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Institutional Complexity and Efficiency: How Universities Scale

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Research Questions

1. What economies or diseconomies of scale do universities exhibit to instruction, research, and bureaucracy?
2. How do different university types vary?
3. Do these institutional economies of scale determine optimal institution sizes, with respect to their different activities?

Why size matters

The growing need for affordable and accessible higher education demands scaling up the system. To explore the topic, our study not only quantifies institutional economies of scale, but suggests the constraints, efficiencies, and mechanisms that underlie them. Analysis may ultimately extend to governments, firms, and other organizations.

The scaling methodology

The recently developed technique of **scaling** offers new perspective on entire classes of **complex systems**. Prime examples include Kleiber's law, the observed 3/4 power law relationship between metabolism and mass of all organisms², and the 7/6 power law relationship between socio-economic outputs and population of cities³. Powerful explanatory theories based on network optimization have followed in both areas^{1,2,3}. We apply scaling to the inner social complexity of institutions.

Scaling is an empirical method that plots, in log-log space, a key attribute versus the size of each individual in a class, like GDP vs Population of all US cities³. University size is defined here as enrollment. After linear regression, the **fitline's slope b reveals returns to scale**.

- $b > 1$: increasing returns to scale; superlinear scaling
- $b \approx 1$: constant returns to scale; linear scaling
- $b < 1$: decreasing returns to scale; sublinear scaling
also "economies of scale"

Higher education data

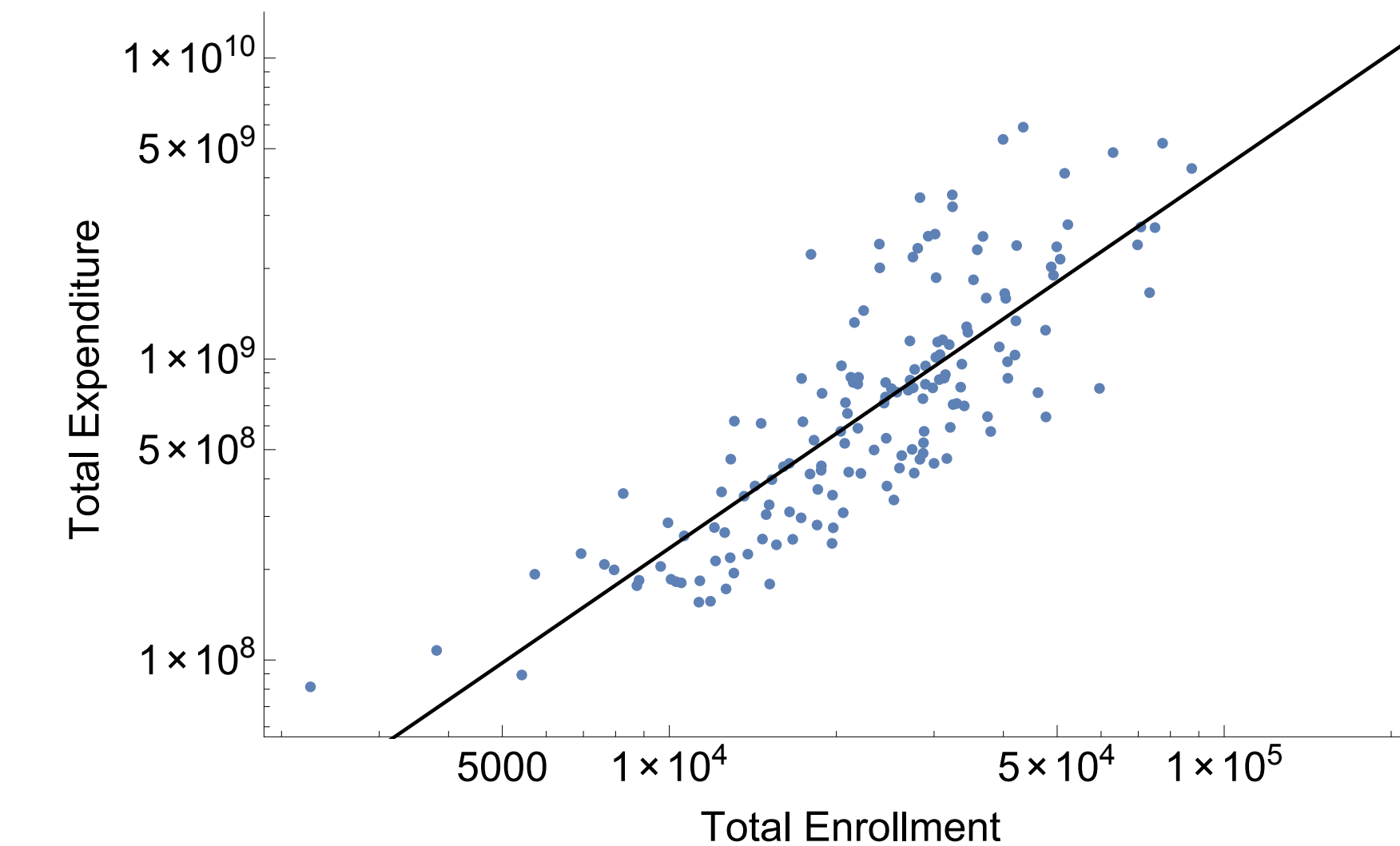
Our dataset uses **2013** data that includes all 6400+ accredited universities that accept Federal Student Aid receiving students, also known as Title-IV schools. Here we focus only on roughly **160 public research universities, 1400 non-profit liberal arts colleges, and 900 public community colleges (2yr)**.

Total enrollment (undergraduate + graduate), faculty, revenues and expenditures are IPEDS data from the Delta Cost Project⁴.

Federal Student Aid receiving students (FSA cohort) and their completion outcomes are National Student Loan Data System (NSLDS) data from the College Scorecard dataset. They capture the 2013 educational outcomes of federal student loan receiving students whose first year was 2007 (grant receiving students were not tracked until 2012).

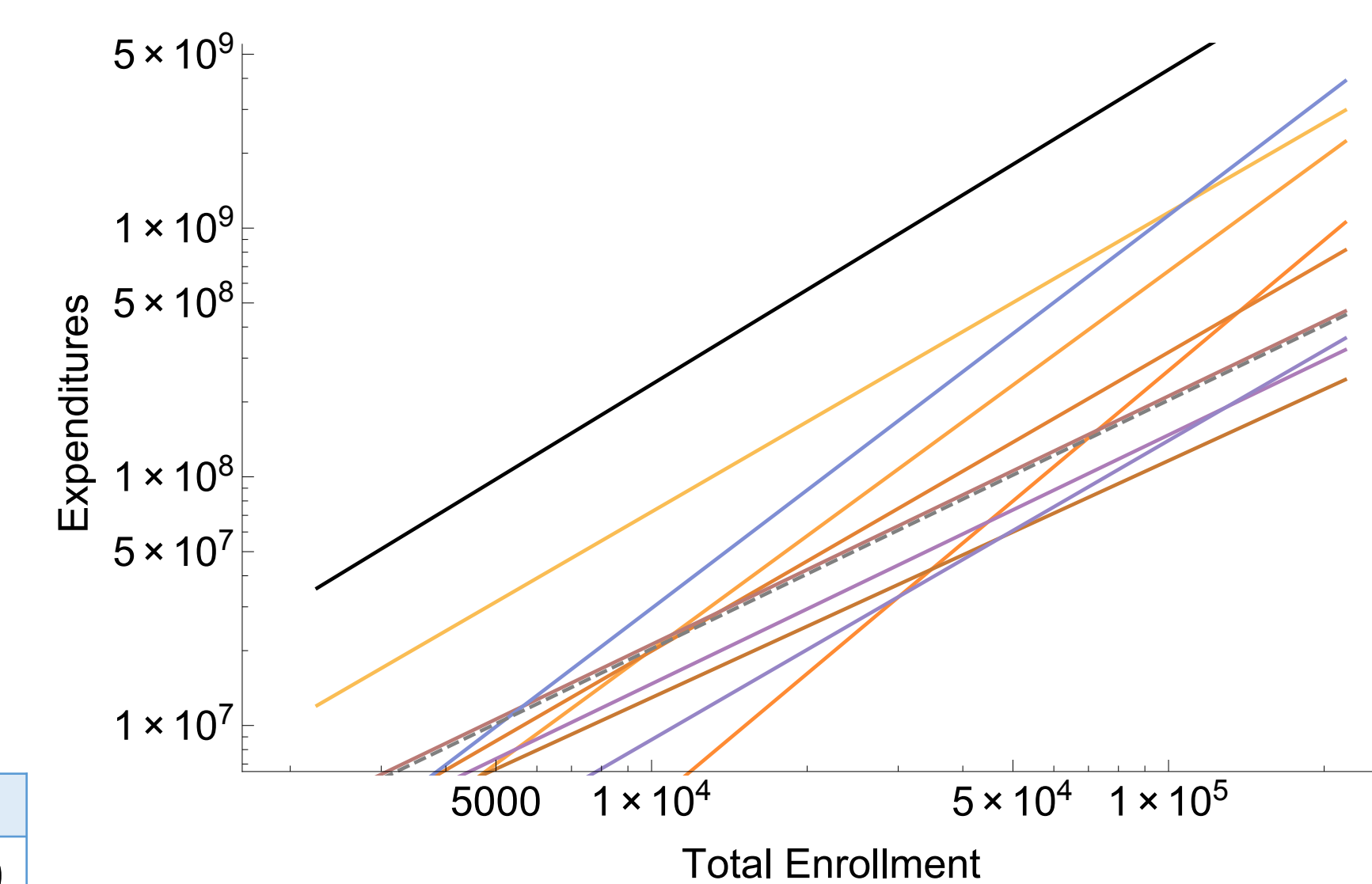
Framework – Subcomponents of expenditure exhibit unique scaling (public research universities)

1. Expenditures and enrollment at public research universities correlate, fit by a power law scaling relationship with slope **b = 1.27**, highly superlinear. Increase in enrollment → a greater increase in exp.

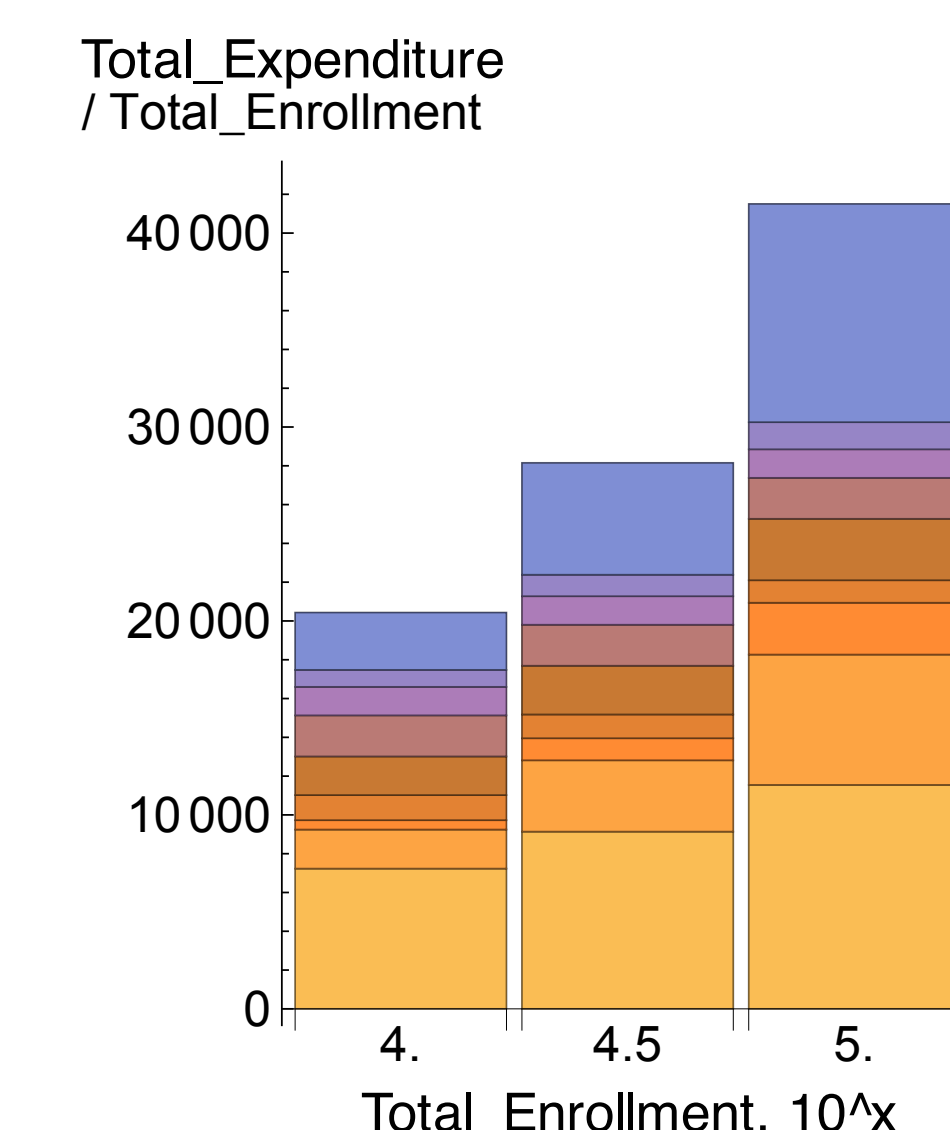


a	b	r ²	bin b	bin r ²	deming b	N
7.62 ± 1.36	1.27 ± 0.134	0.687	1.18	0.988	1.66	159

2. Total expenditures disaggregate into nine **subcomponent variables**. Each is associated with a distinct university function and has its own scaling vs size. In the graph, note how instruction and auxiliary dominate. In the table, the top five subcomponents are considered auxiliary and operational, while the bottom four (instruction, research, public and student services) are considered productive.



Subcomponent of Exp	b	r ²	N
Auxiliary_Exp	1.58 ± 0.23	0.534	159
Grants_to_third_party	1.20 ± 0.17	0.558	156
Operation_Maintenance	1.00 ± 0.13	0.596	159
Institutional_Support	1.00 ± 0.12	0.653	159
Academic_Support	1.20 ± 0.13	0.679	159
Student_Service	0.95 ± 0.12	0.617	159
Public_Service	1.74 ± 0.32	0.422	159
Research	1.52 ± 0.31	0.379	159
Instruction	1.20 ± 0.10	0.775	159



Subcomponents of Rev	
Auxiliary_Rev	
Donation_Investment_Rev	
Federal_Appropriation	
State_Local_Grant_Contract	
State_Local_Appropriations	
Tuition_Rev	

I. Public Research

Total	b	r ²	N
Rev	1.29 ± 0.14	0.674	159
Exp	1.26 ± 0.13	0.687	159

Superlinearity suggests synergies between research and instruction.

II. Liberal arts colleges

Total	b	r ²	N
Rev	0.98 ± 0.03	0.774	1444
Exp	0.95 ± 0.02	0.796	1444

Modest performance and higher tuition, profitability, stability come with scale.

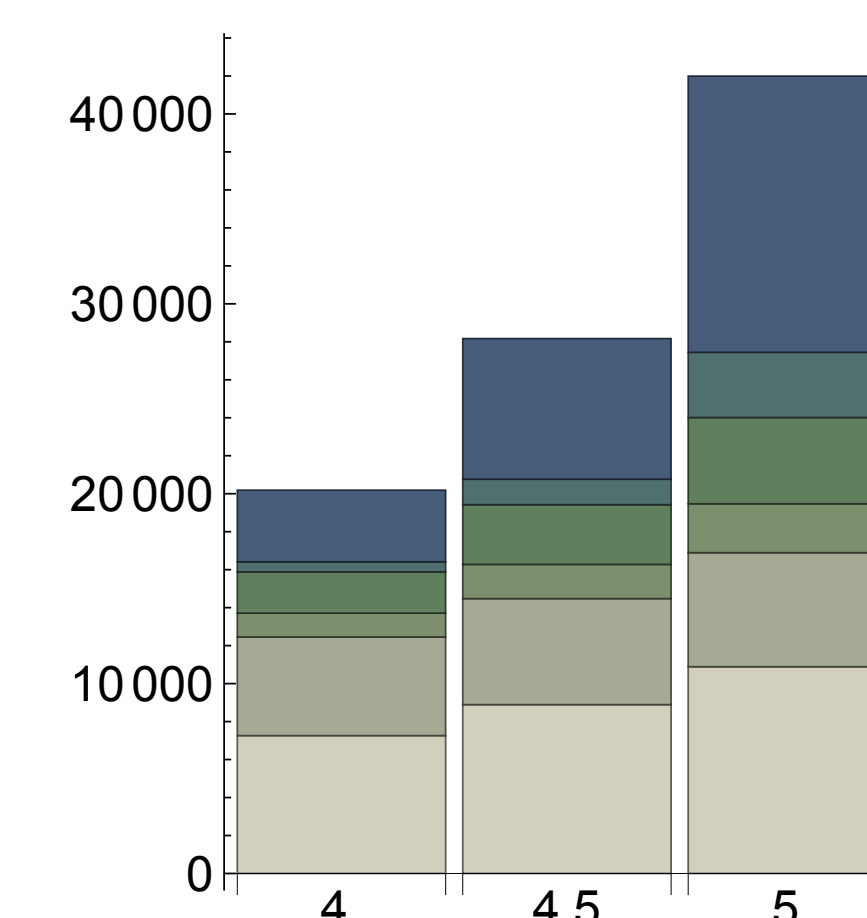
III. Community colleges

Total	b	r ²	N
Rev	0.82 ± 0.02	0.903	912
Exp	0.83 ± 0.02	0.920	912

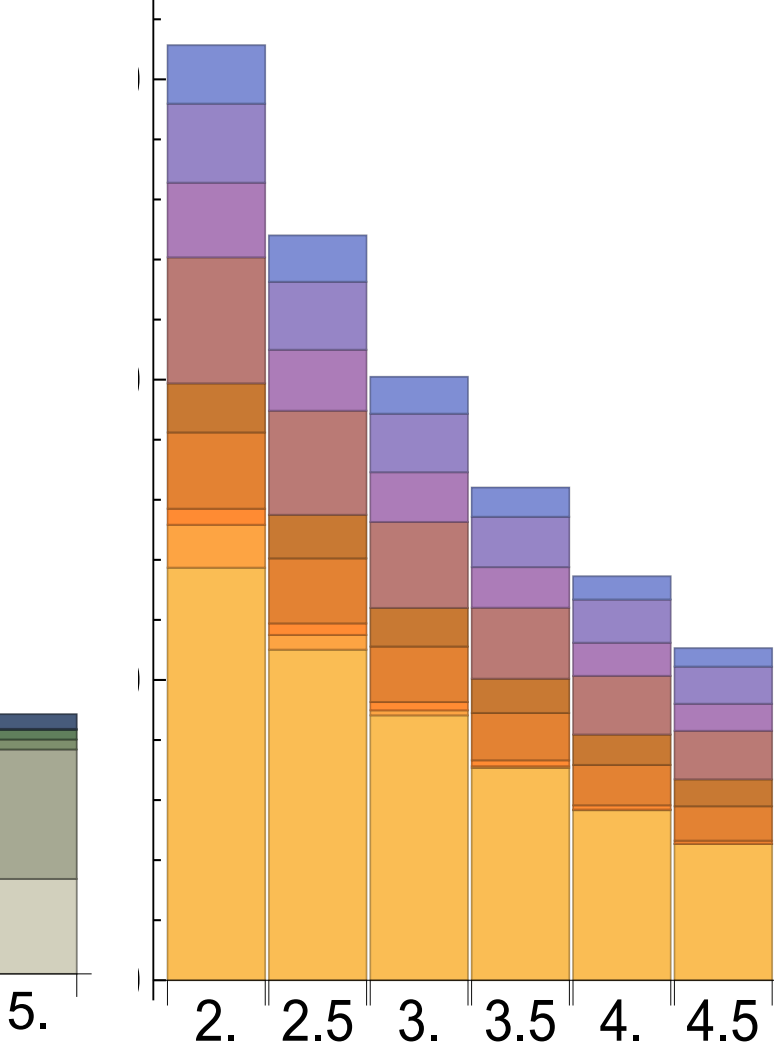
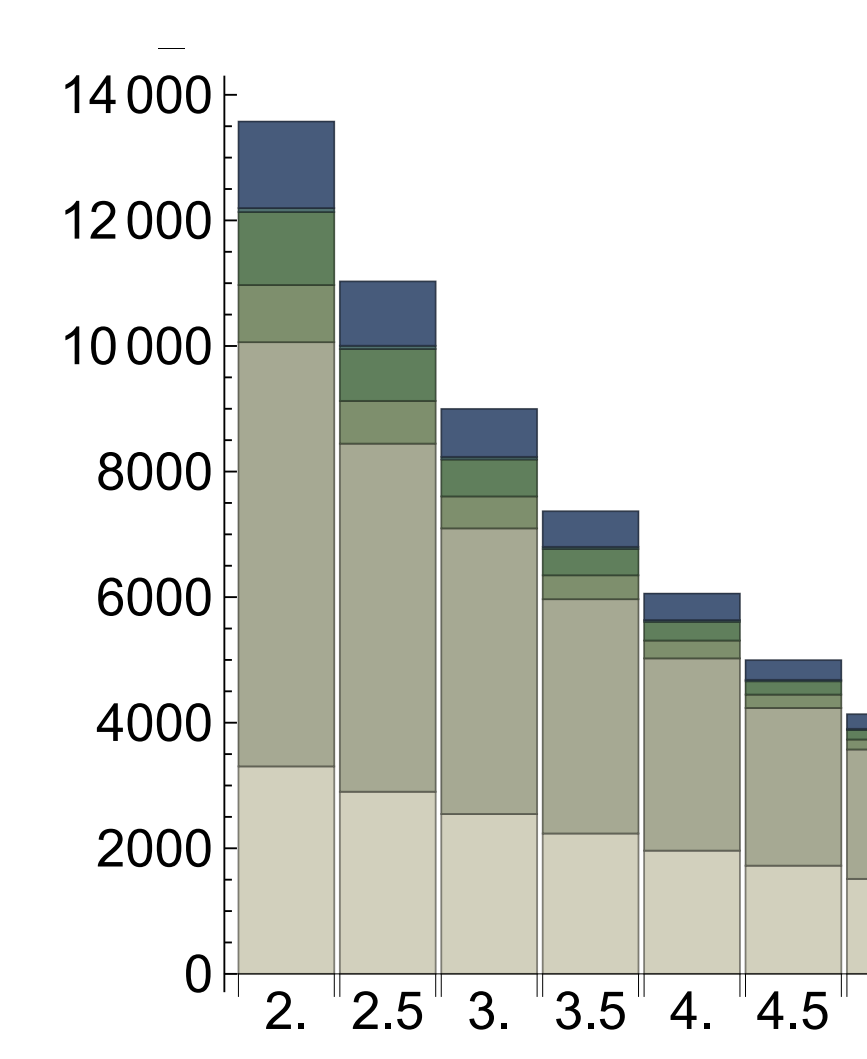
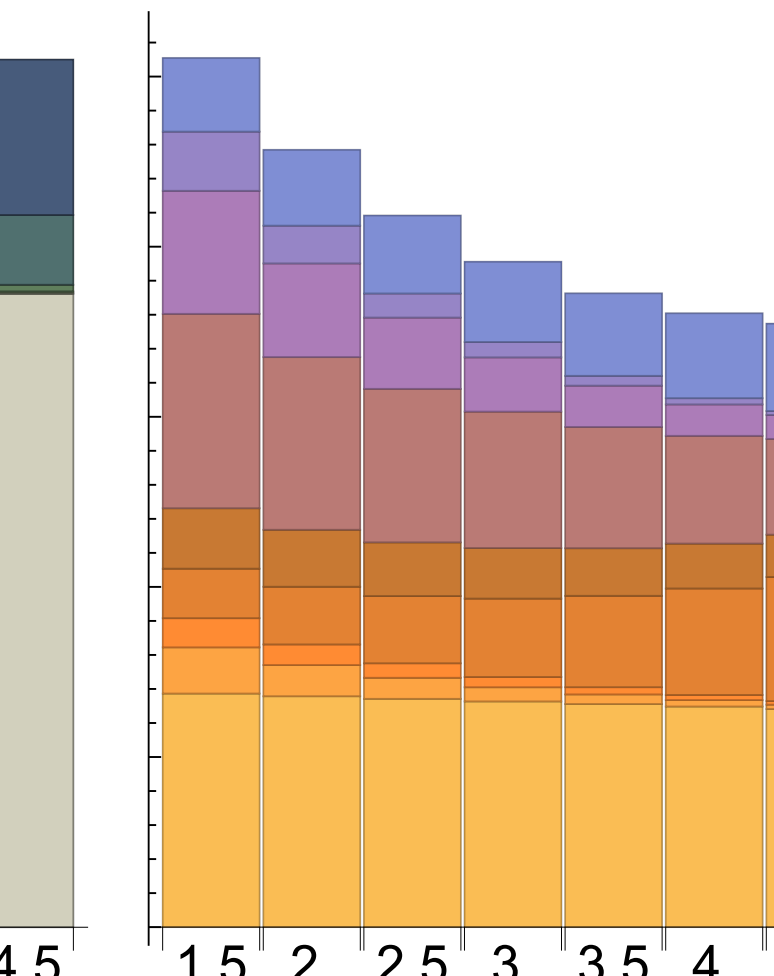
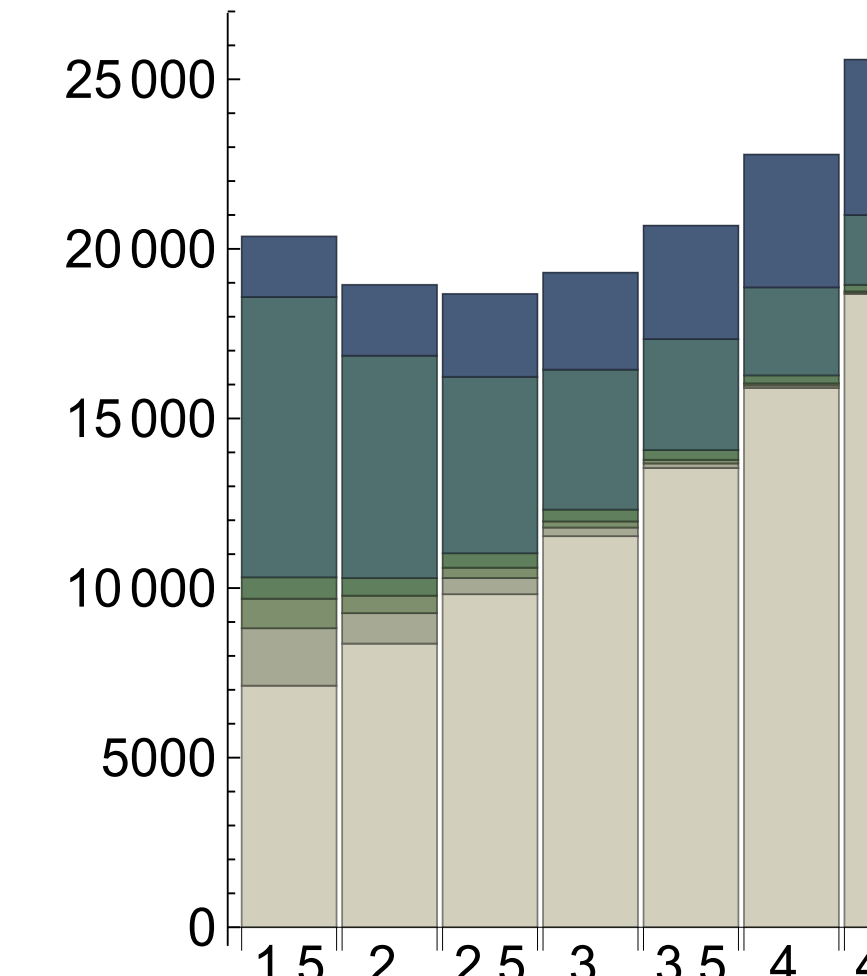
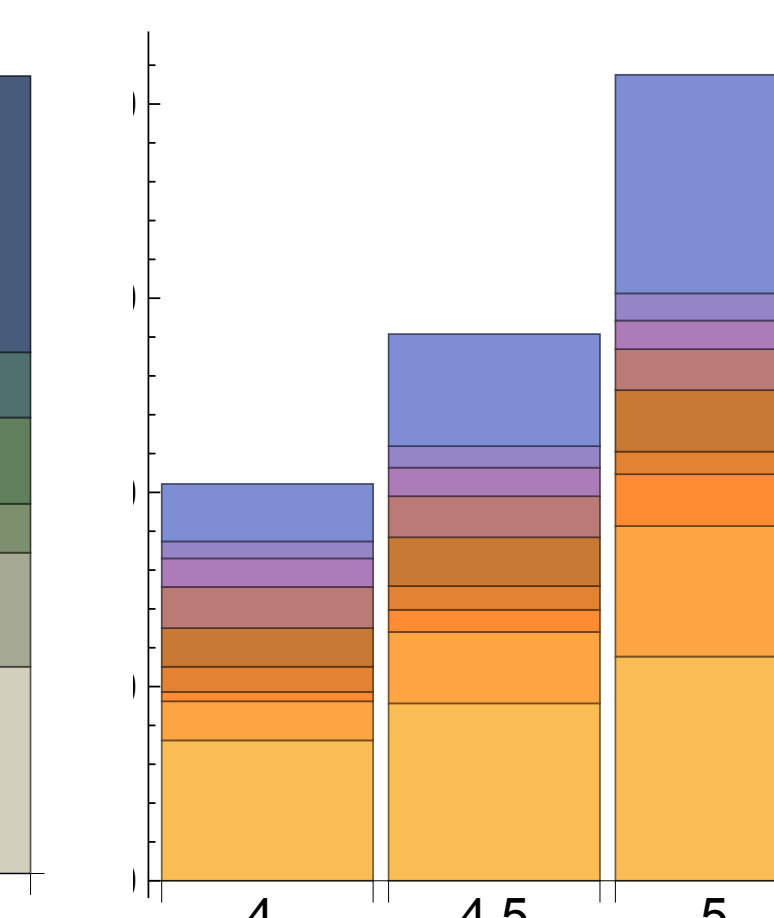
Use educational economies of scale to offer same services at reduced cost, for access to education. Very low completions.

Results – Three sectors of universities

Revenues per student

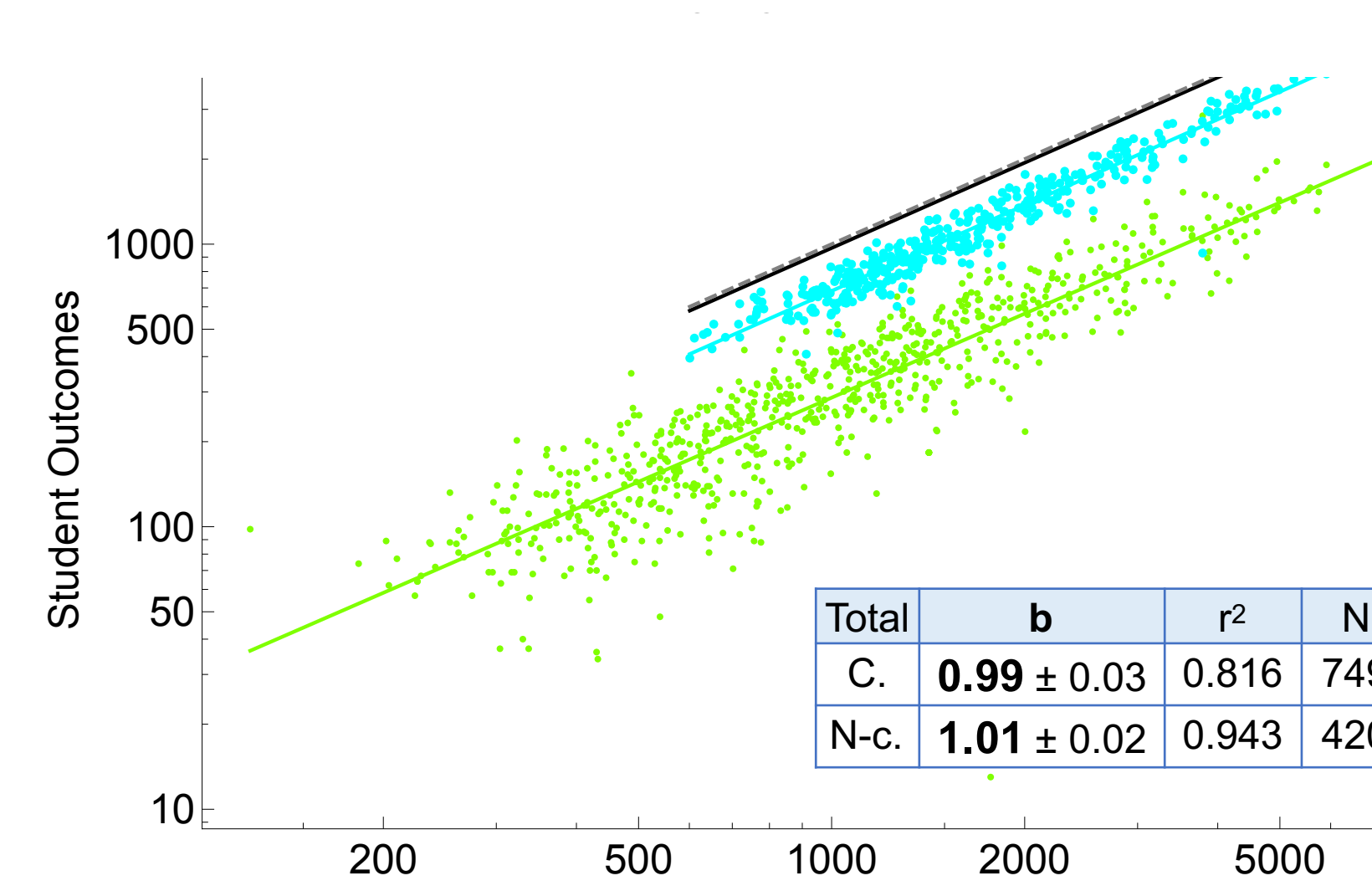
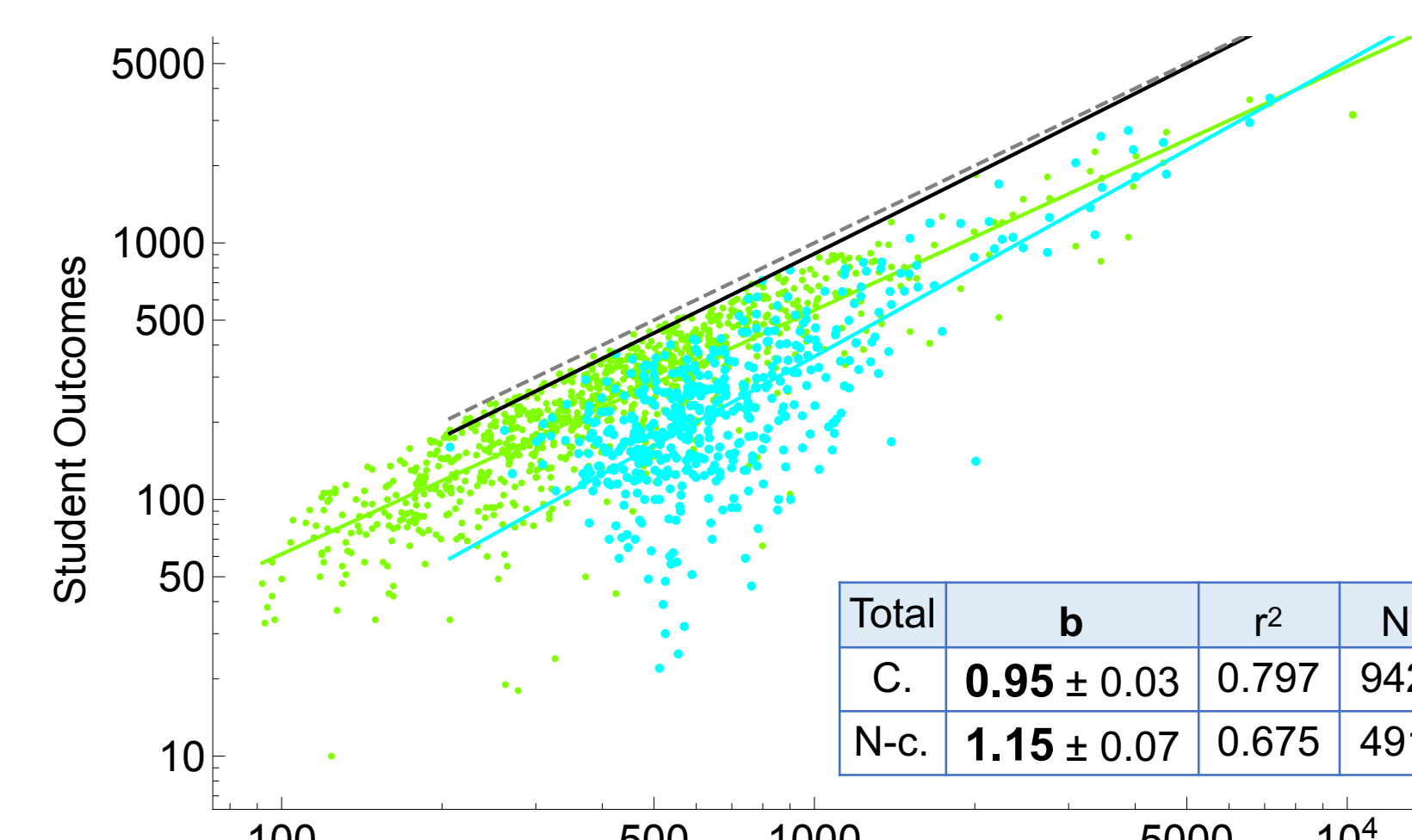
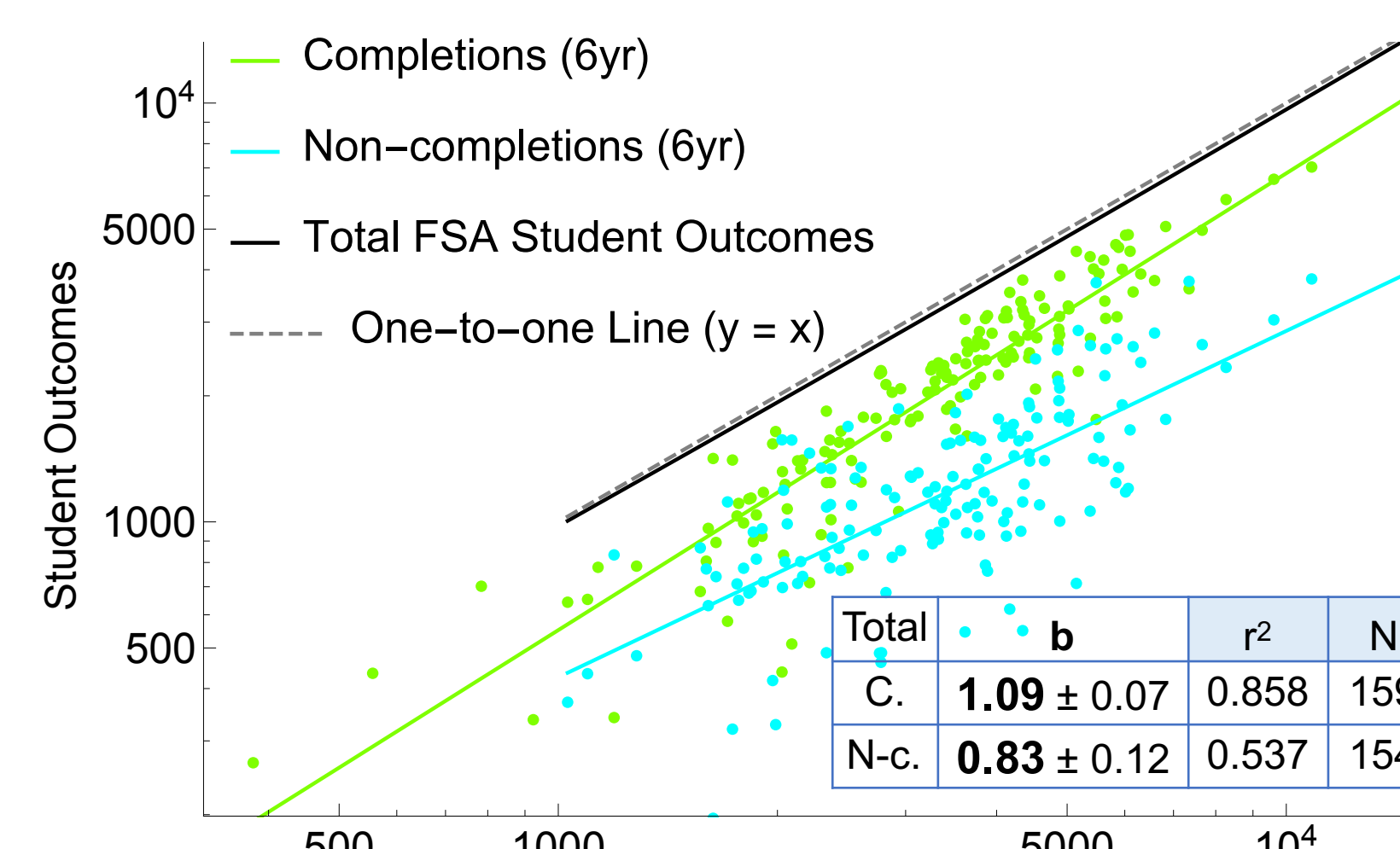


Expenditures per student



Extension – Completions

Completions (number of graduates within 6yrs) shown for FSA-receiving students. Synthesis with rev and exp is unfinished.



Discussion

1. Different economies of scale between sectors represent institutional optimization for different purposes. No evidence for bureaucracy overtaking productivity at scale.

2. At larger scales, research universities show increasing returns; larger liberal arts colleges trade off educational for financial performance, and community colleges gain efficiency.

3. In progress:

- Normalizing results to reflect "value-added" relative to student body composition
- Outlier analysis, research output variables
- Time-series analysis, growth implications

...to identify the organizational structures and their impact on observed scaling relationships, in order to suggest directions for institutional reform.

Acknowledgements

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¹West, G.B. (2017). Scale: The universal laws of growth, innovation, sustainability, and the pace of life in organisms, cities, economies, and companies. New York, Penguin Press

²West, G.B., Brown, J. H. and Enquist, B.J. (1997). A General Model for the Origin of Allometric Scaling Laws in Biology. Science, 276 (5309) 122-126.

³Bettencourt, L., Lobo, J., Helbing, D., Kühnert, C., and West, G.B. (2007). Growth, innovation, scaling, and the pace of life in cities. PNAS, 104 (17) 7301-7306.

⁴<http://www.deltacostproject.org/>

⁵<https://catalog.data.gov/dataset/college-scorecard>