Appendix 1: Additional Tables and Figures

Table A1: Effects of changes in log state appropriations on level and share first-time foreign undergraduate enrollment, 1996-2012

Panel A **Dependent Variable:** Number of Foreign 1st Year Enrollment

	Research		AAU		Flagship		Non-Research	
Explanatory Variable	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Log(State Appropriations)	-171.121	-279.410	-342.709	-315.879	-269.172	-372.264	1.406	9.153
	(62.716)***	(79.569)***	(130.484)**	(196.129)	(104.245)**	(141.419)***	(6.113)	(11.718)
Log(Population 18)	-15.380	24.061	-460.115	-469.332	-41.298	-37.301	16.272	14.176
	(64.504)	(70.379)	(198.852)**	(187.211)**	(96.118)	(94.865)	(12.328)	(21.012)
R-squared	0.293		0.578		0.424		0.053	

Panel B **Dependent Variable:** Share of Total Freshmen that are Foreign

	Research		AAU		Flagship		Non-Research	
Explanatory Variable	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Log(State Appropriations)	-0.685	-1.263	-0.699	-1.476	-0.736	-1.766	-0.021	0.489
	(0.178)***	(0.406)***	(0.268)**	(0.642)**	(0.338)**	(0.673)***	(0.160)	(0.419)
Log(Population 18)	-0.280	-0.070	-1.435	-1.168	-0.020	0.020	-0.693	-0.836
	(0.327)	(0.454)	(0.681)**	(0.606)*	(0.520)	(0.487)	(0.391)*	(0.584)
R-squared	0.266		0.594		0.388		0.090	

Notes: Overall state appropriations to higher education are used as an instrument for institution-level state appropriations in the IV regressions. For the first-stage of the IV regression, see Table 2. All regressions include institution and year fixed effects. Institution-year observations are weighted by the undergraduate population at baseline (1996). Robust standard errors reported in parentheses are clustered at the university level in the OLS and at the state level in the IV.

Table A2: Effects of changes in log state appropriations on F-1 Visa Recipients, 2010-2015 - Instrumental Variable Specification

	Dependent Variable: Ln 1st Year Enrollment, 2004-2012 (All countries and China)							
	Research		AAU		Flagship		Non-Research	
Explanatory Variable	All	China	All	China	All	China	All	China
Log(State Appropriations)	-0.957	-2.112	-2.051	-2.596	-1.048	-1.363	-0.553	-0.702
	(0.531)*	(1.017)**	(0.793)***	(1.348)*	(0.516)**	(0.975)	(0.366)	(0.585)
Log(Population 18)	-1.215	-1.803	-2.505	-6.733	0.014	-1.251	-0.014	-4.681
	(1.398)	(2.824)	(1.816)	(2.581)***	(1.574)	(2.972)	(0.931)	(1.744)***
Partial R-squared	0.288	0.274	0.299	0.299	0.439	0.415	0.359	0.336
F- Statistic	143.2	135.5	59.90	61.18	107.4	96.10	32.23	41.76
Observations	1,174	1,063	305	303	440	411	1,848	1,094
Number of Universities	135	130	34	34	50	50	265	196

Source: F1 Administrative Data

Notes: Overall state appropriations to higher education are used as an instrument for institution-level state appropriations. All regressions include institution and year fixed effects. Institution-year observations are weighted by the undergraduate population at baseline (1996). Robust standard errors reported in parentheses are clustered at the state level.

Table A3: Effects of changes in log state appropriations on log first-time foreign undergraduate enrollment, Private Universities, 1996-2012

	Dependent Variable: Ln Foreign 1st Year Enrollment		
Explanatory Variable	Research	AAU	Non-Research
Log(Overall State Appropriations)	0.452	0.760	-0.084
	(0.332)	(0.354)**	(0.189)
Log(Population 18)	-1.151	0.783	1.151
	(0.888)	(1.043)	(0.571)**
R-squared	0.338	0.596	0.087
Observations	789	393	4,315
Number of Universities	52	25	370
	Foreign 1st Year Enrollment		
	Research	AAU	Non-Research
Log(Overall State Appropriations)	95.577	193.579	-3.419
	(88.833)	(117.974)	(7.896)
Log(Population 18)	-115.121	66.087	64.742
	(133.746)	(213.148)	(42.501)
R-squared	0.338	0.596	0.087
Observations	789	376	4,378
Number of Universities	52	24	370

Note: All regressions include institution and year fixed effects. Institution-year observations are weighted by the undergraduate population at baseline (1996). Robust standard errors reported in parentheses are clustered at the state level.

Table A4: Effects of changes in log state appropriations on log first-time foreign undergraduate enrollment, 1996-2012, Robustness Checks of Instrumental Variables Specification

Panel A: Additional Controls	**Dependent Variable:** Ln Foreign 1st Year Enrollment			
Explanatory Variable	Research	AAU	Flagship	Non-Research
Log(State Appropriations)	-1.374	-1.742	-1.683	0.627
	(0.481)***	(0.568)***	(0.707)**	(0.478)
Log(Population 18)	0.577	-1.037	0.340	0.565
	(0.396)	(0.571)*	(0.436)	(0.550)
Additional Controls	Yes	Yes	Yes	Yes
Partial R-squared	0.197	0.264	0.213	0.216
F-statistic	50.83	36.28	45.99	53.20

Panel B: University Specific Trends	**Dependent Variable:** Ln Foreign 1st Year Enrollment			
Explanatory Variable	Research	AAU	Flagship	Non-Research
Log(State Appropriations)	-0.351	-0.604	-0.526	-0.542
	(0.143)**	(0.264)**	(0.247)**	(0.290)*
Log(Population 18)	-1.327	-1.976	-1.324	-1.540
	(0.278)***	(0.413)***	(0.311)***	(0.454)***
University Specific Trends	Yes	Yes	Yes	Yes
Partial R-squared	0.473	0.559	0.512	0.438
F-Test	247.8	157.6	190.6	90.39

Panel C: Unweighted	**Dependent Variable:** Ln Foreign 1st Year Enrollment			
Explanatory Variable	Research	AAU	Flagship	Non-Research
Log(State Appropriations)	-0.616	-1.219	-1.091	0.570
	(0.363)*	(0.520)**	(0.541)**	(0.452)
Log(Population 18)	0.314	-0.675	0.087	-0.267
	(0.420)	(0.705)	(0.421)	(0.600)
Unweighted	Yes	Yes	Yes	Yes
Partial R-squared	0.281	0.314	0.326	0.261
F-statistic	87.13	24.67	71.56	72.50
Observations	2,121	547	791	3,162
Number of Universities	136	34	50	285

Note: Overall state appropriations to higher education are used as an instrument for institution-level state appropriations Additional controls in Panel A are state unemployment rate, the share of the population below the poverty line, whether the governor is a democrat, the rate of non-farm employment growth, the population at age 18 for all neighboring states, the state level personal income of per capita, median wages of employed workers with at least a bachelor's degree for ages 23-35 , for ages 36-49 , and for ages 50-60. Panel B includes university specific time trends, and Panel C shows unweighted regressions. All regressions include institution and year fixed effects. Institution-year observations are weighted by the undergraduate population at baseline (1996). Robust standard errors reported in parentheses are clustered at the state level.

Table A5: Effects of changes in log state appropriations on log first-time foreign undergraduate enrollment, 1996-2012, Disposable Revenue used as the Instrumental Variable

	Dependent Variable: Ln Foreign 1st Year Enrollment			
Explanatory Variable	Research	AAU	Flagship	Non-Research
Log(State Appropriations)	-1.344	-3.074	-1.607	0.551
	(0.601)**	(1.479)**	(0.891)*	(0.567)
Log(Population 18)	0.392	-0.358	0.001	0.308
	(0.488)	(0.814)	(0.457)	(0.749)
First Stage	**Dependent Variable: Log(State Appropriations)**			
Explanatory Variable	Research	AAU	Flagship	Non-Research
Log(Disposable Revenue)	0.520	0.381	0.448	0.670
	(0.089)***	(0.154)**	(0.102)***	(0.124)***
R-squared	0.582	0.586	0.583	0.573
Partial R-squared	0.117	0.0757	0.129	0.145
F- Statistic	34.22	6.153	19.38	29.01
Observations	2,121	547	791	3,158
Number of Universities	136	34	50	281

Note: Disposable Revenue is defined as state general revenue minus entitlement spending. All regressions include institution and year fixed effects. Institution-year observations are weighted by the undergraduate population at baseline (1996). Robust standard errors reported in parentheses are clustered at the state level.

Table A6 - Estimates of the effect of enrollment and cohort size on in-state and out-of-state enrollment levels, 1996-2012

	Dependent Variable: In-State 1st Year Enrollment			
Explanatory Variable	Research	AAU	Flagship	Non-Research
Out-of-State 1st Year Enrollment	0.153	0.017	0.086	0.060
	(0.122)	(0.147)	(0.095)	(0.278)
Foreign 1st Year Enrollment	-0.550	-0.557	-0.272	1.265
	(0.198)***	(0.259)**	(0.174)	(0.501)**
Log(Population 18)	2,084.228	1,775.804	760.656	1,426.968
	(397.636)***	(321.166)***	(322.178)**	(261.543)***
R-squared	0.403	0.360	0.297	0.322
Observations	2,184	550	796	3,194
Number of Universities	137	34	50	288

Notes: All regressions include institution and year fixed effects. Institution-year observations are weighted by the undergraduate population at baseline (1996). Robust standard errors reported in parentheses are clustered at the university level.

Table A7: Changes in Enrollment and Tuition Revenues

Panel A	**Dependent Variable:** Ln (Tuition Revenue)		
Explanatory Variable	Research	AAU	Flagship
Ln Foreign 1st Year Enrollment	0.018	0.070	0.045
	(0.010)*	(0.017)***	(0.016)***
Log(Population 18)	0.306	0.108	-0.049
	(0.122)**	(0.151)	(0.132)
R-squared	0.808	0.891	0.847
Observations	2,184	529	795
Number of Universities	136	34	50

Panel B	**Dependent Variable:** Tuition Revenue (Levels)		
Explanatory Variable	Research	AAU	Flagship
In-state Undergrads	1,751.705	6,114.817	5,026.125
	(1,210.891)	(3,045.659)*	(3,909.038)
Out-state Undergrads	13,494.231	17,675.366	17,729.168
	(2,466.089)***	(5,880.349)***	(5,324.983)***
Non-resident Undergraduates	38,145.503	41,979.309	45,187.919
	(11,409.255)***	(14,792.541)***	(21,070.485)**
US Graduate Students	16,988.400	15,056.759	8,714.826
	(3,701.755)***	(7,788.387)*	(9,095.163)
Foreign Graduate Students	36,185.562	8,106.566	33,882.986
	(9,833.030)***	(19,886.071)	(21,229.295)
R-squared	0.763	0.573	0.707
Observations	943	229	345

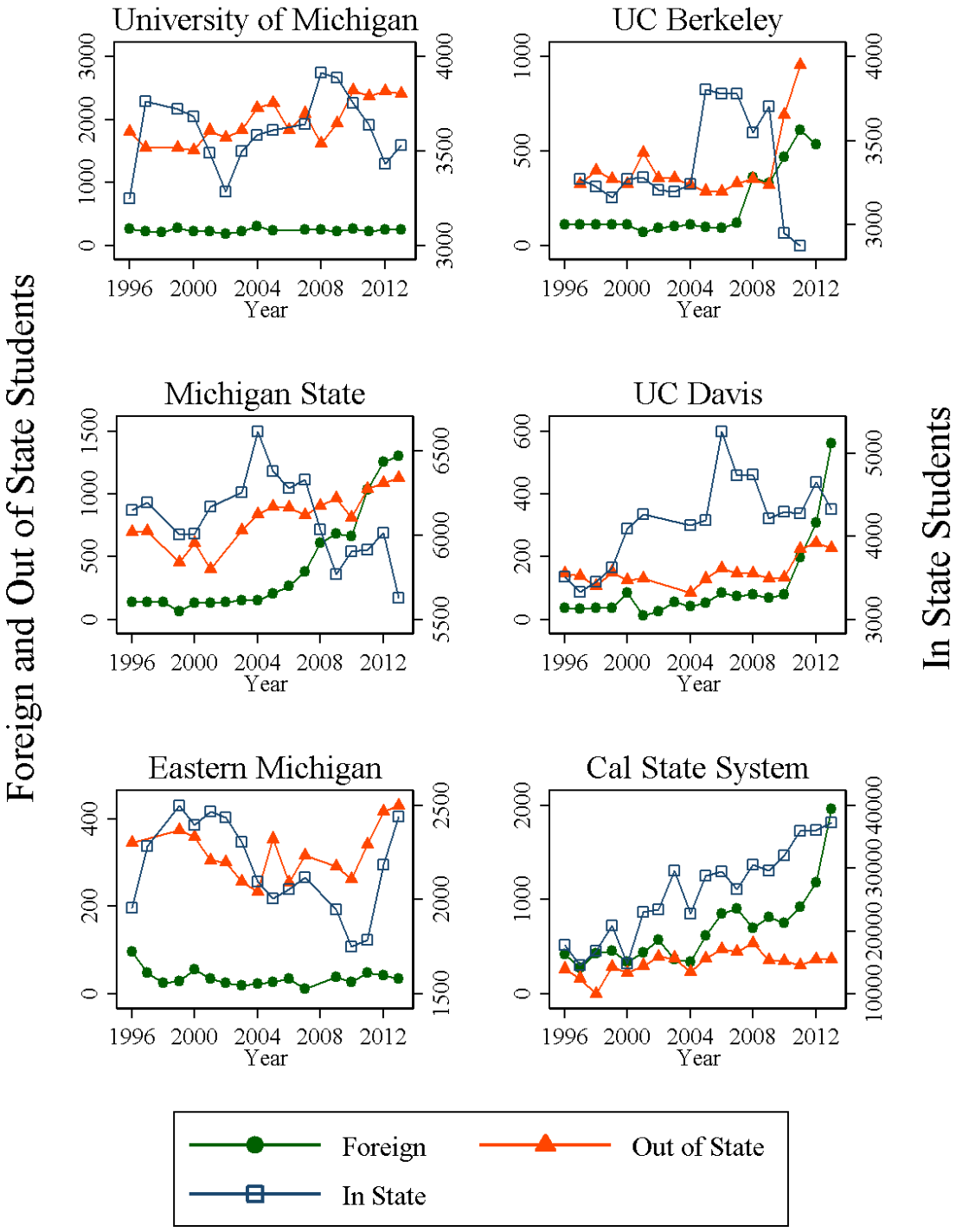
Notes: Panel B had lower number of observations because graduate student enrollment is only available after 2005 in the ACS. Panel A includes institution and year fixed effects. Institution-year observations are weighted by the undergraduate population at baseline (1996). Robust standard errors clustered at the university level are reported in parentheses.

Table A8: Estimates of the effect of changes in state appropriations on university financial variables, 1996-2012, Heterogeneous Effects – Instrumental Variable Specification

	Effect on Expenditures and Tuition Rates			
	Early Period (pre 2005)		Late Period (post 2004)	
Explanatory Variable	In State Tuition	Log(Total Expenditure)	In State Tuition	Log(Total Expenditure)
Log(State Appropriations)	-0.526	0.479	-0.345	0.181
	(0.210)**	(0.133)***	(0.145)**	(0.060)***
Log(Population 18)	-0.011	0.006	1.180	0.099
	(0.123)	(0.048)	(0.401)***	(0.161)
Partial R-squared	0.177	0.271	0.271	0.270
F- Statistic	16.93	129	129	126.9
Observations	1,101	1,062	1,062	982
Number of Universities	128	133	133	123

Note: Overall state appropriations to higher education are used as an instrument for institution-level state appropriations. All regressions include institution and year fixed effects. Institution-year observations are weighted by the undergraduate population at baseline (1996). Robust standard errors reported in parentheses are clustered at the state level in the IV.

Figure A1: Trends in Enrollment by Institution –Michigan and California



Note: Enrollment numbers from ASC data 1996 to 2012. Figures show number of full time first year students by residency and visa status.

Appendix 2: Data Preparation

The data assembled for this project are organized at the university and academic year and draw on multiple sources including the Department of Education's IPEDS survey modules, the American Survey of Colleges assembled by the College Board, and administrative data from the Department of Homeland Security on F-visa recipients. In addition, we assembled annual state-level data on demographics and economic conditions.

We use the 2010 Carnegie Classification to form groups of public universities. The Carnegie Classification taxonomy classifies institutions by the highest level of degrees awarded and research intensity, measured by factors such as research expenditures, doctorates awarded, and number of research-focused faculty. Among institutions awarding doctorate degrees, there are three categories: (1) Very high research activity, (2) High research activity, and (3) Doctoral universities. In all, there are 177 public doctorate-granting universities across eighteen years (1997 to 2014) of which 138 universities are in the first two categories, while there an additional include 265 Master's institutions. We focus our analysis on "Research Universities" defined as the combination of (1) and (2) and create a comparison group of "Non-Research" institutions as the aggregate of (3) and the Master's institutions.

The "Finance" module of the IPEDS data collection contains detailed financial information on revenues and expenditures by source and use. These data are the source of our measures of total tuition revenue, expenditures by purpose and state appropriations measures. For 2010 and prior, we employ the harmonized files assembled as part of the Delta Cost Project and add the subsequent years from the annual IPEDS files. The "Institutional Characteristics" module contains data on in-state and out-of-state tuition charges. We do not use data on University of Texas' tuition prior to 2004 because the Texas Legislature had the regulatory authority to set tuition rates, generally mandating that the same statutory and designated tuition rate be charged across the state.[1] State level data on total appropriations comes from the State Higher Education Finance report (SHEF) provided by the State Higher Education Executive Officers' (SHEEO) in the website <http://www.sheeo.org/projects/shef-%E2%80%94-state-higher-education-finance>.

The enrollment measure we employ is first-time undergraduate enrollment; fall enrollment is recorded in both the IPEDS "Fall Enrollment" module and the Annual Survey of Colleges (ASC). In addition to total enrollment, the ASC reports the number of foreign freshmen and the fraction of domestic first year students who are from out-of-state on an annual basis.[2] Given the

[1] In 2004, the 78th Legislature passed House Bill (HB) 3015, amending Texas Education Code §54.0513 to allow governing boards of public universities to set different designated tuition rates. Tuition deregulation became effective September 1, 2003, and universities began increasing designated tuition in spring 2004. More information can be found at the Overview: Tuition Deregulation and Tuition Set Asides Report.

[2] The IPEDS "Residence and Migration" module records the state of residence of first-time students on a biannual basis; the ASC data have the advantage of measuring enrollment by domicile on an annual basis from 1997 to 2013. Also, the classification of foreign students differs between the "Residence and Migration" and ASC surveys. The

fraction of out-of-state, the number of foreign students, and the total enrollment, we back out the in-state enrollment for freshmen and for all undergraduates. The ASC also has data on international financial aid, and SAT/ACT percentiles for the freshmen.

In addition to the administrative surveys, administrative data on all F-1 visas issued follow from a FOIA request of the U.S. Immigration and Customs Enforcement group of Department of Homeland Security. These data include student-level records of source country, destination university, expected major, and sources of funding.

In order to control for changes to the local economy, we compile historical Census estimates of the population at age 18 by state, and Bureau of Labor Statistics (BLS) data on the state unemployment rate and rate of non-farm employment growth for every year in our data. Median wage of employed workers with at least a bachelor degree at ages 23-35, 36-49, and age 50-60 comes from the March Current Population Survey (CPS), The share of the population below the poverty line and an indicator whether the governor is a democrat comes from the UKCPR National Welfare Data. Finally, state level personal income come from US Bureau of Economic Analysis.

Missing data on enrollment, tuitions and other variables are hand-coded from the universities Common Data Sets (CDS) available on their Institutional Research webpages and the University of California System available at <http://universityofcalifornia.edu/uc-system>. Missing data on appropriations, revenues (tuition and others), and expenditures are hand-coded from university financial statements (Annual Financial Reports), when missing from IPEDS. By using the complement data on enrollment and state appropriations, we add 139 observations to the Research University sample, 84 to the Flagship, 49 to the AAU and 4 to the Non-Research. Our main results are robust to excluding the hand-coded data.

The CDS and the ASC data report the fraction of out-of-state students (excluding foreign students from both the numerator and denominator). We use the total enrollment and the number of foreign students to then back out the number of out-of-state students. We weight our regressions based on the size of the undergraduate cohort in the year preceding the first year of the data.

All the monetary variables (including state appropriations, tuitions and expenditures) are deflated by the Higher Education Price Index (HEPI). Since most of our regression formulations include the logged monetary variable and fixed effects, the method of deflation for these regressions is inconsequential, and the deflation only affects the figures and levels regressions.

ASC and the Common Data Sets (CDS) define foreign students as Non Resident Aliens in the following manner: "A person who is not a citizen or national of the United States and who is in this country on a visa or temporary basis and does not have the right to remain indefinitely"." The "Residence and Migration" classification is determined by where the students reside before attending college. Since we use the ASC data for our enrollment variables, foreign students are enumerated based on their visa status rather than their state of residence.

Appendix 3: A Model of University Decisions and State Legislatures

In this appendix we provide a model that guides our empirical framework. In the model, university administrators have an objective function focused on the quality of the education provided by the public university, which depends on both purchased resources and the academic ability of the student body.[3] State legislatures focus on the number of in-state students enrolled in the public university, and offer state appropriations as a compensation scheme, which creates incentives for public universities to enroll more in-state students. Our model abstracts from specific mechanisms states may use to enforce such schemes. We treat in-state and out-of-state tuition as exogenous. It is reasonable to think that out-of-state tuition is set by the market because state universities have to set these tuitions to be competitive with the private sector. In contrast, it is natural to assume that state universities have some market power, and, as such, have an incentive to raise in-state tuition in response to declining appropriations, though in practice the capacity to do so may face legislative restrictions. We also assume that universities and state legislatures have full information about each other's actions, although it is possible that this oversimplifies the game played by them.

University's Objective Function

The public university's objective of maximizing the quality of education depends on the academic abilities of enrolled students and the expenditure per student, with the latter afforded through tuition revenues and appropriations from the state. As in Epple, Romano, and Seig (2006), the quality of the education is: $q = q(I, \theta)$, where I is the per-student expenditure and θ is a student body quality measure, which can be defined as the mean ability level of the student body. The function $q(.)$ is also twice differentiable, and increasing in both arguments.

The maximization problem of university administrators is given by:

$$max_{I,K_s,K_{o,}\,K_{f,}} q(I, \theta)$$

where, in addition to choosing the resource investment I, the administration determines student quality through the admission and enrollment of students, where K_s , K_o , K_f are the number of the enrolled in-state, out-of-state domestic, and foreign students, respectively. The total enrollment K is the sum of these quantities.[4]

Supply of Students

We assume that a university faces a given supply of applicants that are heterogeneous in terms of their ability. As a college makes its admissions decisions (which translate to enrollment), it takes into consideration how the ability of the marginal applicant to enroll will

[3] This paper relates to Epple et al. (2006) and Epple et al. (2013), which model enrollment decision of public and private universities. Unlike the existing literature, we describe the relationship between universities and state legislators as a principal-agent problem and incorporate foreign enrollment decisions to the university's set of choices.

[4] The scale of the university in this model is given by the cost function. An alternative would be to add an unmodeled scale parameter and measure appropriations and foreign enrollment per-student terms.

affect the quality of its student body. We define the marginal change in the student body quality associated with an increase in enrollment of student of type *j*:

$$\theta_j = \frac{\vartheta \theta}{\vartheta K_j} \text{ for j=}s,o,f,$$

This function reflects the quality of the marginal student that a university can recruit from in-state, out-of-state, and abroad. The university will take θ_j into consideration when deciding who to enroll.

University Cost Function

The cost function for each university is given by

$$C(K_s, K_o, K_f, I) = \varphi(K_s, K_o, K_f) + \rho IK,$$

We assume that the function $\varphi(.)$, which represents the costs associated with expanding enrollment, is strictly increasing and convex in all arguments. We define the marginal costs associated with increases in K_j :

$$\varphi_j = \frac{\vartheta \varphi}{\vartheta K_j} \text{ for } j=s,o,f$$

As in Epple, Romano, and Seig (2006), the university also faces a linear cost function for educational investments – costs that affect the quality of education provided to students.

University Revenue Function

Public university revenue comes from tuition revenue and non-tuition sources like appropriations. The in-state tuition is given by p_s and the out-of-state tuition by p_o, which is paid by both foreign and out-of-state domestic students. As in Epple et al. (2013), we assume that public universities take in-state and out-of-state tuition as given and cannot price discriminate among students.[5]

The university's revenue is given by:

$$Rev(K_s, K_o, K_f) = R(K_s) + p_s K_s + p_o(K_o + K_f),$$

where $R(.)$ denotes the non-tuition income of the public university. In our framework, it corresponds to state appropriations $R(K_s)$, which represent a contract set by the state legislature as a function of the enrollment of in-state students. The transfer from the state (non-tuition revenue) received by a university is an increasing function of the number of in-state students the university enrolls.

It follows that the university budget constraint (or individual rationality constraint in the context of the principal agent model) is given by:

$$R(K_s) + p_s K_s + p_o K_o + p_o K_f = \varphi(K_s, K_o, K_f) + \rho IK.$$

[5] This assumption is consistent with a general equilibrium model where out-of-state tuition is determined by perfect competition between private universities and public universities, and in-state tuition is determined exogenously by the university administrators or governing board.

2.2 The Optimization Problem of a Public University

To maximize its objective function, the public university makes choices on the number of in-state, out-of-state, and foreign students to enroll and, correspondingly, how much to invest in education. The choices must satisfy a budget constraint and a condition of non-negativity of its inputs. The university's problem is defined as:

$$max_{I,K_s,K_o,\,K_f,} q(I,\theta)$$

Subject to the budget constraint:

$$R(K_s) + p_s K_s + p_o K_o + p_o K_f = \varphi\big(K_s, K_o, K_f\big) + \rho I K$$

And non-negativity constraints:

$$K_s, K_o, K_f, I \geq 0$$

Based on the set-up above, we can rewrite the university's behavior as a system of equations defined by the first-order conditions (FOC):[6]

a) FOC with respect to in-state students: $R'(K_s) + p_s = \varphi_s + \rho I - \frac{q_\theta \theta_s}{\lambda}$

b) FOC with respect to out-of-state students: $p_o = \varphi_o + \rho I - \frac{q_\theta \theta_o}{\lambda}$

c) FOC with respect to foreign students: $p_o = \varphi_f + \rho I - \frac{q_\theta \theta_f}{\lambda}$

d) FOC with respect to investment in education: $\frac{q_I}{\lambda} = \rho K$

where $R'(K_s)$ is the derivative of the state appropriations contract between the university and the state with respect to K_s, which is a positive function for every K_s. q_θ, and q_I are the first derivate of the function $q(.)$ with respect to θ, and I respectively, and λ is the Lagrangian multiplier associated with the budget constraint.

The FOCs provide some intuition regarding the decision of the public university. In all equations, the left hand side represents the marginal benefit of increasing the input and the right hand side represents the marginal cost of increasing the input.

- *In-state students*: The marginal benefit of in-state students is the tuition they pay as well as the increase in state appropriations associated with higher in-state enrollment. The marginal cost is the expense of enrolling an additional in-state student as well as the monetized cost of the (potential) decrease in the quality of the current student body associated with expanding the enrollment of in-state students. A public university enrolls in-state students until their marginal benefit is equal to their marginal cost.[7]
- *Out-of-state and foreign students*: The marginal benefit of foreign and out-of-state students is the tuition they pay, which is higher than the tuition paid by in-state students. The marginal cost is the expense associated with their enrollment as well as

[6] We only evaluate interior solutions for the university problem.

[7] Universities benefit from an increase in the number of in-state students through higher appropriations contracts. Our model can be easily modified so that this benefit of higher in-state enrollment comes direct from the objective function of the university rather than the budget constraint, and the results would remain the same.

the monetized cost of the (potential) decrease in the quality of the student body associated with expanding enrollment of out-of-state and foreign students.

- *Investment per student*: The marginal benefit of educational resource investment is the monetized benefit of an increase in the quality of education provided by the university. The marginal cost is the expense associated with the investment.

Overall, a public university enrolls in-state, out-of-state, and foreign students until their marginal benefit is equal to their marginal cost. As a result, the relative tuition, marginal costs, state appropriations contract, and quality of the marginal applicant between in-state, out-of-state, and foreign students will determine the share of each type of student that will be enrolled at a public university.

The set of equations also present some intuition on how the predictions of the model change with state appropriations. Appropriations provide part of the resources that universities can use to purchase education quality. If a university received a worse appropriations contract, it should respond by decreasing investment in education. In the same way, out-of-state tuition revenues provide resources to be used in the purchase of educational quality. Declines in appropriations provide, therefore, a relatively higher return to foreign and out-of-state enrollment. The decision on which with margin of enrollment to adjust on, will depend on the qualifications of the marginal foreign and out-of-state student applicant.

2.3 State Legislature's Decision Problem

State legislatures are assumed to maximize their objective function through the number of in-state students enrolled in a public university as well as their capacity to provide other public goods to the rest of the population (g). We assume that state legislatures have a Cobb-Douglas preference over these two goods: $K_s^{\beta} g^{1-\beta}$, where β is the state preference for higher education, which is greater than zero and smaller than one. In reality, state legislatures might care about the quality of education provided by their public universities, but the extreme case presented here highlights the conflict of interest we want to stress with the model.

State legislatures have a budget constraint: $Y = R + p_g g$, where Y is the exogenous state (disposable) revenue, p_g is the price of the public good provided by the state, and R is the level of state appropriations to public universities. The state legislature chooses a state appropriation contract $R(.)$ and a provision of a public good g:

$$max_{R(),g} K_s^{\beta} g^{1-\beta}$$

subject to the budget constraint:

$$Y = R + p_g g.$$

When making their appropriation decisions, state legislatures must consider the optimal strategy of university administrators, which is given by the incentive compatibility constraint of the university:

$$R'(K_s) + p_s = \varphi_s + \rho I - \frac{q_\theta \theta_s}{\lambda}$$

In addition, state legislators must consider the university's operating constraints, which are given by their budget constraint (individual rationality constraint):

$$R(K_s) + p_s K_s + p_o K_o + p_o K_f = \varphi\big(K_s, K_o, K_f\big) + \rho IK$$

Intuitively, state legislatures must balance benefits and costs to both the state and the university when deciding appropriations. State legislatures know the optimizing goals and budget restrictions of university administrators. If they offer more generous appropriations, they create the incentives for university administrators to enroll more in-state students. But because state legislators must also use state revenues to provide other public goods and services (e.g., roads, elementary and secondary education), their optimal state appropriation contract will balance the marginal benefit of the additional in-state enrollment with the marginal cost of having fewer resources for the other public expenditures.

2.4 Parametric Assumptions and the Optimal State Appropriation Contract

To derive a closed-form solution for the principal agent model, we make some parametric assumptions.

State Appropriations Contract

First, we focus on contracts in which the state appropriation is a fixed-piece rate of in-state enrollment: $R(K_s) = \gamma K_s$. Piece-rate contracts are simple to analyze, create uniform incentives, and are observed in many real-world settings. In this set up, the state legislature's contract is defined by the choice of the parameter γ.

University's Objective Function

We assume that educational investment and mean student academic ability are perfect substitutes: $q = \alpha I + \theta$. In other words, to maximize educational quality, the university can perfectly substitute a lower quality student body with higher investments in education.[8]

Student Body Quality and the Supply of Students

As discussed in the previous section, universities face a given supply of applicants who are heterogeneous in their ability. Universities make enrollment decisions with perfect information on how that changes the quality of the student body. Letting the aggregate ability of the three student types be denoted A_s, A_o, and A_o, the peer quality of the student body can be written as:

$$\theta = \frac{A_s(K_s) + A_o(K_o) + A_f\big(K_f\big)}{K_s + K_o + K_f} \quad (1)$$

We assume that $A_j\big(K_j\big) = T - \frac{\mu_j}{2} K_j^2$ for $j = s\ and\ o$, and $A_f\big(K_f\big) = T - \mu_f K_f$, where T is the highest level of student ability. Under these assumptions, the aggregate ability of group j declines as a university increases K_j, reflecting that students are admitted in order of ability. The

[8] As it will be clear later, this functional form assumption will imply a quasi-linear maximization problem of the university administrators with respect to foreign enrollment.

functional form assumptions for $A_j(.)$ imply that derivative of θ with respect to K_s, K_o, and K_f is negative.

In addition, we assume that the decline in ability is faster for in-state and out-of-state students than for foreign students. This assumption is consistent with an elastic supply of foreigners, which implies that the ability of the marginal foreign student changes relatively little as the university expands foreign enrollment. We believe that this assumption is valid for most public research universities that have experienced a substantial increase in the number of foreign applicants in the past decades.

Cost Function

We assume that the cost of enrolling a student is given by

$$\varphi(K_s, K_o, K_f) = C + \delta K \log K$$

where C and δ are constants greater than zero. The term C represents the fixed costs a university has to operate.[9] The term $\delta K \log K$ are convex variable costs, meaning that it becomes increasingly costly for a university to expand enrollment. This specification is convenient because it sets the difference between the marginal cost and the average variable cost to be constant δ.[10]

2.4.1 Solution

We will focus our analysis on interior solutions for the maximization problem of the university administrators. From the first-order condition with respect to investment, the value of the Lagrangian multiplier is:

$$\lambda^* = \frac{\alpha}{\rho K} \tag{2}$$

Using the FOC with respect to out-of-state enrollment and the marginal change in student body ability, we can demonstrate that for an interior solution, the optimal enrollment of out-of-state students is: $K_o^* = \frac{\mu_f}{\mu_o}$, which decreases with μ_o (decline in ability associated with out-of-state enrollment) and increases with μ_f (decline in ability associated with foreign enrollment). The intuition is that foreign and out-of-state students generate the same (net) revenue to the university. As a result, universities will enroll out-of-state students until their ability is equal to the ability of the marginal foreign student enrolled.

With these assumptions, the incentive compatibility constraint of university administrators can be expressed as:

[10] Universities might also face higher marginal costs to enroll foreign students, as extra administrative expenses may be required to process visa applications, extra language training, etc. Modification of the model to allow for such additional costs would not affect the predictions of the model and for simplicity we ignore them here.

$$K_s^* = \frac{\frac{\alpha}{\rho}(\gamma + p_s - p_o) + \mu_f}{\mu_s} \quad (3)$$

In this setup, the optimal choice of in-state enrollment of university administrators is positively associated with in-state tuition and the monetary compensation they receive from the state to enroll an additional in-state student, and negatively associated with out-of-state tuition and the decrease in the student body quality associated with expanding in-state enrollment. Finally, in-state enrollment is negatively associated with the availability of foreign students through μ_f. The extra appropriation revenue provided by in-state students becomes less attractive to universities if they can access out-of-state tuition revenue from foreign students without compromising the quality of their student body.

Finally, we derive an expression for the enrollment of foreign students:

$$K_f^* = \frac{-\left(\frac{\gamma + p_S - p_0 + \frac{\rho}{\alpha}\mu_f}{2} + \delta\right)K_S^* - \left(\frac{\rho}{2\alpha}\mu_f + \delta\right)K_O^* + C - \frac{\rho}{\alpha}(3T)}{\delta} \quad (4)$$

This expression provides some interesting insights. First, the enrollment of foreign students is negatively associated with in-state and out-of-state enrollment.[11] In the model, foreigners, out-of-state and in-state students are substitutes for a university as they generate revenue used in the purchase of educational resources.

In addition, foreign enrollment is negatively related to total state appropriations γK_s^* and positively associated with university fixed costs C. This result is a direct implication of the fact that foreign students are used as a source of revenue for the university to finance its operations. While the university dislikes increasing its foreign enrollment, since additional foreigners decrease the quality of the student body, the university can use their revenues to increase investment and the enrollment of in-state students. If state appropriations decline, the relative benefit of enrolling foreign students increases.

In terms of the supply of foreign applicants, the parameter that defines the availability of foreign students to the university is the constant μ_f, which represents the decrease in student quality associated with expansion of foreign enrollment. Increases in the supply of highly qualified foreign students would serve to decrease μ_f, as the university can recruit better foreigners without affecting the quality of the student body much. From the expressions above, a decrease in μ_f is associated with lower in-state and out-of-state enrollment, and higher foreign enrollment. With better international applicants, universities can obtain more tuition revenues by increasing foreign enrollment without changing the quality of the student body much.

Optimal State Appropriations Contracts

Substituting the optimal in-state enrollment expression into the state legislature's maximization problem yields:

$$max_{\gamma,g} K_s^*(\gamma)^\beta g^{1-\beta}$$

[11] Note that $\gamma + p_s + \left(\frac{\rho}{\alpha}\right)\mu_f > p_0$ is a necessary condition for positive in-state enrollment.

subject to a budget constraint:[12]

$$Y = K_s^*(\gamma)\gamma + p_g g$$

where $K_s^*(\gamma)$ is the optimal in-state enrollment for a given γ derived in (3). The solution of the model above for the equilibrium state enrollment can be described by a quadratic equation:

$$(2-\beta)K_s^{*2} + \left(\frac{\alpha/\rho\,(p_o - p_s) - \mu_f}{\mu_s}\right)K_s^* - \beta\frac{\alpha}{\rho\mu_s}Y = 0 \tag{5}$$

There are at most two values of K_s^* that can solve the optimal in-state enrollment. For the rest of the paper we will focus our analysis on solution for (6) that provides the highest in-state enrollment level.

Comparative Statistics

Using the implicit function theorem on expression (5) we can demonstrate that:

$$\frac{dK_s^*}{dY} = \frac{\beta\frac{\alpha}{\rho\mu_s}}{2(2-\beta)K_s + \left(\frac{\alpha/\rho\,(p_o - p_s) - \mu_f}{\mu_s}\right)} \tag{6}$$

which is greater than zero for the in-state enrollment levels we consider in this paper. As a state obtains more resources, it can offer better appropriation contracts to universities that translate into higher in-state enrollment.[13]

Using the implicit function theorem, we can also show that $\frac{dK_s^*}{d\beta} > 0$, or in words, the model predicts increasing state preference for higher education is associated with higher in-state enrollment.

In terms of the availability of qualified students, we can demonstrate that in-state enrollment decreases with a higher supply of qualified foreigners and increases with a higher supply of qualified in-state student ($\frac{dK_s^*}{d\mu_f} > 0$ and $\frac{dK_s^*}{d\mu_s} < 0$). Public universities are willing to accept more in-state enrollment if there are better qualified, but also can turn to foreign students if they are more likely to be qualified.

Finally, the model predicts that in-state enrollment is positive associated with in-state tuition, $\frac{dK_s}{dp_s} > 0$, and negatively associated with out-of-state tuition, $\frac{dK_s}{dp_o} < 0$.

[12] In this quasi-linear set-up, state legislator might ignore the individual rationality constraint as universities will adjust investment to balance their budget.

[13] One can show that denominator of the expression is greater than zero for the highest in-state enrollment solution of the quadratic equation presented in (5).

Universities enroll more in-state students if they provide higher tuition revenues but they become relatively less attractive if out-of-state tuition is high.

Now we turn to the predictions of the model for foreign enrollment. Using expression (7) and the deviations above, we can show that foreign-enrollment is a decreasing function of the exogenous state (disposable) revenues:

$$\frac{dK_f^*}{dY} = -\frac{1}{\delta}\left\{\frac{\rho\mu_s}{2\alpha}K_s + \left(\frac{\gamma + p_s - p_0 + \frac{\rho}{\alpha}\mu_f}{2} + \delta\right)\right\}\frac{dK_s}{dY} < 0 \quad (7)$$

which is the main result explored in the empirical section of the paper. The intuition goes as follows: states with higher exogenous revenue can offer better appropriations contracts to universities. In return to more state appropriations, universities will enroll more in-state students and be less dependent on the tuition paid by foreign students.

Model Predictions and Empirical Evidence

The main hypothesis of the paper is that universities increase foreign enrollment as a response to state appropriation cuts. The model provides some rationale for that, as universities use resources from both state appropriations and out-of-state tuition revenues to provide a better quality education for its students. The model is consistent with our empirical strategy, where state appropriations are endogenously determined by the interaction between state legislators and university administrators, but state appropriations are exogenously affected by the amount of the state's disposable revenue. Most importantly, the model predicts that decreases in disposable revenue are associated with state appropriation cuts and consequently an increase in foreign enrollment, which is observed in the empirical section of the paper.

Nonetheless, there is one prediction of the model that is not fully consistent with empirical evidence. In particular, while for most of our specifications we observe a positive relationship between state disposable revenues and in-state enrollment, our estimates are never statistically different from zero and, a visual inspection of enrolment series shows that, in some case, increases in the number of foreign students is not matched by any apparent decrease in the number of in state residents. It seems plausible that universities often feel politically constrained to not reduce the number of in-state students. If we were to modify our model to treat in-state enrolment as downwardly rigid, we still obtain the prediction that foreign enrolment would rise when appropriations fall.