

4.3.2 Supply: Baumol's Cost Disease

We turn now to Baumol's cost disease as a potential tuition driver. Recall from the comparative statics of the stylized model that Baumol's cost disease—implemented as a shift upward in the relative price p and the custodial cost curve $C(N)$—can have ambiguous effects on net tuition and enrollment because of counteracting income and substitution effects. As reported in table 1, the quantitative analysis indicates that Baumol's cost disease is responsible for a \$700–\$1,600 rise in net tuition. Further decomposing the role of the relative price p and custodial cost function $C(N)$, table 8 reveals that the rise in p from 1987 to 2010 drives net tuition higher by \$400–\$1,000, while the shift in $C(N)$ in isolation contributes to a \$400–\$500 tuition hike. This wide range implies that Baumol's cost disease accounts for anywhere from 13%–31% of the observed doubling of net tuition, which highlights the importance of interactions between the different forces in operation. A further breakdown of Baumol's cost disease points to a more significant role for the rise in the relative price compared to that of custodial costs, in large part because p also amplifies the budgetary impact of investment spending pI, particularly given the considerable growth in I from 1987 to 2010. As manifested in figure 9, the impact of Baumol's cost disease is heterogeneous across college types, with net tuition at GRS and GTN colleges responding most strongly in terms of percentage change. By contrast, PTS colleges exhibit the highest expenditure and enrollment sensitivities, as seen in the second and third panels.

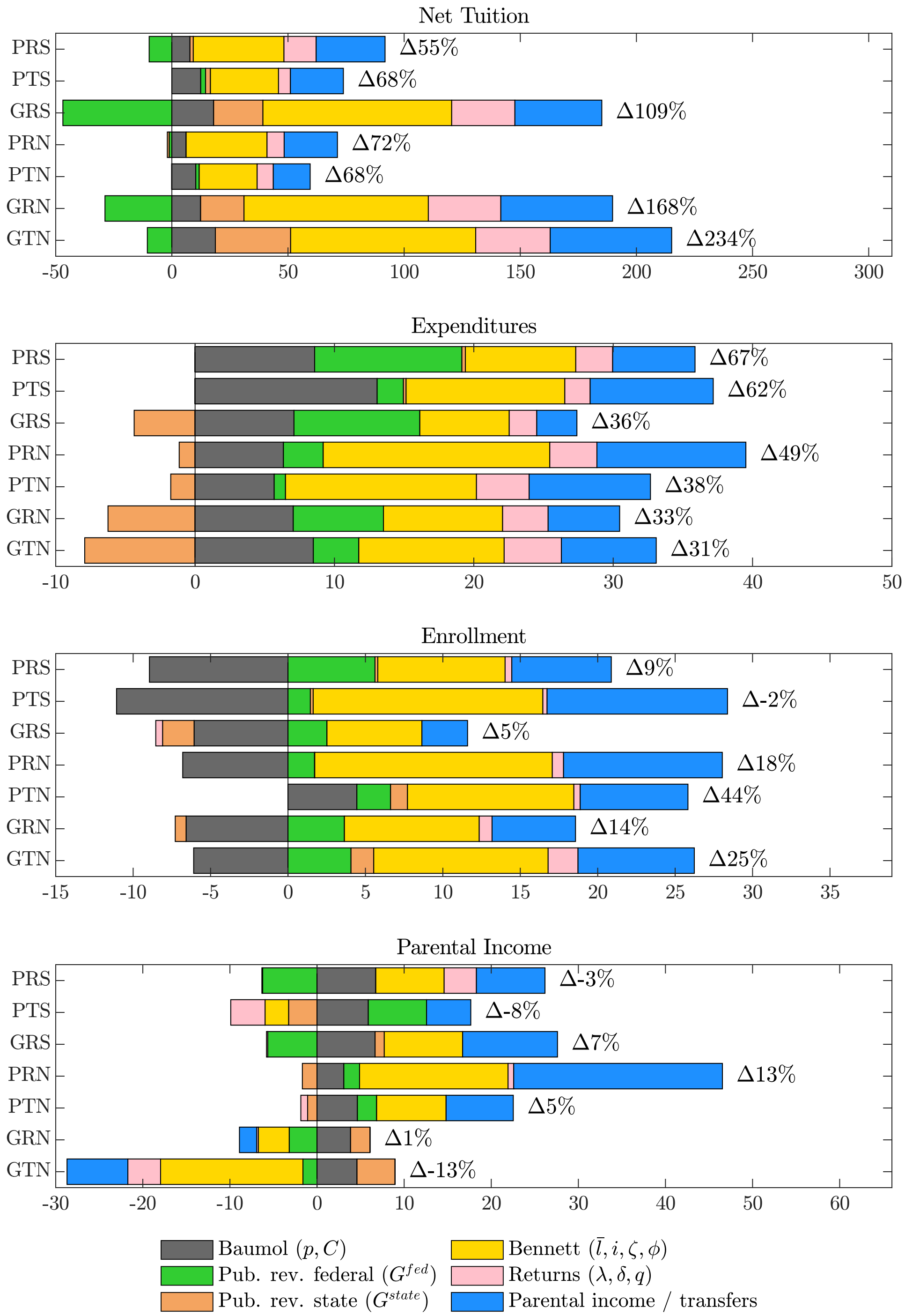
4.3.3 Demand: Expansions in Federal Aid (Bennett Hypothesis)

Switching focus to demand-side factors, the quantitative analysis underscores that the single largest factor driving up college tuition is the expansion in federal financial aid, i.e. the Bennett Hypothesis. Table 1 indicates that, in isolation, the combination of observed changes in student loan limits and interest rates as well as Pell Grants and nontuition expenses that enter aid formulas is responsible for 46% to 57% of the rise in equilibrium net tuition in the aggregate, which amounts to $2,900–$3,600 per student in real terms. Decomposing the contribution of each component of financial aid to tuition changes reveals that the expansion in borrowing limits is relatively more potent than Pell Grants. Section 5 dives deeper into this point in relation to the empirical literature by pointing out the importance of distinguishing between the intensive and extensive margins of financial aid involving eligibility and utilization.

In the cross section of college types, figure 9 reveals that net tuition at public colleges is much more responsive *in percentage terms* to expansions in federal aid than it is at private colleges. However, reflecting the fact that percentage changes are affected by initial tuition levels, appendix figure 18 reveals that the absolute change in net tuition caused by more generous financial aid is somewhat larger at private colleges. Looking beyond tuition, the degree of heterogeneity across college types with respect to the response of expenditures and enrollment to federal aid expansions is comparatively modest, with GRN and GTN schools exhibiting the largest absolute enrollment increases. According to the bottom panel, average parental income actually *rises* in reaction to more generous financial aid, suggesting that in equilibrium, aid may not always effectively target help to lower-income families. Indeed, the introduction of unsubsidized loans directly increased the ability to borrow of families with incomes too high to otherwise qualify for need-based aid.

4.3.4 Demand: Family Income Growth

Family income growth (and the rising parental transfers to college students that accompany it) has also contributed meaningfully to higher tuition, accounting for between 35% and 48%—or $1,900 to $2,500—of the total increase in net tuition from 1987 to 2010, as shown in table 1. This result mirrors the finding in Cai and Heathcote (2022) about the importance of rising income dispersion and a fattening of the right tail as significant drivers of higher tuition. In percentage terms, figure 9 reveals that parental income growth is a more prominent driver of tuition growth at public colleges, but as was the case with financial aid expansion, base effects largely explain this pattern. In absolute levels, the effect of income growth on tuition is nearly twice as large among PRS, PTS, and PRN colleges relative to all other institution



Note: $\Delta x\%$ gives the total percent change including all forces.

Figure 9: Percent Change Relative to 1987 from Adding One Force, Else Equal

types, according to figure 18 in the appendix. In terms of enrollment, the biggest beneficiaries from family income growth are GRN and GTN schools where students are likely to be closer to the attendance vs. nonattendance margin.

4.3.5 Demand: Returns to College Enrollment

Lastly, table 1 indicates that the rise in the returns to college enrollment from 1987 to 2010 drives up net tuition by \$900–\$1,000, making it responsible for around 18% of total tuition inflation over this time period. The increase in earnings premia and amenities (the endogenous rise in flow utility φ_k from growth in investment I_k) each account for roughly half of this effect, with improved completion rates exerting little impact on net tuition. In percentage terms, the link between rising returns and net tuition is much more pronounced at public colleges and to some extent at PRS colleges, as depicted in figure 9.

4.3.6 Taking Stock

The preceding results indicate that a confluence of forces—rather than one single culprit—is responsible for the long upward march in tuition. By disentangling these forces, the decomposition analysis helps assess their relative importance and provides some key insights. First, federal aid expansions and—for public colleges—the *relative* decline in state appropriations as a share of college revenues have the largest overall quantitative effects on tuition inflation. Thus, whether on the demand side or the supply side, government spending meaningfully influences college pricing both in the aggregate and cross-section. Secondly, family income growth and the associated increase in parental transfers emerge as potent drivers of higher net tuition, college expenditures, and enrollment. Third of all, the rising returns to college enrollment account for just under one-fifth of aggregate tuition growth, driven equally in part by monetary returns in the form of higher future earnings and an increase in amenities that students enjoy while in college. Lastly, the potency of Baumol's cost disease depends strongly on its interaction with other forces operating concurrently, with its effects accounting for anywhere from 13% to 31% of observed tuition inflation.

5 Relation to Empirical Studies

The previous quantitative findings also relate to a growing empirical literature on the impact of financial aid and state appropriations on college pricing. This literature follows a range of approaches with regard to time horizon, geographic scope (i.e., state-specific vs. national), and the specific policies under question. To establish a common basis for comparison with this diverse empirical literature, this section undertakes some counterfactual experiments to compute tuition pass-through rates of the financial aid and state appropriations examined in sections 4.3.1 and 4.3.3.

5.1 Financial Aid

To calculate the transmission from financial aid to net tuition, we expose the economy to a \$1,000 increase either in the maximum Pell Grant or in the annual loan limit for subsidized or unsubsidized loans (with a corresponding adjustment in the cumulative loan limit to allow students to borrow more each year). Importantly, the analysis allows for time-varying treatment effects, given that conditions in the higher education market evolve significantly over time between 1987 and 2010.

As depicted in figure 10, the pass-through rate of increases in Pell Grant amounts to equilibrium net tuition is stable between 50% and 60% in the model over the sample period. This result stacks up favorably to the in-state tuition analysis in Rizzo and Ehrenberg (2004), which reports a 58% pass-through rate from increased Pell Grant generosity. More recently, Lucca et al. (2019) estimate a 36% pass-through rate of Pell Grants to net tuition but only a 21% pass-through rate to sticker tuition. Thus, their empirical results confirm one of the messages emphasized throughout this paper, which is that colleges engage in substantial price discrimination and may implement pricing adjustments through changes to institutional aid instead of sticker prices. Turner (2012) also mirrors this point in a student-level analysis of tax-based financial aid, simultaneously finding significant pass-through to the actual prices that students pay while failing to reject the possibility that overall sticker tuition is unaffected. Bridging the findings in Rizzo and Ehrenberg (2004) and Lucca et al. (2019), Singell and Stone (2007) deliver a range of estimates for the pass-through rate depending on methodology and the type of college. For out-of-state and private tuition, the study arrives at pass-through rates in excess of 80%. In our analysis, figure 19 in the appendix portrays PRS colleges as having the highest pass-through rates, hovering around 75%. For in-state tuition, Singell and Stone (2007) report an OLS estimate for the pass-through rate of 36% but a smaller IV estimate of 13%. In this paper, GTN colleges also exhibit pass-through rates well below 50%. The empirical analysis in Turner (2017) confirms this extent of heterogeneity, reporting pass-through rates of

75% at selective nonprofit institutions and 31% for nonselective, nonprofit schools.[23]

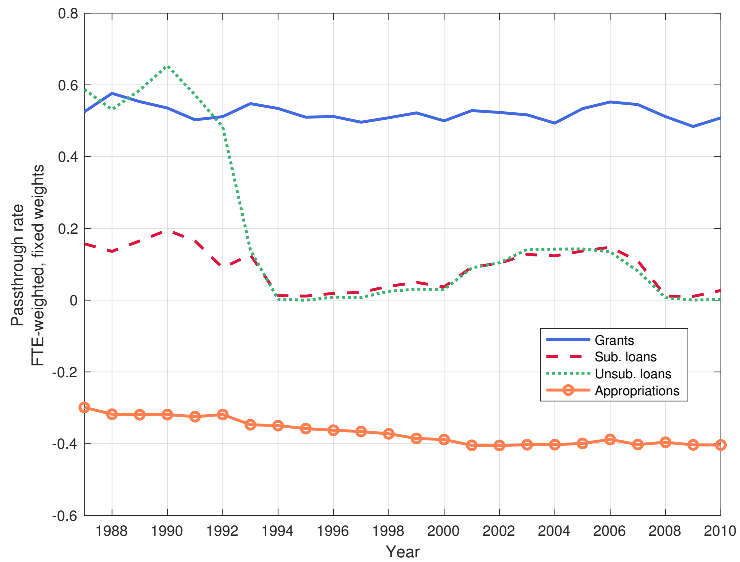


Figure 10: The Dynamics of Equilibrium Tuition Pass-Through Rates

Shifting attention from grants to student loans, figure 10 displays substantial time-variation in model estimates for the pass-through rate of increased subsidized and unsubsidized loan limits to net tuition. In the late 1980s and early 1990s, subsidized loans had a nearly 20% pass-through rate to tuition, indicating that a $1,000 rise in the loan limit translated to an almost $200 increase in net tuition. By contrast, unsubsidized loans had a larger 60% pass-through rate despite offering less financially attractive terms. The broader eligibility for unsubsidized loans on the extensive margin of borrowing helps explain this counterintuitive result. While students eligible for subsidized loans are likely to be more responsive on the intensive margin to increases in subsidized limits than to unsubsidized limit increases, they represent only a subset of borrowing-constrained college students.

Pass-through rates are also state-dependent. In particular, figure 10 reveals that pass-through rates for further marginal loan expansions plummet after the early-1990s introduction of unsubsidized loans and expansion in loan limits temporarily satiated borrowing needs. However, as tuition hikes through the early-mid 2000s ran up against flat nominal loan limits, students became more credit-constrained, and

[23]Turner (2017) employs a different definition of nonselective that includes any school that offers two-year programs. That paper also limits attention to students with EFCs that are no greater than $4,800, whereas we evaluate the global pass-through to net tuition.

pass-through rates began to again approach 15% to 20% until the eventual post-2008 loan expansion resatiated borrowing demand. Empirically, Lucca et al. (2019) report a similar pass-through rate of 18% for unsubsidized loans before 2008. Interestingly, like the post-2008 drop in the pass-through rate of our model, their estimate falls, becoming not statistically different from zero after 2009. Cellini and Goldin (2014) and Frederick, Schmidt, and Davis (2012) also uncover evidence linking student aid to tuition increases, but they examine for-profit and community colleges, respectively, which fall outside the scope of this paper. To summarize, the findings from the model suggest that there is no such thing as "the" pass-through rate from student loan expansions to net tuition. Instead, pass-through rates depend on the tightness of credit constraints, which is related to prevailing prices, the available borrowing instruments, and eligibility criteria.

5.2 State Appropriations

Similar to the previous counterfactual experiments, the analysis here considers a \$1,000 increase in state appropriations per FTE. Figure 10 reveals that the pass-through rate to equilibrium net tuition is relatively stable over time between -40% and -50%, indicating a decline in net tuition of \$400–\$500 for every \$1,000 in more generous state appropriations. One of the most frequently referenced empirical studies that evaluates the relationship between state appropriations and tuition, Koshal and Koshal (2000), estimates a similar -40% pass-through rate. More recently, Webber (2017) estimates a -26% pass-through rate of state appropriations to net tuition, pointing out that the salience of public support has risen over time. In particular, the paper reports that the pass-through rate has grown from -10% prior to the year 2000 to -32% post-2000. Consistent with our analysis, the evidence points to an inverse link between state appropriations and tuition changes but with a magnitude that is far below a \$1-for-\$1 relationship. Instead, in addition to raising net prices, colleges absorb negative nontuition revenue shocks by reducing quality-enhancing spending.

6 Conclusion

Many explanations have been offered for the persistent rise in college tuition, but large-scale quantitative examinations have proven few and far between. Although previous empirical studies have provided varying degrees of support for some of the channels discussed in this paper, the analysis here has gone further by undertaking a comprehensive structural analysis to determine whether they can collectively explain the changes observed in the data and to measure their relative contribution.

We show that the combination of forces studied here can rationalize the time series and cross-sectional behavior of the higher education data between the late 1980s and the Great Recession. In that sense, the results suggest that there is not an urgent need for an entirely new theory of tuition inflation, while also pointing out that there is not a singular smoking gun. Overall, demand-side forces such as financial aid expansions, rising parental income, and increasing college degree earnings premia are the largest drivers of tuition inflation. However, supply trends such as lagging state appropriations have also impacted the trajectory of tuition at public colleges, which is one of several places where heterogeneity proves important.

Many fruitful extensions emerge for future research. For example, many reforms have been proposed to increase college access and reduce the burden of student loan debt, ranging from a greater array of income-based repayment options to free public college. Further study is needed to fully understand the potential impacts of these reforms both on higher education outcomes and on the broader economy.

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Online Appendix

A Additional Tables and Figures

This section includes additional exhibits related to the quantitative experiments.

A.1 The Initial Distribution of Net Tuition and Markups

This section relates to the model fit discussion in section 4.1.

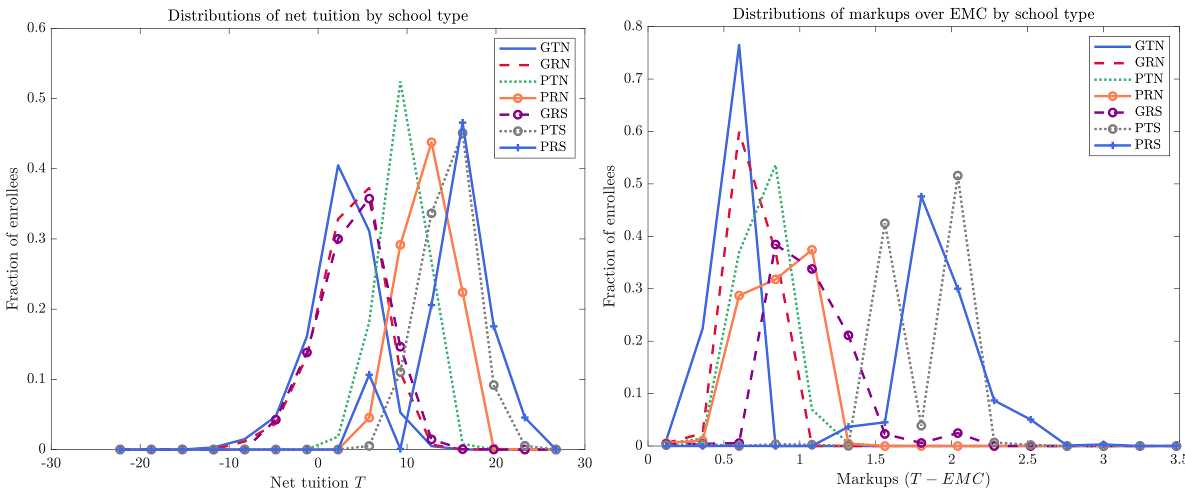


Figure 11: Distribution of Net Tuition and Markups

A.2 Implementation of Tuition Inflation Experiments

The figures below show those exogenous changes most amenable to plotting that we feed into the model to implement the experiments outlined in section 4.1.1.

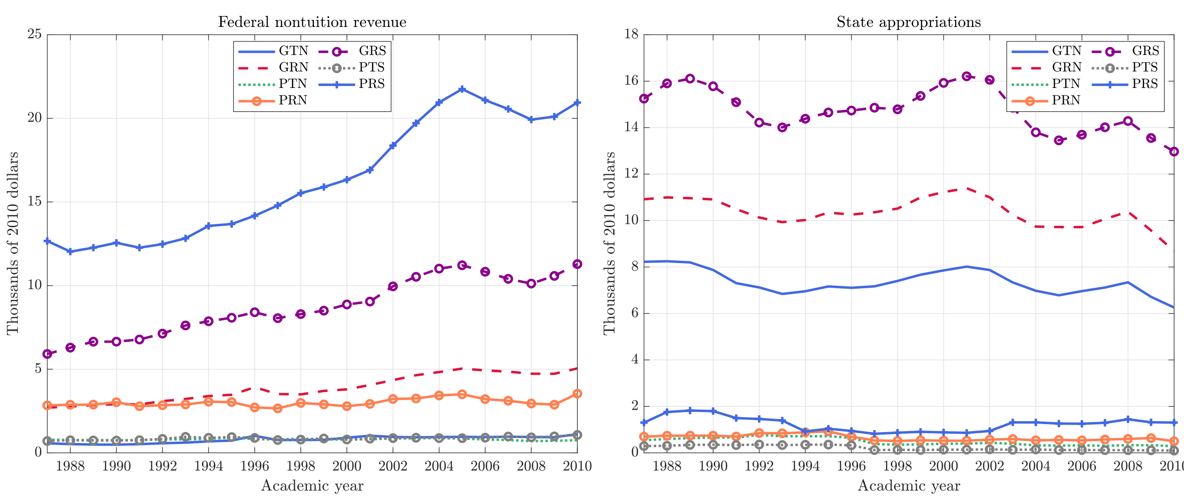


Figure 12: Public Appropriations

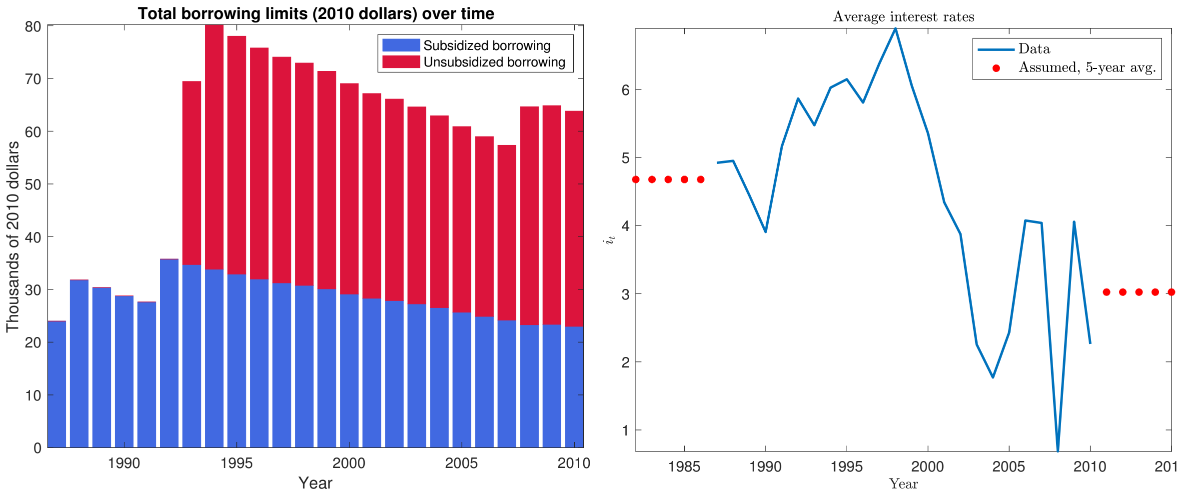


Figure 13: Borrowing Limits and Interest Rates

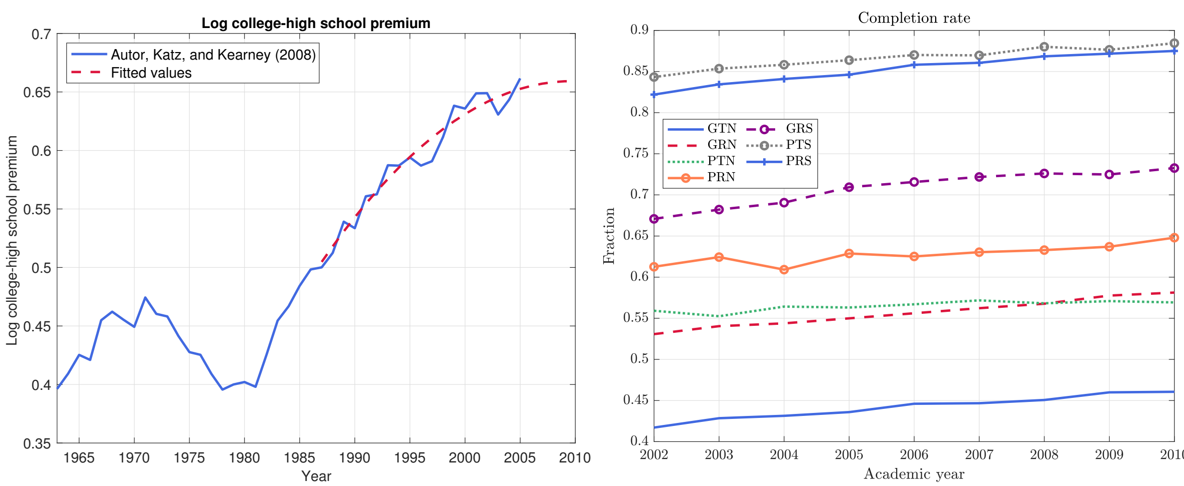


Figure 14: Earnings Premium and Completion Rates

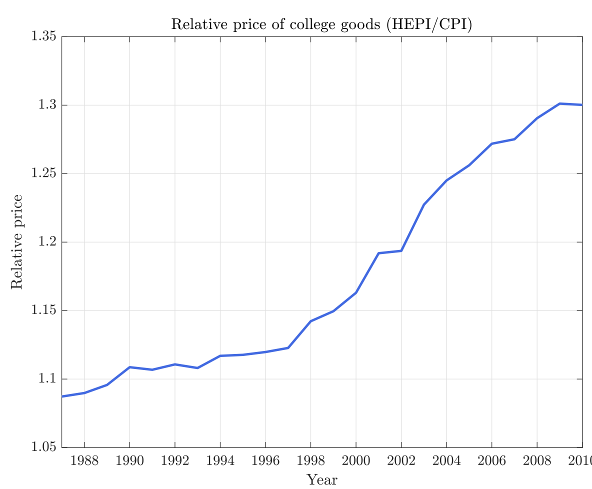


Figure 15: Baumol's Cost Disease: Real Higher Education Price Index

A.3 Additional Benchmark Dynamics

These figures supplement the tuition dynamics shown in section 4.1.3. The left panel of figure 16 displays how q_X/q_I evolves by cohort. The right panel reports the model-implied β_k coefficients from equation 30, which is an OLS regression of deviations from tuition on deviations from parental income for school type k.

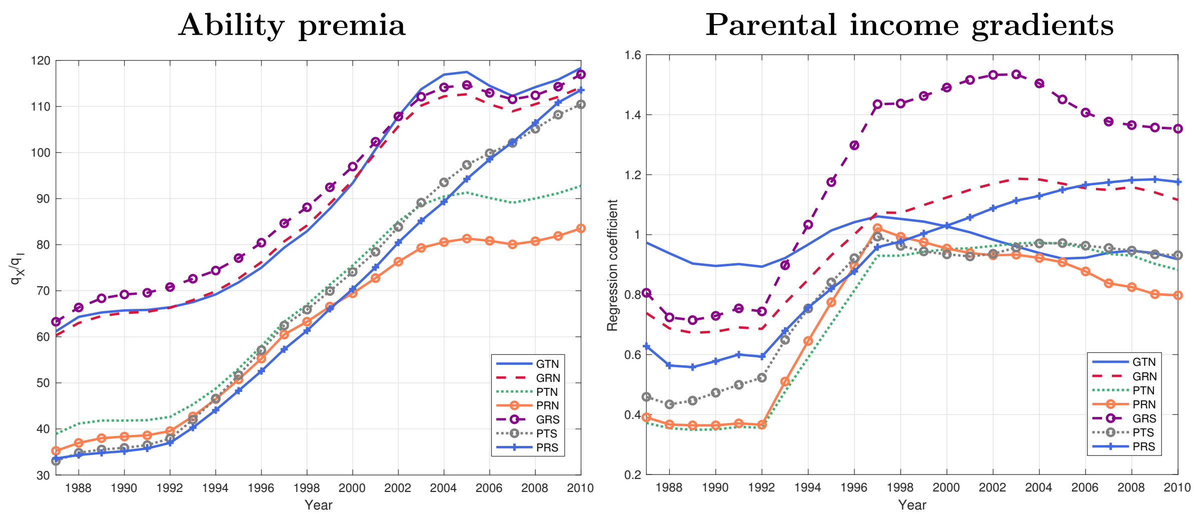


Figure 16: Ability Premia and Parental Income Gradients

A.4 Decomposition: Heterogeneous Effects

These figures complement the decomposition discussion in section 4.3.

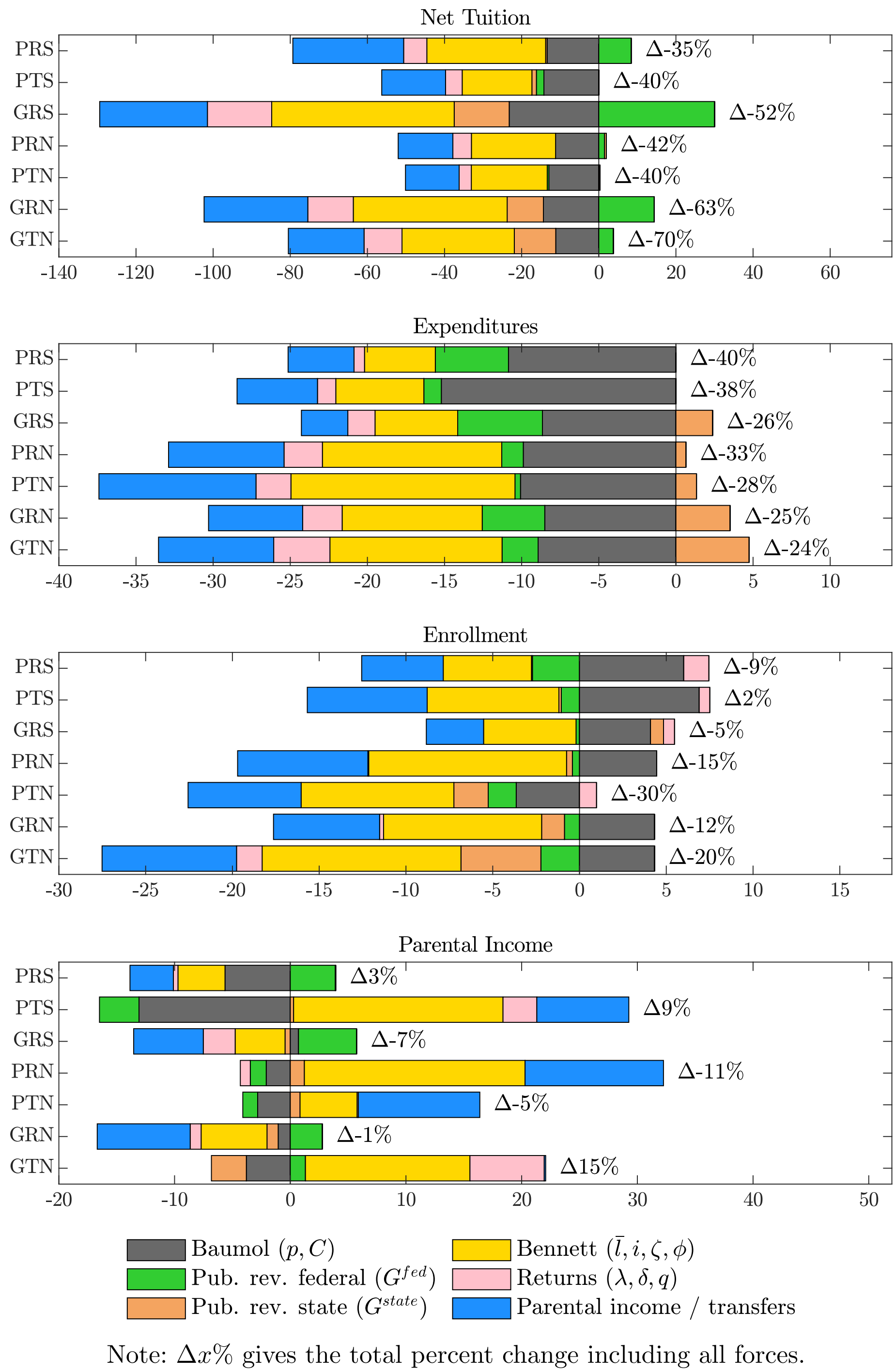
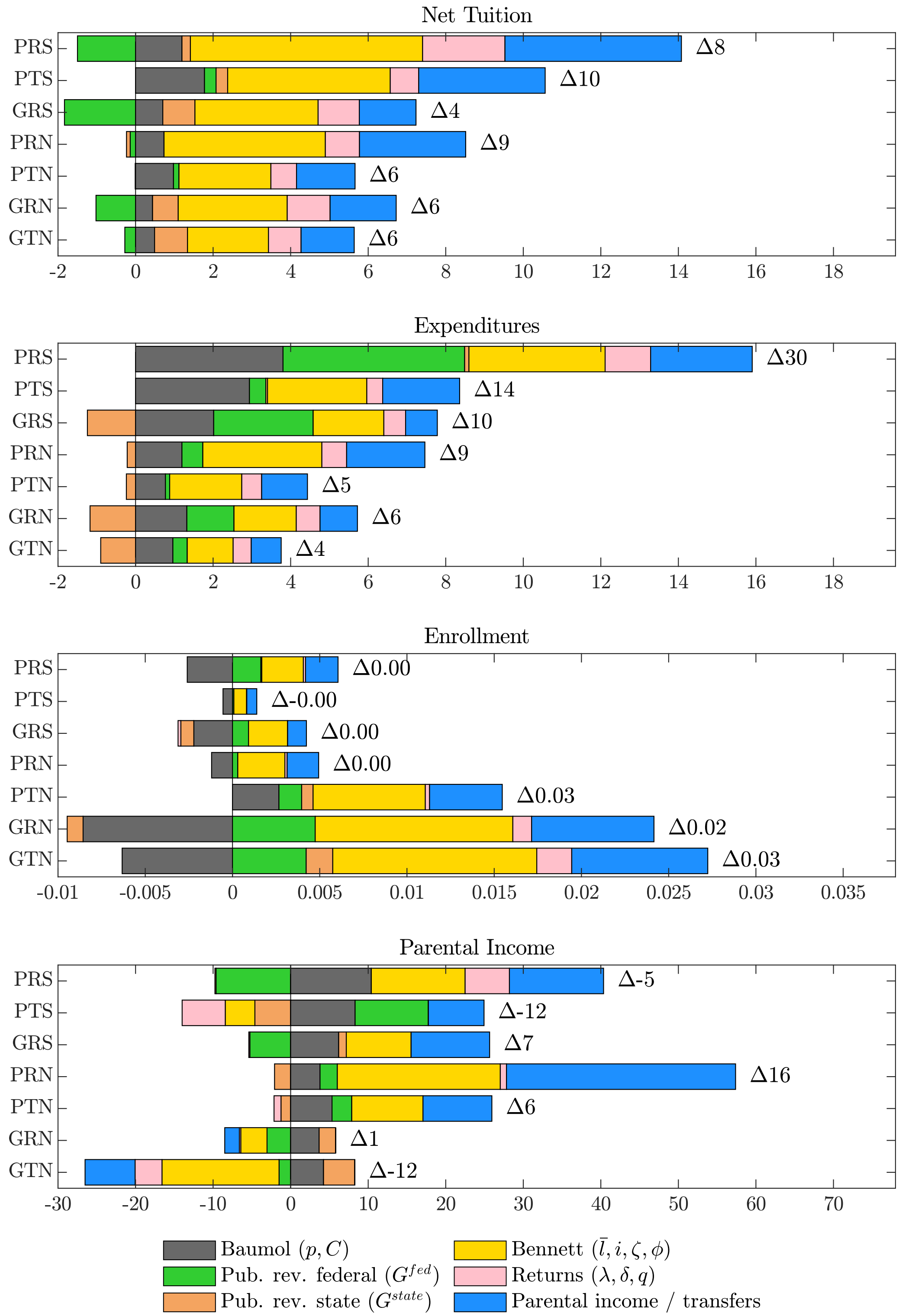


Figure 17: Percent change relative to 2010 from subtracting one force, else equal



Note: Δx gives the total change in model units (1000s of 2010 dollars) including all forces.

Figure 18: Absolute Change Relative to 1987 from Adding One Force, Else Equal

A.5 Heterogeneous, Time-Varying Pass-Through Rates

The figure below plots heterogeneous pass-through rates discussed in section 5.

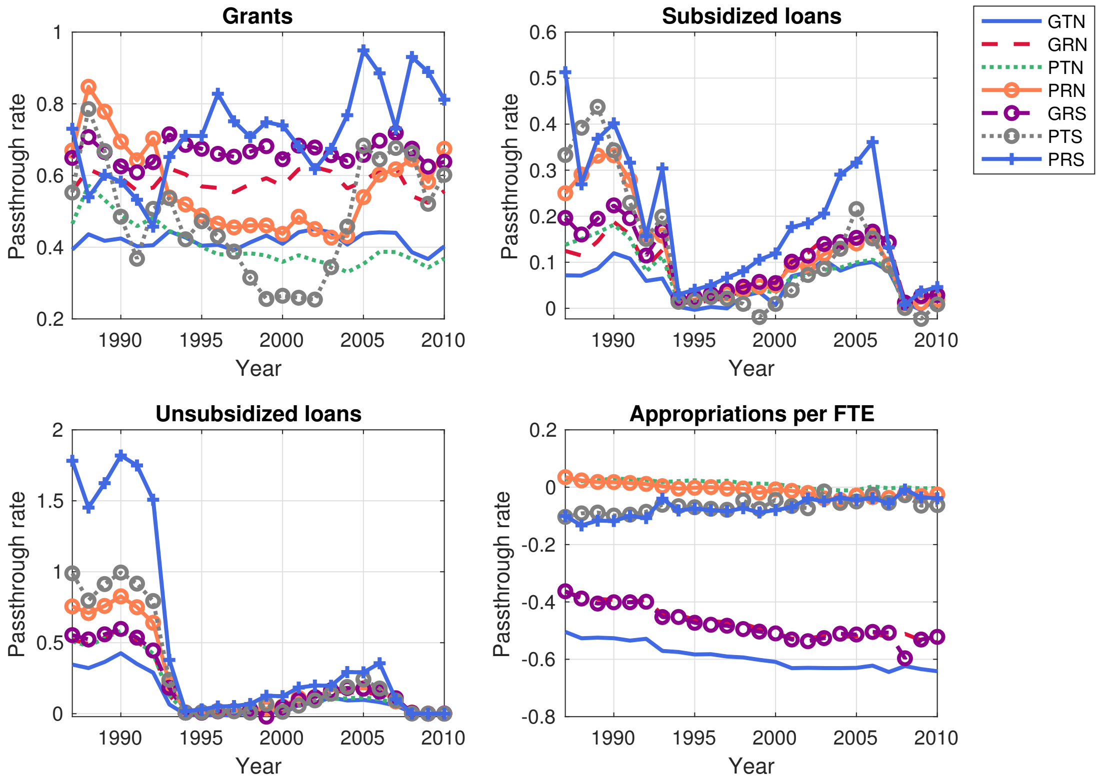


Figure 19: Heterogeneous Pass-Through Rates of Federal Financial Aid to Equilibrium Net Tuition

A.6 Summary of Predictions: Stylized vs. Quantitative Models

The table below summarizes the comparison between some of the theoretical predictions of the stylized model from section 4.2 and the full quantitative results discussed in section 4.3.

		Changes in public support G					
		Simple intuition			Quantitative model		
College type	$\bar{G}$ change	T	pI	N	T	Expend.	N
Private, Research, Nonselective	+0.5	↓	↑	↑	−0.2	+0.3	+1.7
Private, Research, Selective	+8.3	↓	↑	↑	−1.2	+4.8	+5.8
Private, Teaching, Nonselective	−0.3	↑	↓	↓	+0.1	−0.1	+2.6
Private, Teaching, Selective	+0.2	↓	↑	↑	+0.6	+0.5	+1.6
Public, Research, Nonselective	+0.1	↓	↑	↑	−0.2	+0.2	+3.4
Public, Research, Selective	+3.1	↓	↑	↑	−0.8	+1.5	+0.9
Public, Teaching, Nonselective	−1.4	↑	↓	↓	+0.6	−0.5	+5.5

		Changes in private support E					
		Simple intuition			Quantitative model		
College type	$\bar{E}$ change	T	pI	N	T	Expend.	N
Private, Research, Nonselective	+1.4	↓	↑	↑	−0.6	+1.2	+1.3
Private, Research, Selective	+22.3	↓	↑	↑	−4.0	+13.5	+6.2
Private, Teaching, Nonselective	−0.4	↑	↓	↓	+0.0	−0.1	+14.3
Private, Teaching, Selective	+9.1	↓	↑	↑	−2.0	+4.9	−8.2
Public, Research, Nonselective	+1.6	↓	↑	↑	−0.5	+0.9	+2.4
Public, Research, Selective	+6.1	↓	↑	↑	−1.6	+3.1	+4.0
Public, Teaching, Nonselective	−0.1	↑	↓	↓	+0.3	+0.1	+1.1

	Bennet hypothesis changes					
	Simple intuition			Quantitative model		
College type	T	pI	N	T	Expend.	N
Private, Research, Nonselective	↑	↑	↑	+4.2	+3.1	+15.3
Private, Research, Selective	↑	↑	↑	+6.0	+3.5	+8.2
Private, Teaching, Nonselective	↑	↑	↑	+2.4	+1.9	+10.7
Private, Teaching, Selective	↑	↑	↑	+4.2	+2.6	+14.8
Public, Research, Nonselective	↑	↑	↑	+2.8	+1.6	+8.7
Public, Research, Selective	↑	↑	↑	+3.2	+1.8	+6.1
Public, Teaching, Nonselective	↑	↑	↑	+2.1	+1.2	+11.3

Note: financial variables are in thousands of 2010 dollars; enrollments are percent change from 1987 values.

Table 2: Predicted Changes Based on Simple Intuition and Actual Model Implied Changes

B Details of College Data-Model Mappings

This section discusses how we selected our sample from the IPEDS/Delta Cost Project data and how we map expenditure, revenues, and FTEs from the data to the model.

B.1 Sample Selection

Colleges with multiple locations are sometimes grouped together depending on data availability. For example, the University of Missouri is a grouped institution, as we only have consolidated numbers for the entire University of Missouri System rather than the individual campuses (Columbia, Kansas City, etc.). We only keep four-year, nonprofit, nonspecialty institutions (according to their Carnegie Classification) that are present for the entirety of 1987–2010 in the Delta Cost Project (DCP) data.

B.2 Determining College Type

We define research-intensive colleges as those with a 2005 Carnegie Classification of "very high research activity." A college is selective if its mean SAT score is 1250 or higher out of 1600. For colleges without reported SAT scores, we impute from a regression of SAT scores on log(FTE), log(FTE) interacted with a public school dummy, and dummies for 2005 Carnegie Classification, state, flagship status, land grant status, Historically Black Colleges and Universities (HBCUs) status, Hispanic-Serving Institutions (HSIs) status, and whether an institution is grouped.

B.3 Categorizing College Balance Sheets

The model's budget constraint can be written as

$$pC + pIN + \kappa V = T + G + E.$$

The spending breakdown is based on qualitatively evaluating the DCP data definitions to determine whether an item falls under quality-enhancing spending I, pure operational expenses (custodial costs) C, or admissions costs κV. Table 3 provides the definitions with key words highlighted in bold. As a validation exercise for our designations, we compute the correlation between a school's average academic ability and the expenditure share of different DCP components. The spending share should be positively correlated with ability for quality-enhancing spending and negative for other components. The correlations turn out as expected. For instance, the correlation for "research01" (research) is 0.42 versus -0.23 for "opermain01" (operations and maintenance). Table 4 summarizes the mapping from budgetary components into model equivalents.

In terms of college revenues, the mapping is complicated by several issues. First, local appropriations, grants, and contracts are mostly unreported prior to 2002. Consequently, to prevent an artificial jump in G in 2002 driven by accounting changes, we categorize local funding as part of E. Second, empirically, colleges run surpluses (deficits) in the form of positive (negative) gross operating margins, i.e., the difference between revenue and expenditures. We deal with this issue by including the gross operating margin in E.

Variable	Category	Definition
instruction01	pI	Instruction - … Includes **general academic instruction**, … for both credit and noncredit activities. Excludes expenses for academic administration … Information technology expenses related to instructional activities [may be] included …
research01	pI	Research - … expenses for activities specifically organized to produce research outcomes … includes **institutes and research centers**, and **individual and project research**. … [possibly] included are information technology expenses related to research activities …
acadsupp01	pI	Academic support - … **libraries**, museums, and galleries; … academic **administration** (including academic **deans** but not department chairpersons); and formally organized and separately budgeted academic personnel development and course and curriculum development expenses. … [Possibly] included are information technology expenses …
pubserv01	pI	Public service - … **noninstructional services** beneficial to individuals and groups external to the institution. Examples are **conferences**, institutes, general advisory service, … includes expenses for community services, cooperative extension services, and **public broadcasting services**. Also includes information technology expenses [possibly] …
studserv01	$pI/\kappa V$	Student services - … **admissions**, registrar activities, and activities whose primary purpose is to contribute to students emotional and physical well-being and to their intellectual, cultural, and social development outside the context of the formal instructional program. Examples include **student activities, cultural events, student newspapers, intramural athletics**, … may include information technology expenses …
opermain01	pC	Operation and maintenance of plant - … **service and maintenance** related to campus grounds and facilities … [s]pecific expenses include **utilities**, fire protection, property **insurance**, and similar items. … does not include amounts charged to auxiliary enterprises, hospitals, and independent operations …
instsupp01	pC	Institutional support - … **day-to-day operational support** of the institution. … general administrative services, central executive-level activities concerned with management and long range planning, **legal and fiscal operations**, space management, employee personnel and **records**, **logistical services such as purchasing and printing**, and public relations and development …

Note: Emphasis added; definitions are from the Delta Cost Project data dictionary.

Table 3: Qualitative Categorization of Expenditure Types

Balance sheet item	Model equivalent	Measurement method
Total Expenditures	$pI + pC + \kappa V + T^s - T$	(calculated)
Educ & General spending	Part of $pI + pC + \kappa V$	(calculated)
Instruction	Part of pI	instruction01
Research	Part of pI	research01
Academic support	Part of pI	acadsupp01
Public service	Part of pI	pubserv01
Student services	Part of $pI + \kappa V$	studserv01
Operation, maintenance of plant	Part of pC	opermain01
Institutional support	Part of pC	instsupp01
Grants and fellowships	$T^{sticker} - T$	(calculated)
Auxiliary and "other" spending	Part of E (reduces)	(in residual)
Total Revenue	$T^s + G$+part of E	
Sticker tuition and fees	T^s	tuition03
Net tuition and fees	T	nettuition01
Directly from student	Out of pocket for T	(not measured)
From government	Students apply to T	(not measured)
Pell	Students apply to T	(not used)
Local, state, and other federal	Students apply to T	(not used)
Grants and fellowships	$T^s - T$	(calculated)
Approp., contracts, excluding Pell	G and part of pC	
Federal grants, contracts (w/o Pell)	Part of G	federal10_net_pell
State approp., grants and contracts	Part of G	state03+state06
Local approp., grants and contracts	Part of E (see note)	(in residual)
Auxiliary and "other" revenue	Part of E	(in residual)
Endowment revenue, gifts	Part of E	(in residual)
Gross operating margin (rev. - exp.)	Part of E	(in residual)

Note: E is the sum of "Part of E," and pC is the sum of "Part of pC;" T^s denotes sticker tuition; a component of Educ & General spending is expenditures on scholarships and fellowships (see the text for details); local appropriations, grants, and contracts are excluded from G because they are inconsistently reported over time.

Table 4: College Balance Sheet

B.4 Mapping FTEs in the Model and Data

In the model, only youth (recent high school graduates) can enroll in college, which is a stronger restriction than in the data. Moreover, we assume that graduation occurs after 5 years. Thus, to map the definition of FTE enrollment in the model to that in the data, we use the enrollment rate of high school graduates, R, from the NCES, the FTE shares by school type θ_k from the DCP, and the six-year completion rate δ_k^{total} from the College ScoreCard. Specifically, we set $\delta_k = (\delta_k^{total})^{1/5}$ to align completion rates in the model to the data, which implies total FTE enrollment of $N_k = e_k(1 + \delta_k + \delta_k^2 + \delta_k^3 + \delta_k^4) \equiv e_k\Delta_k$ given an inflow e_k of new students. Then the enrollment shares must satisfy $\Delta_k e_k = \theta_k(\Delta' e)$, where Δ and e are $K \times 1$ vectors. Denoting D as the diagonal matrix with elements Δ_k along the diagonal, we arrive the following expression for FTE shares in the model: $(D - \theta\Delta')e = 0$. Next, we impose $\mathbf{1}e = R$ given the unit mass population normalization in the model. Lastly, once we arrive at $N = De$ for each school type, we divide by the number of schools within each type to obtain enrollment at each individual college.

B.5 Custodial Costs

Figure 20 below plots the custodial cost curves estimated in section 3.1.3.

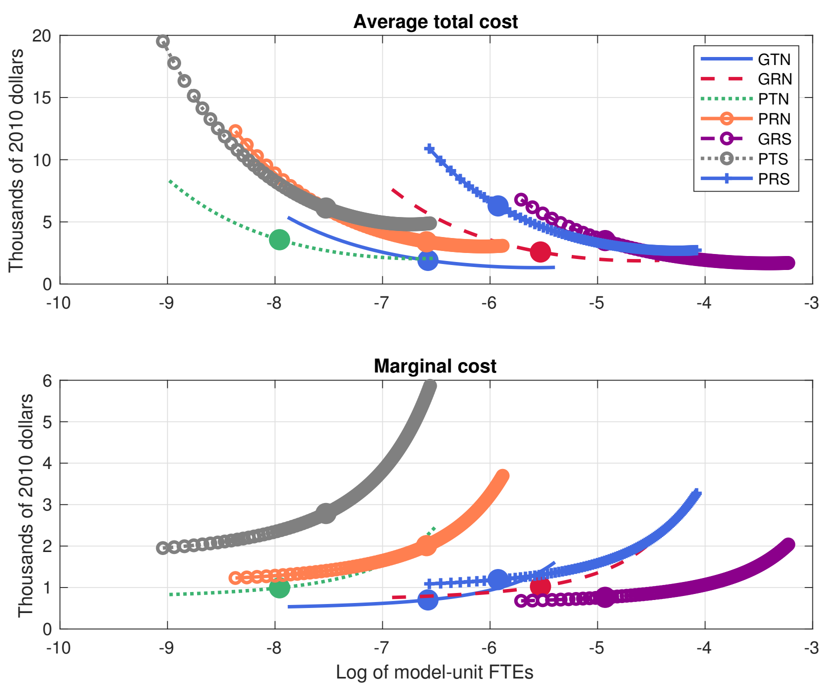


Figure 20: Estimated Cost Function (1987 Values) with Data Enrollments

B.6 Nontuition Revenue

We measure the elasticities with respect to enrollment of both types of nontuition revenue by estimating the following equation:

$$\Delta_5 \log Y_{it} = \beta_0 + \beta_g \mathbf{1}_{[i,public]} \Delta_5 \log N_{it} + \beta_p \mathbf{1}_{[i,private]} \Delta_5 \log N_{it} + \epsilon_{i,t}, \tag{38}$$

where Δ_5 denotes a five-year difference operator, $Y_{i,t}$ is one of {private nontuition revenue per FTE, public nontuition revenue per FTE}, $\mathbf{1}_{i,public}$ and $\mathbf{1}_{i,private}$ are indicators for whether the college is public or private, respectively, and $N_{i,t}$ is FTEs in model units.[24] We take a five-year difference to allow more time for any regular adjustments in state or private support to have some effect. Table 5 presents the estimates. To convert elasticities from per person to level terms, take $\beta_g + 1$ or $\beta_p + 1$. A value of $\beta = -1$ is consistent with the total revenue or cost being fixed, $\beta < -1$ indicates that the level of revenues or costs falls with enrollment, and $\beta > -1$ indicates that they rise with enrollment.

	Private nontuition rev.	Public nontuition rev.
Public×FTEs	-0.881	-0.899
	(-5.99)	(-16.69)
Private×FTEs	-1.407	-0.631
	(-30.12)	(-19.71)
Constant	0.0402	0.0889
	(1.81)	(6.36)
Observations	14110	21771
Year effects	Yes	Yes
School fixed effects	Yes	Yes

Note: FTEs are mapped to model units; revenues per FTE and FTEs are in 5-year log differences; t-stats in parentheses.

Table 5: Elasticities of Nontuition Revenue with Respect to Enrollment

B.7 Vacancy Posting Costs

We set $\overline{n}$ in equation 31 such that the mass of students above that threshold is 40% to be consistent both with the fraction of students paying sticker price (which varies by school but is 40% to 60% at selective schools) and with the mass of students in the top bracket of income reported by the College Scorecard data for PRS, PTS, GRS, and PRN colleges. At the other end, $\underline{n}$ is the threshold below which a student gets in "at cost." We note here that the parental income gradient levels off at the first two income brackets. The mass in these two brackets is around 40% (except at GTN and GRN where it is closer to 60%), which leads us to choose $\underline{n}$ to match this fraction.

We also have three sources of validation to lend credibility to this approach. The first comes from the college budget constraint. There we can compare the posting costs per FTE, $\kappa(\int v d\mu)/N$, with the data's student services category, which contains both admissions-related activity (which we think of as posting costs) and other expenditures. The results are displayed in table 6, which show that equilibrium posting costs fall within the upper bound from the DCP data, which includes admissions costs under a broader category. If the

[24] As discussed in section B.3, our model measures normally include local appropriations in *private* nontuition revenue due to data limitations. For this regression, we instead include local appropriations in public nontuition revenue and exclude it from private.

posting costs had exceeded student services, then we could have rejected our posting costs as unreasonably large. In reality, they seem fine by this measure.

School type	Posting costs	Student services	Pct. of Stud. Serv.
GTN	0.5	1.2	44
GRN	0.7	1.1	63
PTN	0.8	2.7	29
PRN	0.8	2.1	41
GRS	1.1	1.4	75
PTS	1.8	4.5	40
PRS	1.9	3.3	59

Note: postings costs are per-FTE averages from the benchmark; student services is studserv01 per FTE in thousands of 2010 dollars over the sample.

Table 6: Posting Cost Validation: Comparison with IPEDS Admissions Category

The second validation comes from matching the parental income gradients. The comparison of the model and data's parental income gradients can be seen in table 9. For private schools, the model undershoots the gradient at selective schools and overshoots at nonselective colleges, but the magnitudes are not very far off. Interpretation for the public schools is problematic because the public school gradient in the data only depends on in-state tuition, but they may suggest that the posting costs are too large at GTN and GRN.

The final validation comes from matching the parental income distribution across schools. This distribution is influenced by posting costs because the greater κ is, the more high-parental-income students tend to pay. These moments are also displayed in table 9, which shows that the model matches well the order and magnitude of parental incomes.

	GTN	GRN	PTN	PRN	GRS	PTS	PRS
$\hat{Y}$	0.226	0.277	0.183	0.204	0.596	0.826	0.798
	(33.54)	(35.71)	(58.91)	(19.82)	(28.81)	(29.36)	(26.41)
Constant	-0.00269	-0.00649	-0.0149	-0.0170	0.00583	-0.0116	-0.00324
	(-0.38)	(-1.02)	(-6.29)	(-2.54)	(0.45)	(-0.75)	(-0.19)
Observations	1254	610	2518	220	100	180	210

Note: dependent variable is $\hat{T}$; t-stats are in parentheses.

Table 7: Parental Income Gradients by School Type

B.8 Joint Parametrization

This section gives additional details on the joint parametrization procedure of section 3.4.

B.8.1 Deriving Tuition Supply

The first step to arriving at the tuition supply curve is to take the expectation over enrollment (i.e., integrate over $\omega(m)v(m)\rho(\theta(m))/N$) of equation 2 that characterizes active submarkets, giving

$$T = -p\frac{q_N}{q_I}N + \kappa\frac{V}{N} + pI + pC'(N) - G'(N) - E'(N),$$

where T is average net tuition per student, V is total vacancies, and $\kappa V/N$ is the average markup. The ability discount term drops out. Substituting in the CES functional form for q gives

$$T = -p\frac{\alpha_N I^{1/\epsilon}}{\alpha_I N^{1/\epsilon}}N + \frac{\kappa V}{N} + pI + pC'(N) - G'(N) - E'(N). \tag{39}$$

Now, consider the budget constraint expressed in per FTE terms:

$$\kappa\frac{V}{N} + pI + \frac{pC(N)}{N} = T + \frac{G(N)}{N} + \frac{E(N)}{N}. \tag{40}$$

After combining equations 39 and 40 by substitution for T, one has

$$p\frac{\alpha_N I^{1/\epsilon}}{\alpha_I N^{1/\epsilon}}N = pC'(N) - \frac{pC(N)}{N} + \frac{G(N)}{N} - G'(N) + \frac{E(N)}{N} - E'(N).$$

Note that this expression can be rewritten as

$$p\frac{\alpha_N I^{1/\epsilon}}{\alpha_I N^{1/\epsilon}}N = N\frac{d(pC(N)/N)}{dN} - N\frac{d(G(N)/N)}{dN} - N\frac{d(E(N)/N)}{dN}.$$

Some simplification yields

$$p\frac{\alpha_N I^{1/\epsilon}}{\alpha_I N^{1/\epsilon}} = \frac{d\left(\frac{pC(N) - G(N) - E(N)}{N}\right)}{dN},$$

where the right side, $\Delta(N)$, is the derivative of average custodial costs net of nontuition revenue. This expression implies that, absent college preferences over enrollment size, i.e., when $\alpha_N = 0$, the college is an average total cost (ATC) minimizer.

To further simplify, a little bit of algebra yields

$$\frac{\alpha_N}{\alpha_I} = \frac{\Delta(N)}{p}\left(\frac{N}{I}\right)^{1/\epsilon}.$$

Finally, replacing I with

$$I = \frac{1}{p}\left(-\kappa\frac{V}{N} - \frac{pC(N)}{N} + \frac{G(N)}{N} + \frac{E(N)}{N} + T\right)$$

from the budget constraint gives

$$\frac{\alpha_N}{\alpha_I} = \frac{\Delta(N)}{p^{1-1/\epsilon}} \left(\frac{N}{-\kappa \frac{V}{N} - \frac{pC(N)}{N} + \frac{G(N)}{N} + \frac{E(N)}{N} + T} \right)^{1/\epsilon}, \tag{41}$$

where we can normalize $\alpha_I = 1$.

B.8.2 Identification and Model Fit

As discussed in the main text, we follow an overidentification procedure that uses 29 moments to jointly determine 22 parameters in the model. The 7 additional moments come from exploiting the tuition supply curve in equation 41 that defines the locus of points $\{(T_k, N_k, V_k)\}$ consistent with college optimality. Note that if $\kappa_k = 0$, the average markup $\kappa_k V_k / N_k$ is null, which simplifies the locus of points to $\{(T_k, N_k)\}$. In this case, $\alpha_{N,k}$ is uniquely pinned down by plugging in T_k^* and N_k^* from the data. With $\kappa_k > 0$, the average markup matters, so we define $\tilde{\alpha}_{N,k}$ to be the solution to equation 41 when the right side is evaluated at the empirical values of T_k^* and N_k^* along with the *equilibrium* V_k given a choice for all the other parameters, which includes $\alpha_{N,k}$. In other words, we get a mapping $\tilde{\alpha}_{N,k} = f(\alpha_{N,k}, \text{other parameters})$. To increase estimation efficiency, we also target the fixed points $\tilde{\alpha}_{N,k} = \alpha_{N,k}$, resulting in 29 moments.

Figure 21 provides a visual summary of the parameter identification, depicting the sensitivity of different model moments to each of the parameters. The red rectangles connect parameters with the targeted moments that identify them. For example, the ability weight in college quality α_X strongly affects the average ability of the student body. In particular, $d\log X_k / d\log \alpha_{X_k}$ is large (between 100 and 1000), and the cross elasticities $d\log X_j / d\log \alpha_{X_k}$ for $j \neq k$ are considerably smaller. The strong elasticities $d\log \tilde{\alpha}_{N_k} / d\log \alpha_{N_k}$ help pin down α_N. Utility from college quality also strongly effects net tuition (while also influencing another of other moments).

Structurally-estimated parameters varying by school

	GTN	GRN	PTN	PRN	GRS	PTS	PRS
Enrollment weight α_N, log	-20.6	-19.4	-25.0	-22.4	-18.9	-24.3	-22.4
Ability weight α_X, log	-3.9	-5.6	-4.4	-5.9	-6.8	-5.7	-8.5
Student valuation of quality q, initial s.s.	0.01	0.02	0.06	0.07	0.04	0.07	0.11
Residuals from projection on I and public	0.01	0.00	-0.01	-0.01	-0.01	0.02	0.01

Structurally-estimated parameters common to schools

Search intensity disutility ψ_s	0.0075
CES elasticity ϵ of quality (see note)	0.3

Independently-determined parameters varying by school

	GTN	GRN	PTN	PRN	GRS	PTS	PRS
Vacancy posting cost κ	2.1	3.7	6.2	8.3	8.8	36.4	44.1
Elasticity of G at N^*	0.10	0.10	0.37	0.37	0.10	0.37	0.37
Elasticity of E at N^*	0.12	0.12	-0.41	-0.41	0.12	-0.41	-0.41
Expenditure weight α_I (normalization)	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Independently-determined parameters common to schools

Match elasticity γ	0.50
Independent fraction of earnings premium μ_λ	0.66
Independent fraction of continuation rate μ_δ	0.66

Note: The CES elasticity is manually adjusted to match enrollments in the terminal steady state.

Table 8: College Parameters

	Net tuition T		Sticker tuition		Expenditures		G revenue		E revenue	
School	Model	Data	Model	Data	Model	Data	Model	Data	Model	Data
GTN	2.6	2.7	4.2	2.8	11.4	11.4	8.8	8.8	-0.1	-0.1
GRN	3.5	3.7	5.5	4	18.8	18.9	13.6	13.6	1.6	1.6
PTN	9.5	9.5	12.3	11.3	13.6	13.6	1.3	1.3	2.7	2.7
PRN	11.9	11.9	15.2	13.4	18.9	18.8	3.5	3.5	3.4	3.4
GRS	3.9	4	5.9	4.7	28.4	28.5	21.2	21.2	3.3	3.3
PTS	14.3	14.3	16.6	17.8	22.5	22.5	1	1	7.2	7.2
PRS	15.3	15.4	18.5	19.3	44.3	44.3	14	14	15	15

	Log FTEs		FTE share		College premium		Ann. dropouts		Accept. rates	
School	Model	Data	Model	Data	Model	Data	Model	Data	Model	Data
GTN	-6.58	-6.58	0.27	0.27	1.32	1.32	0.16	0.16	0.91	0.67
GRN	-5.53	-5.53	0.34	0.34	1.52	1.52	0.12	0.12	0.74	0.74
PTN	-7.96	-7.96	0.16	0.16	1.41	1.41	0.11	0.11	0.51	0.72
PRN	-6.6	-6.59	0.05	0.05	1.73	1.73	0.09	0.09	0.43	0.73
GRS	-4.93	-4.93	0.1	0.1	1.9	1.9	0.08	0.08	0.52	0.55
PTS	-7.53	-7.53	0.01	0.01	2.04	2.04	0.03	0.03	0.23	0.45
PRS	-5.93	-5.93	0.08	0.08	2.6	2.6	0.04	0.04	0.2	0.38

	Rel. ability		Rel. ability s.d.		Relative p. inc.		P. inc. gradient*	
School	Model	Data	Model	Data	Model	Data	Model	Data
GTN	0.25	0.26	0.65	0.37	0.89	0.79	0.97	0.23
GRN	0.48	0.49	0.46	0.34	0.92	0.97	0.74	0.28
PTN	0.37	0.37	0.56	0.37	1.11	1.05	0.37	0.18
PRN	0.53	0.52	0.44	0.32	1.19	1.22	0.39	0.2
GRS	0.9	0.9	0.09	0.09	0.9	1.15	0.81	0.6
PTS	0.94	0.94	0.05	0.06	1.36	1.65	0.46	0.83
PRS	0.96	0.96	0.03	0.04	1.49	1.37	0.63	0.8

Note: The data's parental income gradient measure for public schools is based only on in-state tuition; FTEs are stated in model units; all financial variables are thousands of 2010 dollars.

Table 9: Model Fit (values in 1987)

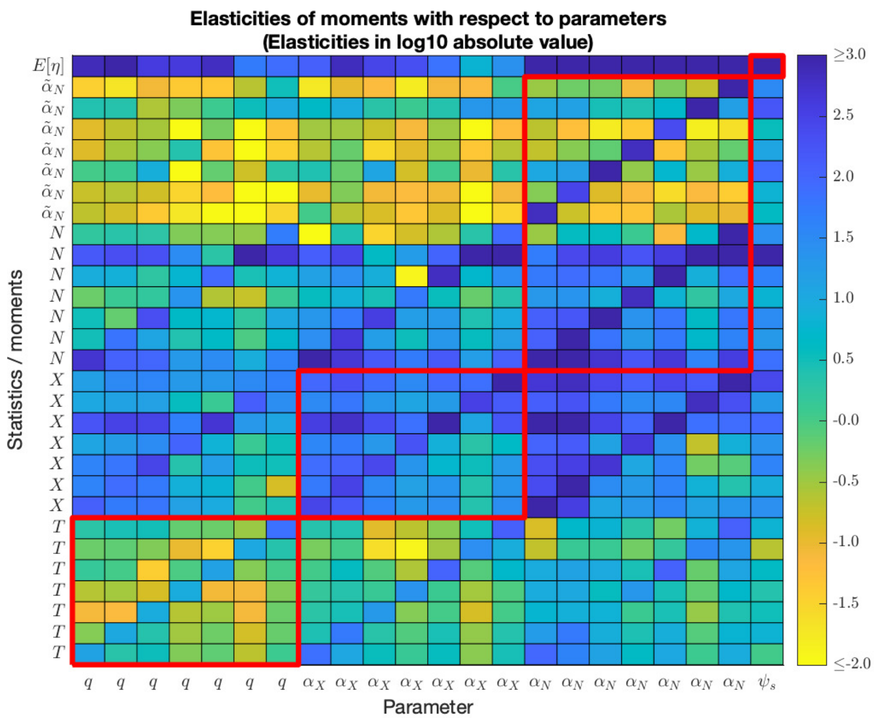


Figure 21: Estimated Parameter Identification

C Earnings and Tax Estimates from the PSID

We use sample C of the cleaned data from Heathcote et al. (2010), adjusting it from constant 2000 dollars to constant 2010 dollars using the CPI. To recover the flat tax rate τ used in the model, we regress

$$y_{i,t} = (1 - \tau)e_{i,t} + \varepsilon_{i,t},$$

where $e_{i,t}$ is equivalent household labor income plus private transfers, and $y_{i,t}$ adds government transfers less taxes.[25] The estimated implied tax rate is 0.184.

Then, we estimate earnings dynamics by running a first stage equation on observables and, in a second stage, modeling the dynamics of the residual. Specifically, our first stage is a cubic polynomial in age with year, educational attainment, and year by educational attainment with the dependent variable being log pretax earnings from above. The educational attainment variable is in three groups: weakly fewer than 12 years, strictly between 12 and 16 years, and weakly greater than 16 years. In the regression, we also require the additional sample restriction that the age less years of education is strictly greater than 6. That way 18-year-olds who just completed their 12th year (high school) are excluded. The estimates are given in Table 10.

	Log pre-tax earnings	
Age/10	0.774	(4.17)
$\text{Age}^2/100$	-0.0706	(-1.58)
$\text{Age}^3/1000$	-0.00196	(-0.57)
Some College	0.270	(7.53)
College Grad	0.595	(18.18)
Constant	1.530	(6.13)
Observations	39308	
Year effects	Yes	
Year $\times$ education effects	Yes	
Note: t-statistics in parentheses.		

Table 10: First Stage Regression

In the second stage, we estimate dynamics with GMM using the specification from equation 35. We follow the identification strategy of Heathcote et al. (2010) by looking at two-year changes (because the PSID earnings are biannual after 1996) and in levels.[26] This procedure gives an estimate by cohort and year. We then take the average across cohorts within each year, and then the average across years. Heathcote et al. (2010) produce yearly estimates that have a mean very close to our point estimate (see figure 18, p. 40 of their paper).

[25] We equivalize by dividing by 2 (1) if there is (is not) a "wife" (in the PSID sense) present.

[26] See equation 5 and 6 of their paper.

D Summary Statistics by School Type

Table 11 reports summary statistics for the various school types.

School type	1987 financial measures and shares				
	T	Expend	G	E	FTE share
Public, Teaching, Nonselective	2.7	14.9	9.2	3.0	0.25
Public, Research, Nonselective	3.7	25.9	13.7	8.5	0.36
Private, Teaching, Nonselective	9.6	19.9	1.4	9.0	0.15
Private, Research, Nonselective	11.9	27.0	3.8	11.3	0.05
Public, Research, Selective	4.0	39.5	21.3	14.3	0.10
Private, Teaching, Selective	14.3	32.6	1.0	17.3	0.01
Private, Research, Selective	15.5	72.2	14.1	42.7	0.08

School type	2010 financial measures and shares				
	T	Expend	G	E	FTE share
Public, Teaching, Nonselective	6.4	17.8	7.9	3.5	0.25
Public, Research, Nonselective	8.8	35.5	14.9	11.8	0.35
Private, Teaching, Nonselective	15.1	22.5	1.1	6.3	0.18
Private, Research, Nonselective	20.3	34.0	4.1	9.6	0.05
Public, Research, Selective	10.0	65.3	29.1	26.2	0.09
Private, Teaching, Selective	24.3	50.0	1.2	24.5	0.01
Private, Research, Selective	23.7	115.4	22.0	69.6	0.07

School type	Additional 2010 measures				
	Rel. premium	Comp. rate	P. inc.	Rel. X	# schools
Public, Teaching, Nonselective	0.83	0.47	53	0.26	242
Public, Research, Nonselective	0.95	0.58	65	0.48	129
Private, Teaching, Nonselective	0.89	0.58	71	0.34	639
Private, Research, Nonselective	1.08	0.65	81	0.51	50
Public, Research, Selective	1.19	0.73	77	0.90	20
Private, Teaching, Selective	1.29	0.89	110	0.94	36
Private, Research, Selective	1.63	0.87	91	0.96	42

Note: Monetary values are in 2010 dollars deflated using the CPI.

Table 11: Data Measures in 1987 and 2010