2015

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Keywords

higher education, high tuition, financial aid, public universities

Comments

Suggested Citation

Fethke, G. (2015). *Achievably-efficient enrollments using high tuition-high aid in public higher education* [Electronic version]. Retrieved [insert date], from Cornell University, School of Industrial and Labor Relations site: https://digitalcommons.ilr.cornell.edu/workingpapers/209/

Required Publisher Statement

Published by the Cornell Higher Education Research Institute, ILR School, Cornell University.

Achievably-Efficient Enrollments Using High Tuition-High Aid in Public Higher Education

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Abstract

With public universities tuitions and state appropriations are determined as efficiently as possible ("quasi-efficiently") to cover fixed costs, an opportunity arises to admit additional low-income students at marginal cost. Using this tuition-appropriation approach, an implementable form of pay-what-you-can-afford tuition policy (PWYCA) can realize fully-efficient enrollments. This construction can be extended to include a standard, often legal, constraint that state appropriations must be used to support reduced resident tuitions. When applied to budget, tuition, enrollment and appropriation data of colleges at Penn State University, this high tuition-high aid policy not only accommodates additional low-cost enrollments but also increases social welfare.

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1. Introduction

There are considerable differences among public universities, which range from open-access, two-year programs that depend almost entirely on public support, to selective, "very-high research" universities that possess considerable tuition-setting autonomy. To various degrees, however, public universities share several prominent features: i) there are two primary revenue sources (state appropriations and tuition revenues); ii) appropriations are employed to enhance resident access; iii) a break-even requirement is imposed on university profitability; iv) fixed cost is a high percentage of total cost; and v) nonresidents pay more. Implications of these features are examined in tuition-setting models that compare welfare rankings associated with adopting so-called "pay-what-you-can-afford" (PWYCA) tuitions.[1] This approach charges more to those with high ability to pay, enabling support of students with low ability to pay. While PWYCA directly considers ability to pay, it is extended here to consider cost differences as well as residency restrictions placed on state appropriations. A requirement that taxpayer funds can only be used to enhance resident access is shown here to be a primary contributor to inefficient tuitions.

Turner (2018) considers a long- standing issue: "whether a "high tuition- high aid" strategy would be more equitable and efficient than would a low tuition strategy at state universities?" Equity consideration focus on issues surrounding: Who should pay? For example, recent calls for "free higher education" imply that it is best supported by taxpayer appropriations; alternatively, full privatization implies exclusive reliance on tuition revenue. With greater reliance on private tuition revenue, an opportunity arises to move beyond a resident-nonresident

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[1] A PWYCA tuition approach is promoted by Robert Birgeneau, chancellor of UC Berkeley (2004-13), and Mary Sue Coleman, president of the University of Michigan (2003-14), who serve as co-presidents of the Lincoln Project on Higher Education supported by the American Academy of Arts and Sciences; see https://www.amacad.org/content/Research/researchproject.aspx?d=929.

distinction to charge more to some residents as a way to subsidize others. A welfare issue concerns whether average tuition increases with tuition discrimination. Using standard welfare criteria, where efficiency is based on students' and taxpayers' willingness to pay net of opportunity costs, the models developed here address these issues. Specifically, using consumer surplus as a measure of value, monetary gains to low-pay residents are compared to monetary losses of high-pay residents and nonresidents. Comparative evaluations of tuition-appropriation arrangements are presented in a context of familiar public university budgeting templates, with distinctions made among colleges.

In a specified two-stage model, a legislature in stage one determines appropriations, based on tuitions set in stage two.[2] Appropriations can support specific programs by reducing marginal costs, or they can be applied with an equivalent welfare effect as a direct offset against fixed cost. Additionally, legislatures typically impose residency restrictions that permit all residents to pay less than nonresidents, and these restrictions adversely affect the attainable degree of efficiency; absent residency restrictions, social welfare increases. A university in stage two takes appropriations and residency restrictions as given and determines rules for setting tuitions. Resulting tuition structures encompass both average tuition and deviations in tuitions across programs.

Several specific tuition-setting rules are evaluated, with a progression introducing increased endogeneity of appropriations and tuitions. The first situation, called "Pay-What-You-

[2] Allowing endogenous changes in tuitions and appropriations can accommodate consideration of the enrollment mix across colleges, for example, with nonresidents replacing residents. Some public universities, with limited pricing discretion, must reduce expenditures when facing declining public appropriations. While it is typically assumed that exogenous reductions in appropriations lead to increases in tuition and reduction in expenditures, there remains an issue of causation. Baum et al. (2018) provide a non-technical discussion of these and related issues.

Can-Afford" (PWYCA), is suggested by AAAS (2016). Their proposal is to allocate a given state appropriation to high willingness to pay residents (H-residents) such that their tuitions equal nonresident tuitions (N-residents) net of a uniform state appropriation per H-resident. Resulting incremental resident tuition revenue is then used to subsidize low-income residents (L-residents). For the AAAS suggested example of the University of Michigan, a claim is made that nearly $100 million of annual incremental revenue will result by adopting PWYCA; this increment is about 8 percent of tuition revenue. A key assumption in this version of high tuition-high aid is that state appropriations will remain fixed when there are changes in rules for determining resident tuitions.

PWYCA ideas can be extended and generalized by embedding them into a welfare-maximizing context, where resident tuitions, nonresident tuitions and appropriations are selected to maximize social welfare. Student welfare is measured by the (real) monetary value students receive after paying subsidized tuitions (net consumers' surplus); university welfare is measured by net revenue; and social welfare is student welfare plus university welfare minus the appropriation. With prominent fixed costs and a break-even requirement, tuitions charged to N-residents and H-residents and state appropriations are determined to be as close as possible to efficient structures; see Baumol and Bradford (1970) for a seminal discussion of quasi-efficient pricing; Burer and Fethke (2016) provide an extension, with applications, to include subsidized arrangements of American public higher education; and Vogelsang and Finsinger (1979) develop an implementable algorithm. One motivation for this pricing exercise is a claim that public universities will make efficient adjustments in their tuitions if given latitude to do so; Kim and Strange (2016) indicate, at least for the Texas System, that this is indeed a plausible outcome.

A standard feature of quasi-efficient tuitions is that they must exceed marginal costs to provide sufficient net tuition revenue to cover fixed costs net of the public appropriation — higher tuitions are optimally charged in programs that feature less elastic demands. This standard pricing result is of interest in a PWYCA context: with H-residents and N-residents paying tuitions that exceed marginal costs, it is possible to admit L-residents at marginal at costs and still meet the break-even requirement. Indeed, the more H-resident and N-resident tuitions optimally deviate from marginal costs, the higher is the achievable lower-price L-resident enrollment share. This result holds even when there is an imposed residency restriction; the restricted quasi-efficient tuition structure can still accommodate additional L-resident enrollments at marginal cost. Put another way, second-best tuitions supplemented with incremental enrollments priced at marginal-costs can support a first-best enrollment outcome for residents. While tuition discrimination can eliminate an enrollment inefficiency for residents, a residency restriction increases it for nonresidents.

To evaluate appropriation-tuition structures, demand and cost functions are calibrated to replicate standard budget templates. The example used is for Pennsylvania State University-Main Campus (PSU-MC), which is a large, "very high research" public university. PSU stands out for experiencing large cuts in state appropriations per enrollment between 2001 and 2017 (SHEF); these cuts were associated with charging comparatively high net tuitions, with limited discounting (Burd, 2018). The approach here examines alternative high tuition-high aid appropriation and tuition structurers and provides comparative dollar-based measures of student, university and social welfare. It is shown that actual PSU-MC tuitions can be reasonably replicated using a modified version of a residency-restricted-tuition model developed by Burer and Fethke (2016). An efficiency loss occurs because of residency restriction placed on tuitions— removing this residency restriction increases economic efficiency by placing emphasis on willingness to pay.

Section 2 presents tuitions-setting models that illustrate main PWYCA features, with subsequent progression accommodating increased endogeneity for both tuitions and appropriations. Section 3 provides budget, tuition, enrollment, and appropriation data for PSU-MC that are used to quantify efficiency and equity implications of adopting particular tuition-setting scenarios. Section 4 contains a summary. Section 5, Appendix, presents demand and cost parameters used for PSU.

2. PWYCA tuition-setting rules

Distinguishing among colleges (programs) at the university level and between resident and nonresidents, let the set of colleges be $I \equiv \{1,...,n\}$ indexed by i, and let $J \equiv \{1,2\}$ be the enrollment types within each college—resident and nonresident— indexed by j. For each pair (i, j) there are demand curves $E_{ij} = a_{ij} - b_{ij}T_{ij}$ with given positive parameters a_{ij} and b_{ij}, where E_{ij} are enrollments type j in college i and T_{ij} are corresponding tuitions. The parameters a_{ij} and b_{ij} reflect maximum enrollment and tuition responsiveness for each program, respectively, with a_{ij} / b_{ij} being maximum willingness to pay. Tuition elasticity is $\eta_{ij} = -b_{ij}(T_{ij} / E_{ij}),$ and net consumer surplus for each program is $E_{ij}^2 / 2b_{ij}$. Marginal costs, c_i, are constant and independent of residency status, and there are fixed costs, F, with total cost: $C = \sum_{i=1}^{n} c_i \sum_{j=1}^{2} E_{ij} + F.$

2.1 PWYCA resident tuitions with exogenous nonresident tuitions and state appropriations

A proposed PWYCA rule for representing "high-pay" resident tuitions (H-residents) in a public university is:

$$T_{iH} = T_{iN} - A / \sum_i E_{iH} \text{, for } i = 1, 2, ..., n \quad (1)$$

Here, T_{iH} and T_{iN} are H-resident and nonresident (N-residents) tuitions, respectively, for each academic program, with A representing the state appropriations. Absent state support, H-residents pay the same as N-residents; "free education" for residents requires tuition per resident to equal zero. It is initially assumed that appropriations and N-resident tuitions are given, with these restrictions subsequently removed. Using Eq. (1), H-resident enrollments in program i are:

$$E_{iH} = a_{iR} - b_{iR}(T_{iN} - A / \sum_i E_{iH}). \quad (2)$$

A program's enrollment depends positively on appropriations and negatively on non-resident tuitions. Summing and solving for total H-resident enrollment yields:

$$\sum_i E_{iH} = (1/2)\{(a_R - \sum_i b_{iR}T_{iN}) + [(a_R - \sum_i b_{iR}T_{iN})^2 + 4b_R A]^{1/2}\}, \quad (3)$$

where $a_R \equiv \sum_i a_{iR}$ and $b_R \equiv \sum_i b_{iR}$. Incremental revenue from H-residents and N-residents is:

$$I = \sum_i (T_{iN} - c_i)(E_{iH} + E_{iN}) - F. \quad (4)$$

Marginal contributions of H-resident and N-resident enrollments toward covering fixed cost are equivalent to N-resident tuitions minus marginal costs. Positive incremental revenue requires that N-resident tuitions exceed fully allocated cost. In particular, if N-resident tuitions equal fully allocated costs, $T_{iN} = c_i + F / \sum_{i,j} E_{ij}$, then Eq. (4) implies that $I = 0$.

One motivation behind PWYCA is to use its positive incremental revenue to provide access for low-pay residents (L-residents).[3] L-residents are assumed to confront the segments of residual demand curves below T_{iH}, and therefore they face the same intercept and slope parameters as H-residents. When $I > 0$, one way to ration student demand according to willingness to pay (efficient rationing) involves identifying a uniform rate to charge L-resident enrollments, $T_L < T_{iH}$, which satisfies:

$$\sum_i (c_i - T_L) b_{iR} (T_{iH} - T_L) - I = 0, \text{ with } T_L \le T_{iH}. \tag{5}$$

Eq. (5) indicates that net expenditure required to accommodate additional L-resident enrollments will just offset incremental revenue captured by charging more to H-residents.[4] When $I \ge 0$, the solution to Eq. (5) is:

$$T_L = \frac{\sum_i b_{iR}(c_i + T_{iH})}{2b_R} + \frac{1}{2}\left[\left(\frac{\sum_i b_{iR}(c_i + T_{iH})}{b_R}\right)^2 + 4\left(\frac{I - \sum_i c_i b_{iR} T_{iH}}{b_R}\right) \right]^{1/2}. \tag{6}$$

Public universities have two primary revenue sources, tuition and appropriation revenue, and they are required by their non-profit charters to break even.[5] A break-even constraint acts as

[3] Incremental revenue can be used to fully offset tuitions and fees to qualified, low-income applicants, which is a program developed at the University of Michigan; see Dynarski et al. (2018). This approach requires some type of rationing process.

[4] This approach represents a simple way to avoid having to arbitrarily allocate a given incremental revenue across various programs. Effectively, each L-resident is charged the university's marginal cost, which is reduced to include any incremental revenue that develops using PWYCA.

[5] Other income sources include: private donations, annual gift and endowment income, interest payments, and indirect cost recovery for research grants. For most public universities these sources are relatively minor, but a few major research universities have significant donor income. For example, annual payouts from endowment for the University of Michigan are as

a form of rationality constraint in the following sense: unless total revenue covers expenditures, the university cannot (rationally) provide education services. The break-even condition for an L-resident-augmented PWYCA is:

$$\sum_i [(T_{iN} - c_i)(E_{iH} + E_{iN}) + (c_i - T_L) b_{iR} (T_{iH} - T_L)] - F = 0. \tag{7}$$

Here, T_L is given by Eq. (6). Once fixed costs are covered, since $(c_i - T_L) b_{iR} (T_{iH} - T_L) = 0$, additional L-residents can be admitted without violating the break-even condition,

2.2 PWYCA resident tuitions with an endogenous appropriation

Will legislatures provide an unchanged appropriation when they are confronted with a change in rules for setting resident tuitions? A more complete solution accounts for endogeneity of appropriations. This problem can be described as a two-stage game, with appropriations determined in stage one and resident tuitions, predicated on the appropriation, set in stage two. With breakeven holding, a plausible stage one objective describes a legislature as seeking a constant subsidy per resident enrollment, s, which maximizes student welfare (consumer surplus) net of the appropriation:

$$\max_s [\sum_i E_{iH}^2(s) / 2b_{iR} + \sum_i E_{iL}^2(s) / 2b_{iR} + \sum_i E_{iN}^2 / 2b_{iN} - s \sum_i E_{iH}(s)], \tag{8}$$

s.t.

$$s \sum_i E_{iH}(s) \le M, \text{ with } i = 1, 2, ..., n. \tag{9}$$

Expression (8) is total welfare. Expression (9) implies that subsidy of H-residents is constrained by state resources, M. Assuming Eqs. (1) – Eqs. (7) hold, resident enrollments depend only on s.

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large as state appropriations; see: https://record.umich.edu/articles/u-m-endowment-rebounds-109b-138-percent-return.

The optimal appropriation is determined by solving Expression (8) and Expression (9) for the optimal value of s. Using PSU data, numerical solutions to this problem are presented in Section 3.3.

2.3 Endogenous tuitions and appropriations

In this section, tuitions and appropriations are endogenously determined. Appropriations can be used differentially to subsidize individual program enrollments, or they can be used to offset fixed cost. The appropriation is specified as: $A \equiv \sum_{ij} s_{ij} E_{ij} + S,$ where s_{ij} is the subsidy per enrollment, and S is a direct offset against fixed cost. Burer and Fethke (2016) establish the optimal rule for determining stage two enrollments is:[6] $E_{ij} = \rho b_{ij}(d_{ij} + s_{ij}),$ where $d_{ij} \equiv a_{ij} / b_{ij} - c_i$ $\rho = (1/2)(1 + \sqrt{1-\kappa}),$ and $\kappa \equiv (F - S) / \sum_{i,j} b_{ij}(a_{ij} / b_{ij} - c_i + s_{ij})^2 / 4.$

Enrollment in every program is proportional to subsidy-adjusted efficient enrollment, where a factor of proportionality, ρ, is the determined degree of efficiency.[7] Since d_{ij} represents maximum net private willingness to pay, an enrollment subsidy, s_{ij}, is equivalent to a public-supported net willingness to pay. Of operational significance is the implication that changes in fixed cost have no effect on the ratio of adjusted enrollments between any two programs.

[6] A two-stage model is also developed by Bound et al. (Forthcoming), who find empirical support for an inverse relationship between endogenous state appropriations and foreign student tuition revenue in major public universities.

[7] A more general representation for an enrollment rule can be derived using a generic student benefit expression, increasing marginal costs, and independent demand functions. With linear demand and increasing marginal cost, $E_{ij} = \rho(s,S) b_{ij}(d_{ij} + s_{ij}) / (1 + b_{ij} e_i),$ with $e_i > 0$ representing the slope of marginal cost.

To include PWYCA features, appropriations are used entirely to support H-residents. Specifically, for N-resident, $s_{iN} = 0$ and $\rho = \rho^*$ initially fixed $(1/2 \le \rho^* \le 1)$, a stage-one optimization over unrestricted s_{iH} and S is:

$$\max_{s,S}\{\frac{1}{2}[\rho^{*2}(\sum_i b_{iH}(s_{iH}+d_{iH})^2+\sum_i b_{iN}d_{iN}^2)-[\sum_i \rho^* b_{iH}(s_{iH}+d_{iH})s_{iH}+S]\} \tag{10}$$

s.t.

$$\sum_i \rho^* b_{iH}(s_{iH}+d_{iH})s_{iH}+S \le M \tag{11}$$

$$\sum_i \rho^*(1-\rho^*)b_{iH}(s_{iH}+d_{iH})^2+\sum_i \rho^*(1-\rho^*)b_{iN}d_{iN}^2 = F-S \tag{12}$$

$$\frac{1}{2} \le \rho^* \le 1 \tag{13}$$

Appropriation combines subsidies per H-resident enrollment, s_{iH}, with a direct offset against fixed cost, S. With enrollment rules given by $E_{iH} = \rho^*(d_{iH}+s_{iH})$ and $E_{iN} = \rho^* d_{iN}$, the legislature at stage one determines an appropriation structure that maximizes consumers' surplus net of the constrained appropriation. In this context, Burer and Fethke (2016) demonstrate that a constant ad valorem subsidy is consistent with achievement of quasi-efficient enrollments. Specifically, $s_{iH} = kd_{iH}$, where k is an ad valorem subsidy rate applied uniformly to all H-resident enrollments. Using the break-even condition, Eq. (12), to eliminate S, the problem reduces to:

$$\max_{k}\{\frac{1}{2}\rho^{*2}(\theta_H(1+k)^2+\theta_N)-\theta_H\rho^*(1+k)k-[F-\rho^*(1-\rho^*)(\theta_H(1+k)^2+\theta_N)]\} \tag{14}$$

s.t.

$$\theta_H\rho^*(1+k)k+[F-\rho^*(1-\rho^*)(\theta_H(1+k)^2+\theta_N)] \le M, \tag{15}$$

where $\theta_j \equiv \sum_i b_{ij} d_{ij}^2$, with $j \in \{H, N\}$. The optimal solution is the right-hand endpoint of Eq. (15):

$$k^* = \frac{1}{2\rho^*}[1 - 2\rho^* + \sqrt{\frac{4(\rho^*(1-\rho^*)\theta_N - F + M) + \theta_H}{\theta_H}}]. \tag{16}$$

Specification of ρ^* determines unique values for k^* and S^*. Consistent with Expression (15), these values ensure that the total appropriation equals its constrained amount, M. Eq. (16) is used to eliminate k^* in Eq. (14), yielding a concave expression for welfare in terms of ρ^* :

$$W(\rho^*) = \frac{1}{4}(-2F - 2M + 2\rho^*\theta_N + \theta_H + \sqrt{\theta_H}\sqrt{-4F + 4M + 4\rho^*(1-\rho^*)\theta_N + \theta_H})) \tag{17}$$

Finally, the critical point of Eq. (17) is:

$$\rho^*(0, M) \equiv \rho^M = \frac{1}{2}(1 + \sqrt{1 - \frac{4(F-M)}{\theta_H + \theta_N}}). \tag{18}$$

The optimal, unrestricted solution for the tuition structure employs the entire appropriation to offset fixed costs. The associated rule for tuitions is:

$$T_{ij}^M = (1 - \rho^M)a_{ij} / b_{ij} + \rho^M c_i. \tag{19}$$

Tuitions in each program are a weighted average of maximum willingness to pay and marginal cost, with weights reflecting the optimal degree of efficiency. Increased efficiency reduces the relative importance of willingness to pay.[8]

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[8] It can be demonstrated that: $(T_{ij}^M - c_i)/c_i = -(1-\rho^M)/\eta_{ij}$, where η_{ij} is elasticity of demand, measured where tuition equals marginal cost. This is an established quasi-efficient pricing result—programs that exhibit less elastic demands are charged higher prices. Here, the

Eq. (19) indicates that optimal tuitions must exceed marginal costs to offset fixed cost. This condition in a PWYCA context creates an opportunity to provide enhanced access for L-residents. Specifically, once fixed costs are fully covered by H-residents and N-residents, additional enrollments can be admitted at marginal cost ("marginal-cost enrollments"). Specifically, these additional L-residents can be accommodated at marginal costs, without reducing welfare of either those already enrolled, the university or taxpayers.

Marginal-cost enrollments are: $\Delta E_{ij}^{M} = b_{ij}(T_{ij}^{M} - c_i)$. When these enrollments are added to quasi-efficient enrollments, total enrollment is fully-efficient, that is, $E_{ij}^{M} + \Delta E_{ij}^{M} = b_{ij}(a_{ij} / b_{ij} - c_i)$. Thus, a third-degree tuition discrimination scheme that adds marginal-cost priced L-enrollments to quasi-efficient enrollments achieves first-best total enrollment.[9] Using this result and Eq. (19) implies:

$$\frac{E_{ij}^{M}}{\Delta E_{ij}^{M} + E_{ij}^{M}} = \rho^{M}. \tag{20}$$

The ratio of quasi-efficient to fully-efficient enrollment for each program equals the common degree of efficiency. With $\rho^{M} = 1$, all enrollments are priced at marginal costs; alternatively, with $\rho^{M} = 1/2$, N-resident and H-resident enrollments are priced at profit-maximizing rates, and L-resident enrollments are priced at marginal costs.

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conceptual enhancements are inclusion of public-appropriation support and closed-form determination of optimal efficiency, as given by Eq. (18).

[9] Total consumer surplus is still affected by a dead-weight loss associated with the need to set H-resident and N-resident tuitions above marginal cost to cover any fixed costs not offset by the appropriation.

When the appropriation is used entirely to reduce H-resident tuitions:

$E_{iH} = \rho^*(1+k^*)b_{iR}(a_{iR}/b_{iR} - c_i)$, $E_{iL} = (1-\rho^*(1+k^*))b_{iR}(a_{iR}/b_{iR} - c_i)$, $E_{iN} = \rho^* b_{iN}(a_{iN}/b_{iN} - c_i)$,

and $S^* = F - \rho^*(1-\rho^*)(\theta_u(1+k^*)^2 + \theta_r)$. Here, k^* and S^* depend on the fixed value of ρ^*. Regardless ρ^*, and the associated unique values of k^*, and S^*, the combined enrollments of H-residents and L-residents will equal first-best (efficient) enrollment, that is,

$E_{iH} + E_{iL} = b_{iR}(a_{iR}/b_{iR} - c_i)$.

One interesting solution is found by identifying ρ^* and associated unique values of k^* for which $S^* = 0$. The determined value of ρ^* reduces H-resident enrollments and increases L-resident enrollments, but has no effect on total resident enrollment, which remains fully efficient. N-enrollments, however, inefficiently decline from unrestricted levels. Basically, appropriations used to subsidize H-residents reduce the achievable degree of efficiency and welfare by imposing a larger dead-weight loss on N-residents.

3. Examples using PSU-MC budgets, enrollments, tuitions and appropriation

3.1 PSU base-level

The data in Table 1 are budget allocations, enrollments, and shared-service expenditures for Pennsylvania State University-University Park, for FY 2018 (PSU-MC). These data are used to calibrate enrollment demand curves, $E_{ij} = a_{ij} - b_{ij}T_{ij}$, with $i = 1,2,...,n$ colleges and $j = 1,2$ resident and nonresident enrollment categories, respectively. Cost functions presume independent, constant marginal cost for each program, c_i.[10] In developing demand-curves, it is

[10] These demand and cost expressions can be used to replicate standard budget data as prepared by public universities. In particular, this approach permits asking “What If?” questions in context of familiar budgetary templates. Calibration details for demand and cost expressions are given in notes associated with Table 1, and in the Appendix, Table 7; they are also discussed in

assumed that a common elasticity of demand is – 1.[11] Marginal costs are college budget allocations divided by total enrollment. Values for demand and cost parameters are presented in the Appendix, Table 7.

Demand and cost curves developed for the base case exactly replicate actual college budgets, tuitions and enrollments for PSU-MC (FY 2018). Marginal cost per SCH for the entire university is $400; enrollment-weighed N-resident tuition is $1,324 and H-resident tuition is $713. The appropriation per H-resident is $220. Across all programs, tuitions are greater than marginal costs, with N-residents always paying more.[12] Similar tuitions are charged across colleges, regardless of differences in program costs— the mean absolute deviation of H-resident tuition, for example, is $19.5 per SCH, while that for marginal cost is $118 per SCH. Welfare, which is measured by consumers' surplus of H-residents and N-residents plus university net revenue minus the state appropriation, is $515.6 M. The majority of student credit-hours (SCHs) are in the College of Liberal Arts (LA). Maximum willingness to pay in LA per resident SCH is $1,387 and $2,597 per nonresident SCH; marginal cost in LA is $279; base-level LA resident tuition is $693, and base-level LA nonresident tuition is $1,299. Other colleges can be similarly described. Alternative tuition configurations constructed using base-level parameters can

Burer and Fethke (2016). Also, see Altonji and Zimmerman (2018, Table 3) for their attempt to develop cost estimates for various majors, using Florida System data.

[11] There is flexibility is selecting initial elasticities, which can vary from program to program as well as by residency status. Alternatively, maximum willingness to pay, a_{ij} / b_{ij}, can be specified a priori, and these values, along with initial values of T_{ij} and E_{ij}, can be used to calibrate demand curves.

[12] The fact that H-resident tuitions exceed marginal costs is noteworthy. In similar calibrations for the University of Iowa, Iowa State University, the University of Florida, and the University of Michigan, actual resident tuitions are uniformly below marginal costs.

provide useful insights about their effectiveness. In particular, the level and distribution of welfare among residents, nonresidents and taxpayers will be compared to these base-level amounts.

TABLE 1 Here

Since H-resident tuitions all exceed marginal costs in the base configuration, it is possible to consider a counter-factual circumstance of admitting additional L-residents by charging them less. The results shown in Table 1.1. Using actual H-resident tuitions in Eq. (6), with $I = 0$, each additional L-resident can be charged a uniform rate of $405.3— this contributes 315,244 SCH enrollments. Welfare augmented to include additional L-residents is $564.1 M. Since base-case $I = 0$, an efficient alternative is to charge L-residents their marginal program costs, with the resulting augmented welfare being $572 M.

TABLE 1.1 HERE

3.2 PWYCA with exogenous appropriations

The results of imposing Eqs. (1)— (7) with a *given* appropriation are presented in Table 2. Here, H-resident tuition in each college equals N-resident tuition minus a uniform allocation of $349 per H-resident SCH that exhausts the state appropriation. While the appropriation per H-resident is larger than the base level of $220, H-resident tuition increases by $262 per SCH. The incremental revenue generated, $I = \$37.5M$, accommodates a uniform L-resident tuition of $345 per SCH, which covers the variable cost of 646,500 L-resident SCHs. Upward Adjustment of welfare to include these enrollments is $562.6 M, which is just $1.5 M (-0.27%) less than similarly-adjusted base welfare. With the appropriation given, average resident tuition becomes $623, which is lower than the base level of $713.

TABLE 2 HERE

3.3 PWYCA with exogenous appropriation.

Determining the appropriation to maximize constrained welfare, as represented by Eq. (8) and Eq. (9), provides the results in Table 2. When free to adjust, the appropriation declines from \$161.3 M to \$132.2 M (-18%). This decline is offset by a \$6.7M increase in tuition revenue and a \$29M decrease in variable expenditures. H-resident tuitions increase in every college, with an average increase from the base level of \$37 per SCH. There is a decline in incremental revenue, from \$37.5 M with a given appropriation to \$2.3 M with an adjusting appropriation; L-resident tuition increases from \$345 to \$400. With a declining appropriation, value is transferred from residents to taxpayers, however, total welfare of \$564.1 M is essentially the same as augmented base-level welfare, \$564.3 M. The total PWYCA enrollment is just 5,677 SCHs greater than the similarly augmented base enrollment.

TABLE 3 HERE

3.4 Endogenous tuitions and appropriation with the appropriation subsidizing H-residents

This case presents endogenously determined tuitions and appropriation. To capture a key feature of PWYCA, the appropriations is restricted to subsidizing only H-resident enrollments; otherwise all tuitions are determined. For the optimal solution, programs featuring high net willingness to pay are assigned a high subsidy per H-resident SCH. The legislative budget constraint binds at its capacity amount. These results are presented in Table 4. The determined ad valorem subsidy rate per H-resident SCH when $S^* = 0$ is: $k^* = 21\%$. The degree of efficiency determined such that $k^* = 21\%$, $S^* = 0$ is $\rho^* = 59\%$, and welfare is: $W^* = \$563.6M$. With H-resident tuitions exceeding marginal costs, a uniform tuition charged L-residents, as determined by Eq. (6), is: $T_L = \$447$. An additional 258,703 L-resident enrollments contribute

$21.5 M to both tuition revenue and variable costs. The resulting L-resident augmented budget is presented in the first column of Table 4.

TABLE 4 HERE

A striking aspect of this subsidy-restricted case is its conformity to base levels, as presented in Table 1. N-resident total enrollment and average tuition are practically the same. Average H-resident tuition of $690 is just $23 per SCH lower than base tuition of $713. Minor differences in program tuitions are due primarily to the fact that H-resident tuitions in LA and Science are moderately lower. Charging quasi-efficient tuitions does, however, increase differences among tuitions—the mean absolute deviation in H-resident tuitions is $96, compared to $19.5 for the base case. Differences in total welfare are not material. Welfare declines slightly from base welfare, but the decrease is only −0.27%.

3.5 Unrestricted tuitions and appropriation

The final situation considered places no restrictions on either tuitions or appropriations. The optimal tuitions and enrollments are those occurring when the entire appropriation is applied entirely to offset fixed costs, with results presented in Table 5. Eliminating a subsidy of H-residents increases H-resident tuitions in most colleges and reduces N-resident tuitions. The only H-resident tuition to decline slightly— from $693 to $681— is that for LA. Average H-resident tuitions increase by $51, and average N-resident tuition decreases by -$114. There is also a modest reduction for L-resident tuition from $447 per SCH to $432 per SCH. This unrestricted case, however, stands out with its pronounced efficiency implication. Eliminating favorable treatment of H-residents increases total welfare by $49 M (9 %). Thus, a major impediment to greater efficiency is associated with using the appropriation to subsidize H-residents.

TABLE 5 HERE

3.6 Who wins and who loses?

Table 6 summarizes patterns of tuitions, enrollments and value distribution for each tuition-setting configuration. When compared to base levels, H-resident tuitions increase for PWYCA and decreases for QE. Enrollment-weighted tuition typically decreases, except for the endogenous-appropriation PWYCA case. The lowest average tuition occurs when there are no residency restrictions; this result is entirely due to reductions in N-resident tuitions.[13] Turner's earlier question ("whether a "high tuition- high aid" strategy would be more equitable and efficient than would a low tuition strategy at state universities?") appears to be answered in affirmatively with adoption of the unrestricted tuitions.

For PWYCA, where appropriations are used to support H-resident enrollments, total welfare is basically unaffected by the designated tuition structure. What does change is assignment of "who pays." PWYCA tuitions with a given appropriation reallocates value from H-residents to L-residents, without changing N-resident value. When the appropriation adjusts, this value transfer is accompanied by a decline in the appropriation. For the restricted-subsidy QE case, results are remarkably similar to the base case. When no restrictions are placed on tuitions, there is an increase in welfare over the equivalent base of nearly 9%, which signifies value transfers to L-residents and N-residents from H-residents.

TABLE 6 HERE

[13] Starting from base enrollments, adoption of quasi-efficient (QE) tuitions decreases average tuition, increases total enrollment, and increases welfare. Standard economic efficiency implies that all students have the same marginal valuation for the same education. If marginal cost is the same for everyone, there develops a loss in efficiency by charging different tuitions. Setting differentiated tuitions offset this loss in value only if they lead to an increase in total enrollment; see Schmalensee (1981) for establishment of this condition under general conditions.

4. Summary

Under one version of "Pay What You Can Afford" (PWYCA), residents are charged nonresident tuitions net of a uniform allocation of a given state appropriation. The motivation is to charge nonresidents and some residents more to support enhanced access for low-income residents. In an initial proposal by AAAS (2016), it is assumed without question that both nonresident tuitions and state appropriations are exogenous. These restrictions can be relaxed, allowing both tuitions and appropriations to be endogenously determined.

High tuition-high aid situation considered here develop "quasi-efficient" tuitions and appropriations that may include a constraint that state appropriations be used to support resident enrollments. The presence of fixed costs and a break-even requirement typically imposed on public universities reduce obtainable degrees of efficiency. When appropriations are used to support reduced resident tuitions, small differences in total welfare develop among the considered versions of PWYCA, regardless of whether state appropriations respond to changes in rules for setting tuitions. There are, however, substantial transfers of value among high-pay residents, nonresidents, low-pay residents and taxpayers. Inefficiency in tuition setting is imposed by subsidizing residents, and is a distinguishing equity-related factor in deciding "Who Pays." When this restriction is removed, there is a 9% increase in total welfare, nearly all of which accrues to nonresidents.

Under quasi-efficient pricing, once some residents and nonresidents are charged enough to cover variable and shared fixed costs, the resulting tuitions will optimally exceed marginal costs. Under these conditions, there exists an opportunity to enroll lower-ability-to pay students by charging tuitions that cover marginal costs. If PWYCA approach is taken, the tuition structure can support first-best total enrollment outcomes. Put another way, combing quasi-efficient tuitions for high-pay residents and nonresidents with marginal-cost pricing for low-pay residents will increase both enrollment and welfare. Even when state support is restricted to residents, adding marginal-cost enrollments can accommodate increases in resident enrollment and overall welfare. The numerical results for this restricted-tuition case closely mimics the actual Penn State budget, enrollment and tuition-structure configuration. This, admittedly, limited example does imply that quasi-efficient tuition-setting structures can provide a plausible description for public university pricing.

5. Appendix

TABLE 7 HERE

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Table 1

Base-level Budgets, Enrollments, Tuitions, Costs, Appropriation, and Welfare for PSU-Main Campus (MC), FY-2018

PSU-MC	Base-Budget Allocations	N-Res Enrollments	N-res. Tuitions	H-Res. Enrollments	H-Res. Tuitions
Ag Science	$27,266,142	17,743	$1,332	31,748	$712
Arts & Architecture	$38,358,447	34,148	$1,298	39,570	$693
Business	$56,294,907	56,665	$1,349	64,447	$746
Communications	$14,617,498	21,729	$1,310	19,390	$705
E&M Sciences	$41,097,810	41,037	$1,356	37,136	$732
Education	$28,384,682	15,045	$1,349	25,506	$735
Engineering	$92,176,379	76,274	$1,363	86,204	$737
Health & Human Dev.	$40,535,510	49,203	$1,305	71,574	$703
Info. Sci. & Tech.	$15,615,059	14,976	$1,337	18,022	$725
Liberal Arts	$98,489,672	171,412	$1,299	182,024	$693
Nursing	$4,838,637	2,661	$1,370	7,087	$772
Science - Eberly	$86,052,890	127,801	$1,322	149,042	$707
Total to Colleges	$543,727,633	628,693	$1,324	731,749	$713
Fixed Cost	$971,366,890				
Total Perm. Expenses	$1,515,094,523				
Appropriation	$161,305,200				
Appro. Per Resident	$220				
Tuition Revenue	$1,353,789,323				
Total Rev.	$1,515,094,523				
Resident. Elasticity	-1				
Nonresident Elasticity	-1				
Base Welfare	$515,589,461				

Notes: Actual college budgets, enrollments and tuitions are provided from publically available sources by PSU administrators in the Smeal College of Business. There are 12 colleges with enrollments and tuitions distinguished by H-residentt, and N-resident. Budget allocations are "permenent" allocations that do not reflect temporary adjustments. Welfare is total consumers' surplus plus net university revenue minus the appropriation. Demand and cost parameters developed from the data in Table 1 are presented in the Appendix, Table 7.

Table 1.1

Augmented Base-Level Budgets to Include L-Resident Enrollments

PSU-UC	Base L-Res. TL Enrollment	Augmented Base TL Budgets
Ag Science	13,677	$32,805,429.23
Arts & Architecture	16,430	$45,012,794.84
Business	29,439	$68,217,645.56
Communications	8,248	$17,957,817.79
E&M Sciences	16,594	$47,818,345.67
Education	11,449	$33,021,607.44
Engineering	38,808	$107,893,776.56
Health & Human Dev.	30,332	$52,820,095.10
Info. Sci. & Tech.	7,960	$18,838,854.55
Liberal Arts	75,695	$129,146,165.38
Nursing	3,370	$6,203,530.64
Science - Eberly	63,625	$111,821,176.80
Total to Colleges/Campus	315,629	$671,557,240
L-Res. Uniform Tuition (TL)	$405	
Augmented Welfare at TL	$564,256,080	
Augmented Welfare at MC	$571,970,158	

Notes: L-Resident enrollments are computed using base-level resident tuitions and Eq. (6) to calculate TL. Augmented base-level budget allocations associated with these enrollments are presented, as are two measures of welfare—welfare including TL enrollments and welfare measured when L-Residents pay marginal cost (marginal-cost enrollments).

Table 2

PWYCA Budgets, Enrollments, Tuitions, and Welfare with Exogenous Appropriation

PSU-MC Exogenous Case	Budget Allocations	N-Res. Enroll.	N-Res. Tuitions	H-Res. Enroll.	H-Res Tuitions	L-Res. Enroll.
Ag Science	$36,268,393	17,743	$1,332	19,630	$983	28,457
Arts & Architecture	$48,681,933	34,148	$1,298	24,919	$949	34,491
Business	$72,376,264	56,665	$1,349	42,466	$1,000	56,578
Communications	$18,133,111	21,729	$1,310	12,337	$961	16,942
E&M Sciences	$51,412,925	41,037	$1,356	23,178	$1,007	33,578
Education	$37,848,576	15,045	$1,349	16,287	$1,000	22,739
Engineering	$118,154,733	76,274	$1,363	53,694	$1,014	78,302
Health & Human Dev.	$52,755,234	49,203	$1,305	45,800	$956	62,183
Info. Sci. & Tech.	$20,083,379	14,976	$1,337	11,491	$988	15,973
Liberal Arts	$123,948,804	171,412	$1,299	114,711	$950	158,675
Nursing	$6,783,303	2,661	$1,370	4,806	$1,021	6,199
Science - Eberly	$109,741,957	127,801	$1,322	92,870	$973	132,382
Totals	$696,188,611	628,693	$1,324	462,189	$975	646,500
Fixed Cost	$971,366,890					
Total Perm. Expenses	$1,667,555,501					
Appropriation	$161,305,200					
H-Res. Appropriation	$349					
Tuition Revenue	$1,506,250,301					
Total Revenue	$1,667,555,501					
Incremetal Revenue	$37,556,612					
L-Resident. Tuition	$345					
Welfare	$562,626,460					
Total Enrollment	1,737,381					
Average tuition	$867					

Notes: N-resident enrollments and tuitions are those given in Table 1. To calculate H-resident enrollments and tuitions, Eq. (2) and Eq. (3) are used, along with the respective demand curves. L-resident enrollments are given by $E_{iL} = b_{iR}(T_{iH} - T_L)$, where T_L is given by Eq. (6).

Table 3

PWYCA Budgets, Enrollments, Tuitions, and Welfare with Endogenous Appropriation

PSU-MC Endogenous Case	Budget Allocations	H-Res. Enrollments	H-Res. Tuitions	L-Res. Enrollments
Ag Science	$34,928,134	17,973	$1,020	27,681
Arts & Architecture	$47,061,019	22,797	$986	33,498
Business	$70,185,647	39,255	$1,037	55,075
Communications	$17,599,870	11,315	$998	16,464
E&M Sciences	$49,959,058	21,295	$1,044	32,697
Education	$36,523,968	14,998	$1,038	22,136
Engineering	$114,534,959	49,347	$1,052	76,268
Health & Human Dev.	$50,891,841	42,018	$993	60,413
Info. Sci. & Tech.	$19,442,378	10,568	$1,025	15,542
Liberal Arts	$119,959,935	104,960	$987	154,111
Nursing	$6,534,929	4,465	$1,058	6,040
Science - Eberly	$106,167,645	85,037	$1,010	128,716
Totals	$673,789,381	424,029	$1,012	628,640
Fixed Cost	$971,366,890			
Total Perm. Expenses	$1,645,156,271			
Appropriation	$132,238,668			
H-Res. Appropriation	$312			
Tuition Revenue	$1,512,917,603			
Total Revenue	$1,645,156,271			
Incremetal Revenue	$2,308,040			
L-Resident. Tuition	$400			
Welfare	$564,153,604			
Total Enrollment	1,681,362			
Average tuition	$900			

Notes: Base N-resident enrollments and tuitions are those presented in Table 1. With a endogenous appropriation, the Solver NLP routine contained in Excel is used to find the subsidy per H-residents that maximizes total welfare, Eq. (8), constrained by a legislative budget constraint, Eq.(9).

Table 4

Quasi-Efficient Tuition-Appropriation Structure with Subsidies Restricted to Reducing H-Resident Tuitions

PSU-MC	Restricted QE Allocations	N-Res. Enroll	N-Res. Tuitions	H-Res. Enroll.	H-Res. Tuitions	L-Res. Enroll.
Ag Science	$33,091,186	16,495	$1,426	27,573	$805	15,994
Arts & Architecture	$44,553,726	32,002	$1,380	35,012	$772	18,611
Business	$67,519,651	54,972	$1,389	62,862	$764	27,425
Communications	$17,243,350	22,013	$1,293	20,549	$663	5,944
E&M Sciences	$47,523,674	38,777	$1,431	33,733	$799	17,885
Education	$33,998,563	13,061	$1,527	18,931	$924	16,579
Engineering	$108,324,116	70,800	$1,461	75,122	$831	45,019
Health & Human Dev.	$49,645,954	50,254	$1,277	77,215	$647	20,452
Info. Sci. & Tech.	$18,642,316	14,447	$1,384	17,210	$759	7,738
Liberal Arts	$118,751,211	179,355	$1,239	206,119	$602	40,672
Nursing	$6,268,641	2,554	$1,425	6,816	$802	3,260
Science - Eberly	$104,463,458	132,184	$1,277	164,765	$632	39,123
Totals	$650,025,845	626,914	$1,324	745,906	$690	258,703
Fixed Cost	$971,366,890					
Total Permanent Expenses	$1,621,392,735					
Appropriation	$161,305,200					
Appropriation per H-Res.	$216					
Tuition Revenue	$1,460,087,535					
Total Revenue	$1,621,392,735					
L-Resident Tuition	$447					
ad valorem rate k	0.21					
Offset to fixed cost S	$0					
Efficiency rate ρ*	0.59					
Welfare	$563,560,726					

Notes: Demand and cost parameters used are presented in Appendix, Table 7. Enrollments and tuitions are calculated assuming the appropriation is efficiently allocated to reduce H-resident tuitions. The optimal solution is found by iterating on ρ^* to find a value of k^* that is consistent with $S^* = 0$. Tuition for L-residents is given by Eq. (6). Budget allocations in Col. 1 use base-level marginal costs and QE restricted enrollments for N-residents, H-residents, and L-residents.

Table 5

Unrestricted Quasi-efficient Enrollments and Tuitions for PSU-Main Campus

PSU-MC	Unrestricted Allocations	N-Res. Enroll.	N-Res. Tuitions	H-Res. Enroll.	H-Res. Tuitions	L-Res. Enroll.
Ag Science	$34,234,295	17,915	$1,319	24,768	$868	19,454
Arts & Architecture	$46,423,515	34,757	$1,275	31,449	$835	23,011
Business	$70,308,972	59,704	$1,277	56,466	$838	35,090
Communications	$18,060,537	23,908	$1,179	18,458	$739	8,438
E&M Sciences	$49,669,965	42,115	$1,321	30,301	$867	22,062
Education	$35,142,120	14,185	$1,427	17,005	$980	19,015
Engineering	$112,756,167	76,895	$1,352	67,479	$897	54,380
Health & Human Dev.	$51,599,477	54,580	$1,162	69,359	$725	29,803
Info. Sci. & Tech.	$19,403,394	15,691	$1,273	15,459	$829	9,854
Liberal Arts	$124,127,406	194,795	$1,122	185,147	$681	65,496
Nursing	$6,444,623	2,774	$1,312	6,122	$877	4,088
Science - Eberly	$108,962,587	143,563	$1,159	148,001	$712	58,982
Totals	$677,133,059	680,881	$1,210	670,015	$764	349,673
Fixed Cost	$971,366,890					
Total Permanent Expenses	$1,648,499,949					
Appropriation	$161,305,200					
Appropriation per HP Res.	$241					
Tuition Revenue	$1,487,194,748					
Total Revenue	$1,648,499,948					
L- Resident Tuition	$432					
k	$0					
S	$161,305,200					
Rho	0.64					

Notes: Tuitions and accompanying enrollments are given by closed-form expressions, Eqs (18) and (19).

Table 6

Comparative Efficiency and Equity Implications Associated with Tuition-setting Rules

Tuition Structure	Base	PWYCA	PWYCA	QE	QE
Value Distribution	Case	Given Appro.	Variable Appro.	Restricted	Unrestricted
H-Resident Tuition	$713	$975	$1,012	$690	$764
N-Resident Tuition	$1,324	$1,324	$1,324	$1,324	$1,210
L-resident Tuition	$405	$345	$400	$447	$432
Average Tuition	$922	$868	$924	$895	$874
H-Resident Enrollment	628,693	462,189	424,029	745,906	670,015
N-Resident Enrollment	731,749	731,749	731,749	626,914	680,881
L-Resident Enrollment	315,629	646,500	628,640	258,703	349,673
Total Enrollment (SCHs)	1,676,071	1,840,438	1,784,418	1,631,523	1,700,569
Tuition % change	-	9.44%	12.07%	-0.08%	-2.77%
N-Residents Value	$416.1 M	$416.1 M	$416.1 M	$414.3 M	$488.7 M
H-Residents Value	$260.7 M	$104.1 M	$87.7 M	$273.3 M	$220.5 M
L-Residents Value	$48.5 M	$203.7 M	$192.7 M	$37.3 M	$63.6 M
Appropriation	($161.3 M)	($161.3 M)	($132.2 M)	($161.3 M)	($161.3 M)
Total Value	$564.1 M	$562.6 M	$564.2 M	$563.6 M	$611.5 M

Note: In the first three situations, N-resident value is given. With QE, both tuitions and the appropriation are endogenously determined. In the restricted case, the entire appropriation is assigned to H-residents. In the unrestricted QE, no residency constraints are imposed. The reported "tuition % change" is measured by a Laspeyres index, using base enrollments, base tuitions and calculated tuitions. Welfare is measured as net consumers' surplus plus net university revenue minus the states appropriation, with value distributed among residents, nonresidents, and taxpayers.

Table 7

Slopes, intercepts and marginal costs for PSU-MC

PSU-MC	Resident Slopes	Resident Intercepts	Nonresident Slopes	Nonresident Intercepts	Marginal Costs
Ag Science	45	63,495	13	35,485	$551
Arts & Architecture	57	79,140	26	68,296	$520
Business	86	128,893	42	113,329	$465
Communications	28	38,780	17	43,458	$355
E&M Sciences	51	74,272	30	82,074	$526
Education	35	51,012	11	30,090	$700
Engineering	117	172,408	56	152,548	$567
Health & Human Dev.	102	143,147	38	98,405	$336
Info. Sci. & Tech.	25	36,044	11	29,952	$473
Liberal Arts	263	364,048	132	342,824	$279
Nursing	9	14,174	2	5,322	$496
Science - Eberly	211	298,084	97	255,602	$311
Totals	1,027	1,463,497	475	1,257,385	$400

Notes: Demand-curve slopes and intercepts are developed using PSU-MC FY2018 data, gathered from publically available sources and provided by administrators at the Smeal College of Business at PSU. With linear demand, $E_{ij} = a_{ij} - b_{ij}T_{ij}$, and using the assumed tuition elasticity of -1, slope parameters are determined from: $-b_{ij}T_{ij} / E_{ij} = -1$. These estimates use actual tuitions and SCH enrollments in Table 1. Intercepts are: $a_{ij} = E_{ij} + b_{ij}T_{ij}$. Maximum willingness to pay for each program is a_{ij} / b_{ij}. Marginal costs are calibrated by dividing actual FY 2018 permanent budget allocations by total enrollments for each program.