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Technical Appendix to

HETEROGENEOUS CLASS SIZE EFFECTS: NEW EVIDENCE FROM A PANEL OF UNIVERSITY STUDENTS

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Appendix A: Input Adjustment

We present evidence that departments cannot adjust on all margins in response to aggregate changes in student enrolment. This opens up the possibility that changes in enrolment partially feed through into undesired changes in class size which may in turn affect student achievement as measured by end of year test scores. We focus first on inputs in the form of numbers of teaching faculty. We also distinguish between two types of student that can enrol on to courses offered by a given department d – either students can be registered on a degree programme offered by department d itself, or students can be enrolled on related programmes in other departments d' and their degree programme regulations allow them to take courses in department d. We therefore estimate the following specification for inputs into department d in academic year t (y_{dt}),

$$y_{dt} = \alpha_d + \beta_0 E_{dt} + \beta_1 R_{dt} + u_{dt}, \tag{8}$$

where y_{dt} refers to the number of teaching faculty, E_{dt} is the number of students enrolled in department d, and R_{dt} is the number of students enrolled in related departments. Note that R_{dt} is dt specific so that each department has a series of bilateral agreements with a subset of other departments over whether students registered on programmes offered by department d' are permitted to take courses organised and run by department d, and these agreements can change over time. By controlling for department fixed effects α_d we only exploit variation in year to year student enrolments and therefore shed light on whether and how student enrolments correlate with departmental inputs such as numbers of teaching faculty. We allow the error term u_{dt} to follow an AR(1) process where the autocorrelation coefficient is restricted to be the same across departments.

Table A1 presents the results. Column 1 shows that as the number of students enrolled in the department increases, the number of teaching faculty also significantly increases ($\hat{\beta}_0 > 0$). The magnitude of the coefficient implies if the number of students enrolled in department d were to increase by 17.7, this would be associated with there being one more faculty member teaching, as reported at the foot of Column 1. In contrast, there is no correlation between the number of teaching faculty and the number of students enrolled in related departments and so who could potentially attend courses offered by department d – we find $\hat{\beta}_1 \approx 0$ and $\hat{\beta}_0$ is significantly different to $\hat{\beta}_1$.

Columns 2 to 4 break this result down by faculty rank. We see that as more students enrol in department d the number of full and other professors that teach, significantly increases. As expected, the increase in enrolment of students registered with department d associated with one more full professor teaching (37.9) is larger than the increase in enrolment associated with either an associate or assistant professor teaching (26.4). In contrast, we again see that the number of teaching faculty is uncorrelated with students that enrol in related departments and so can

Table A1

Departmental Inputs and Student Enrolment
Prais-Winsten Regression Estimates

	Numbers of Teaching Faculty				Class Size	
Dependent Variable	(1) All Faculty	(2) Full Professors	(3) Other Professors	(4) Non Professors	(5a) Mean	(5b) Mean
Number of students enrolled in department	0.057** (0.029)	0.026** (0.010)	0.038* (0.021)	−0.007 (0.007)	0.112*** (0.014)	0.110*** (0.016)
Number of students enrolled in related departments	−0.006 (0.012)	−0.000 (0.005)	−0.004 (0.007)	−0.000 (0.002)	0.025** (0.011)	0.026** (0.011)
Number of courses offered by department						0.044 (0.030)
Number of programmes offered by department						−0.011 (0.418)
Mean of dependent variable	13.4	4.27	7.56	1.43	26.4	26.4
Test: equal enrolment effects (p-value)	[0.024]	[0.030]	[0.050]	[0.410]	[0.000]	[0.000]
Number of own department enrollees required to increase outcome by one unit	17.7	37.9	26.4	−145	8.95	9.09
Number of related department enrollees required to increase outcome by one unit	–	–	–	–	40.0	37.8
Department fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations (department-year)	105	105	105	105	105	105

Notes. *** denotes significance at 1%, ** at 5%, and * at 10%. Panel corrected standard errors are calculated using a Prais-Winsten regression. This allows the error terms to be department specific heteroscedastic, and contemporaneously correlated across departments. A common AR(1) process is assumed for all departments. All observations are at the department-year level. Observations for 2 of the 23 departments in which students can be enrolled are dropped either because that department only offers its own courses in the last year of data, or because the department always offers all courses jointly with other departments. Hence the sample is based on a balanced panel of 21 departments over five academic years (1999/00–2003/4). The number of students enrolled in related departments is defined to be those students that are eligible to take any given course in the department for credit as part of their graduate degree programme. We first calculate this enrolment for each module within the department and then take its average over all courses within the department for each academic year. All faculty numbers refer to faculty that teach on at least one course during the academic year. In Column 4 non professors refers to teaching faculty that do not have a doctorate degree. In Columns 5a and 5b, class sizes are averages within the department-year. Hence in these columns we weight observations by the number of courses in the department that academic year. Weighted means of class size are then reported at the foot of the Table. At the foot of the Table we also report the p-value of a t-test of equality of the coefficients on own department and outside department enrolments. We also report the implied inverse of the coefficients on own department and outside department enrolments to calculate the change in these variables that are associated with a one unit increase in each dependent variable.

potentially attend courses offered by department *d*. Finally, Column 4 shows that enrolment for neither source – in department *d* or related departments d' – affects the number of non-professors that teach. [1]

Taken together these results show that although departmental inputs in terms of teaching faculty do partially adjust to student enrolments, they do so only in response to students that enrol into department *d* itself and are unrelated to those students that can enrol on to

[1] These figures are in line with anecdotal evidence given to us by heads of department suggesting that if around 25 more students enrol in programmes in the department, the department is often able to negotiate additional resources from the university to hire one more faculty member to teach.

Table A2

Robustness Checks

	Course Omitted Variables		
	(1) Course Difficulty	(2) Course Fixed Effects	(3) Time Variation
Class size	−0.015***	−0.006*	−0.014**
	(0.003)	(0.004)	(0.007)
Share of students that are re-sitting the course	0.747		
	(2.75)		
Implied Effect Size	−0.108***	−0.042*	−0.045**
	(0.020)	(0.025)	(0.023)
	[−0.148, −0.069]	[−0.091, 0.007]	[−0.090, −0.001]
Fixed Effect	Student, Faculty	Course	Course
Adjusted R-squared	0.618	0.089	0.630
Observations (clusters)	40,851 (1,775)	40,851	1,775 (116)

Notes. *** denotes significance at 1%, ** at 5%, and * at 10%. Dependent variable: test score. Standard errors are clustered Columns 1 and 3, and robustly estimated in Column 2. In Columns 1 and 2 the dependent variable is the student's test score on the course, and observations are at the student-course year level. In Column 3 the dependent variable is the average test score across students on the course, observations are at the course-year level. In Column 1 (3) the standard errors are clustered by course-year (department-year) and in Column 3 they are robustly estimated. We control for the number of faculty that teach on the course, the share of them that are full professors, the total number of credits obtained for completing the course, the share of the overall mark that is attributed to the final exam, and the following course-year characteristics – the share of women, the mean age of students, the standard deviation in age of students and the ethnic fragmentation among students, where the ethnicity of each student is classified as white, black, Asian, Chinese or other, the fragmentation of students by department, the share of students who completed their undergraduate studies at the same institution, and the share of British students. In Column 1 we additionally control for a complete series of faculty dummies, such that each faculty dummy is equal to one if faculty member j teaches on the course-year, and zero otherwise. In Columns 2 and 3 we control for a complete series of course fixed effects rather than student fixed effects. The foot of each column reports the implied effect size, its standard error, and the associated 95% confidence interval.

programmes in department d' are are eligible to enrol on to courses offered by department d. In other words the resources departments have to finance teaching faculty appear to be related to the number of students enrolled in the department (E_{dt}), not directly related to the number of students actually taught.

However, both sources of student – namely those enrolled into department d and those enrolled in related departments – influence class sizes in courses offered by department d. More formally, Column 5a shows that student enrolments in the own and related departments are both significantly associated with larger class sizes in courses organised by department d. The coefficients imply that if 8.95 more students enrol in department d then class size will increase by one on the average course offered by department d, and class sizes will on average increase by one if 40 more students enrol in related departments. Column 5b shows these effects remain controlling for the number of courses and programmes offered by department d. Hence even if departments respond to increased enrolment by adjusting along these margins, these adjustments do not appear to be sufficient to prevent class sizes from increasing overall.[2]

[2] Note that on average a department offers 16 courses, of which students take around 4 or 5. Hence we expect β_0 to be far smaller than one in the class size regressions in Columns 5a and 5b. Second, although students in related departments can potentially take courses offered by the department, many of them will choose not to do so. Hence we also expect β_1 to be far smaller than β_0 in absolute value.

These results show that departments can adjust inputs to a greater extent in response to changes in their own student enrolment, than in response to changes in enrolment in related departments ($|\beta_0| \geqslant |\beta_1|$). However, class sizes are positively correlated with both sources of student enrolment. Taken together this implies that student enrolments in department d' impose a negative externality on to class sizes in related department d. This negative externality stems from the fact that

(*i*) departments cannot deny students from related departments enrolling on to their courses;
(*ii*) the resources departments command for organising and running their courses relate to the number of students enrolled in the department, not the numbers of students actually taught.[3]

[3] These results beg the question why departments are allowed to impose this negative externality on to each other? Although this lies outside the scope of this article, we speculate it may relate to there being potentially a very large number of bilateral agreements that would need to be considered for these externalities to be internalised – in this university there are 24 departments and so potentially up to ($\frac{1}{2}(24 \times 23)$) bilateral agreements across departments. Moreover, the flows of students from department d to d' need not be symmetric to flows from d' to d. In addition, it is far more straightforward from an accounting perspective to reward department on the basis of students enrolled on programmes offered by the department, rather than based on the number of students actually taught.