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The Effects of Class Size on Student Grades at a Public University

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Abstract

We model how class size affects the grade higher education students earn and we test the model using an ordinal logit with and without fixed effects on over 760,000 undergraduate observations from a northeastern public university. We find that class size negatively affects grades for a variety of specifications and subsets of the data, as well as for the whole data set from this school. The specifications tested hold constant for academic department, peer effects (relative ability in class), student ability, level of student, gender, minority status, and other factors. Average grade point declines as class size increases, precipitously up to class sizes of twenty, and more gradually but monotonically through larger class sizes. JEL Classification; I21

Keywords

Economics Of Scale, Educational Economics, Student Performance, Logit Analysis, Fixed Effects Models

The Effects of Class Size on Student Achievement in Higher Education[a]

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ABSTRACT

We model how class size affects the grade higher education students earn and we test the model using an ordinal logit with and without fixed effects on over 760,000 undergraduate observations from a northeastern public university. We find that class size negatively affects grades for a variety of specifications and subsets of the data, as well as for the whole population. Average grade point declines as class size increases, precipitously up to class sizes of twenty, and more gradually but monotonically through larger class sizes. Evidence suggests that this phenomena is not exclusively caused by a "small-class" effect.

INTRODUCTION

Budget pressures in many states have forced them to seek efficiencies in one area of their expenditures, higher education. Thus, we find concerns about graduation rates and the average time-to-degree performance of universities (NYS Executive Budget, 2005-06), the increasing use of part-time and non-tenure track faculty (Ehrenberg, 2004), increasing tuition, fees, and corporate sponsorship (Rizzo, 2004), and the pressure to achieve class size economies of scale (Toth and Montagne, 2002; and Nelson and Hevert, 1992; Moore, 2003). Economies of scale are a particularly attractive possibility for cost reduction at schools experiencing increasing demands for education and where the quality of the incoming students appears to be rising or steady. Schools often look to spreading the costs of a faculty over more students by increasing class sizes or by increasing workload (number of courses taught per term). This latter method is resisted by faculty senates, unions, and often trustees, leaving the easier option of marginally increasing class size as a way to realize economies of scale.

But the questions arises, is the education received in a large class the same as that in a small class? To bring further light on the economics of scale question, we estimate the influence of class size on student achievement in higher education. The K-12 literature on class size suggests class size negatively influences student outcomes though this is not universally held. In the case of higher education, the evidence is even more mixed.

In this paper, we present a model of grades and test this model using a very large dataset from a medium-sized public research university. Applying a logistic regression with and without a fixed effects model we find that class size is an important variable in predicting grades and that the functional form of the relationship is consistent with the theoretical model developed by Glass et al. (1982) to explain the negative effect of class grades on K-12 student performance. We explore several specifications, additional models, various proxies for a key variable (student ability), and how the effect of class size on grades differs for advance placement, at-risk, underrepresented and female undergraduates. We also test the results by academic department. In all cases we find class size negatively affects student grades. In the few exceptions (several academic departments), the class size coefficient is not statistically significantly different from zero.

BACKGROUND

K-12 studies.

By the 1970's there was near consensus in the educational research community that class size had little effect on student achievement.[1] However, Glass and Smith, in a series of articles beginning in the late 1970s (Glass and Smith, 1979; Smith and Glass, 1980; Glass, McGraw and Smith, 1981) presented a theoretical model suggesting that the functional form of the relationship between class size and student achievement should be negatively sloped and concave.[2] This model has become a basis for further normative discussion on whether, or how, class sizes should vary[3]. Glass and Smith also presented the results of their own meta-analysis of studies looking at the effect of class size sustaining the negative logarithmic relationship between class size and student performance.[4] Given this apparently beneficial evidence of smaller class sizes, several states designed experiments to replicate Glass's et al. findings.[5] In 2003, a number of articles appeared in a special editions of The Economic Journal (V113, February) concentrating on U.S. and U.K. experiences and summarizing a vast amount of literature. The papers therein concentrate on data from K-12 to examine this question (see Dustmann, 2003).

Even though there is now strong evidence that smaller class sizes improve student performance, at least in some circumstances, and using common methodologies to test the data, the debate continues. In particular, economists point out the need to weigh the costs of achieving smaller classes versus the costs of improving student achievement by other means. (Nelson and Hevert, 1992; Maxwell and Lopus, 1995; and Hanushek, 2003).[6] Further methodological challenges have possibly weakened these claims (Maasoum, Millmet, and Rangaprasad, 2003; Kruger, 2003).

Class Size at the College Level

Though there is debate about the extent of benefits small classes bring, or how much it costs to achieve, there is at least some agreement in the K-12 literature that using certain tests, class size matters in some circumstances. No such agreement exists in the literature concerning the effect of class size in higher education. Indeed, in two well-respected reviews of the literature (William et al., 1985; Pascarella and Terenzini, 1991), the authors conclude that the overall evidence suggests that class size plays no or little influence on student achievement. This however has not quelled the debate. McKeachie (1980) and McKeachie et al, (1990) have presented arguments that class size is the primary environmental variable college faculty must contend with when developing effective teaching strategies. They argue that while class size may not be significant in courses best suited for lecture style learning, courses geared toward promoting critical thinking and advanced problem solving are best taught in a smaller classroom environment

McKeachie's view is consistent with findings that suggest that students' (and professors') motivation and attitude toward learning tends to be more negatively affected by larger classes. (Feldman, 1984; Bolander, 1973; McConnell and Sosin, 1984; Spahn, 1999) Though they may have learned the material, students do not feel as satisfied with the classroom experience as they would have in smaller classes, suggesting that some learning opportunities may have been lost. A summary of more recent research is given in Toth and Montagne (2002) and Kwantlen University (2004). Toth and Montagne summarize eight studies from 1990 to 1999 which find mixed results for three studies, positive increases for outcomes or class sizes are reduced for two, outcomes are better in large classes for one, and no significant results for two studies. Kwantlen summarizes other recent research showing no relationship between class size and achievement; negative relationship (larger classes yield less student achievement); larger classes enhance student outcome; large classes are as effective as smaller classes; and that student characteristics and instructional design are important factors. Kwantlen quotes an Ohio State website "Research Results: Mixed" and concludes that for courses that emphasize recall of facts, large classes are equally effective as small classes; for courses emphasizing "problem-solving, critical thinking, long-term retention, and attitude toward the discipline… small classes are more successful." (Kwantlen, 2004, pg 3).

Also, there is some further evidence that class size may matter in some courses or disciplines, but not in others. Raimondo et al (1990) found that students in smaller sized introductory macroeconomic courses did better in subsequent intermediate macroeconomic courses even though the same was not true when conducting the analysis for microeconomic courses. They suggest, consistent with McKeachie argument, that smaller classroom environments enhance the more wide-ranging, non-formula based knowledge necessary for understanding macroeconomic principles and there is argument for small classes in the performing arts where skills and techniques are individually taught.[7]

There is also a debate about how to measure student outcomes at the university level. In the K-12 studies, pre and post testing is ubiquitous: the change in student performance, relative to the improvement found in students not subjected to the whatever the variation in teaching method or classroom that is under study, is attributed to the changed element. Investigators have both a control group, and a tested, agreed upon metric. We lack control groups and an agreed upon metric in most relevant studies focusing on higher education. Hence, the increased student performance in higher education can be measured by a variety of metrics: grade in the class under study or a subsequent course, performance on a graduate admissions exam, graduation or retention rates, percentage going on to graduate or professional work, self reported "satisfaction" with a course, or even salary or wealth at some time post graduation. There are numerous problems associated with measurement of many of these and as one moves further away through time from the course under study, many extraneous factors cloud the conclusion. Finally, much of the K-12 testing is done for specific academic subjects, such as chemistry or reading comprehension. There is no comparable single set of before and after test scores that is applicable across academic subjects in higher education.

In an attempt to contribute to the debate, in this paper we present findings, based on a larger dataset from a single institution, of how class size effects student outcomes, as measured by grades, after controlling for other relevant student and course characteristics. We motivate the discussion using the economic theory of wages as a way to think about the nature of grades from a student's perspective.

THE MODEL

Labor theory (Mincer, 1974) suggests that earnings or wages depend upon ability, education, and experience. Applying this to higher education, we postulate the following story:

Students attend institutions of higher education to gain experience and education. They pay for this education through tuition, fees, living expenses, living conditions, and foregone wages. At the end of some period of study they are rewarded with some sort of certification, which in turn may result in earning higher lifetime incomes and increased non-monetary utility. During this time they are paid by a form of scrip, that is, credit hours and individual grades, which when amassed, indicate the extent and quality of their performance in school. When accumulated sufficiently, the script can be used to "buy" a certificate or degree. The quality of the script, and indeed its acceptability in buying a degree, is represented by the course grade. Since there often are grade point standards, course grades have an additional screening importance.

We can consider a course grade then, as a form of reward or payment denoting the quality of the script for the performance the student achieved in a specific course. We define W as the wage, and hypothesize that a student's wage (grade) can be explained by her ability and experience, controlling for individual-specific and environmental characteristics. We thus write for the *i th* student in the *j th* class during period t:

(1) $W_{ijt} = b_0 + \phi(E_{it})'\beta + \theta(A_{it})'\Gamma + Z_{it}'\lambda + V_{jt}'\kappa$

Here, *W* represents the wage, or, in this case, the grade, *E* the *i th* student's experience (e.g. level in college), *A* represents ability, *Z* a vector of student related variables, and *V* is a vector of environmental, faculty, and subject matter factors including class size (CS). ϕ(E) and θ(A) are allowed to be polynomials in E and A, and β, Γ, λ, and κ are vectors of parameters to be estimated while b_0 denotes a vector of constants, also to be estimated.

The null hypothesis is that class size does not affect student learning or performance and this would be reflected in the stability of grade distributions over various class sizes for various subjects, while holding the other independent variables constant.

DATA

This study was conducted using data from a highly selective research institution (new Carnegie classification) located in a small city in the Northeast. There is one observation per student per course for each semester analyzed totaling 998,898 observations. The population consists of all undergraduate students for the period Fall 1992 through Spring 2004. Students take courses in five schools; Arts and Sciences, Education and Human Development, Engineering, Nursing, and Management. The dependent variable is the grade a student receives in a course. Only grades that count toward a student's GPA are considered; thus incompletes and withdrawals are dropped from the analysis reducing the number of observations. Further reductions incurred when certain variables were censored. The resulting basic overall dataset contains over 764,000 observations. The variables and data are discussed further in Appendix A.

MODEL ESTIMATION

The model represented by Equation (1) was estimated via the logistic procedure in SAS, version 9.0. Initially, the model was developed using one fifth of the data. A full specification of Equation (1) including a large number of proxies for several variables and polynomials in experience, ability and class size, was then estimated. We also tested a number of demographic variables such as race, EOP, talent level, registration as a degree seeker, and county of residence. Other variables explored included faculty rank, a variable for majors(s), whether the course was a laboratory course, and whether the course had a discussion section and used teaching assistants. The model was then simplified using both the forward and backward routines in SAS and statistical tests for the significance of explanatory variables. A simplified model with a limited number of observations - limited by deleting the top and bottom class sizes, was next tested on a second subset of the data. After this, three variants of the model given by Equation (1) were estimated using the full dataset of 672,489 observations, and various sub-datasets as explained below.

RESULTS

The Base Model

We begin by presenting the results of a model of grades (W) as explained by relative ability (A_r), the class mean grade, class size (CS), ($\overline{W}_C$),the departmental mean grade ($\overline{W}_D$), initial objective ability (SATM, SATV), the presence of advanced placement courses in high school (AP), experience on campus as a student (entered as a freshman (F), and student level (L), gender (G), minority (M), and time (Y). The model (sans subscripts) is given as

(2)

$$W = b_0 + \beta_1 A_r + \beta_2 A_r^2 + \beta_3 \overline{W_C} + \beta_4 \overline{W_D} + \beta_5 CS + \beta_6 CS^2 + \beta_7 SATM + \beta_8 F + \beta_9 SATV +$$

$$\beta_{10} G + \beta_{11} M + \beta_{12} L + \beta_{13} Y + \beta_{14} AP + \beta_{15} CS * G$$

The results are shown in Table 1. The first numeric column is for the full dataset whereas the next two columns show the results for two sub samples of the data. The first of these, labeled IQ1, is for the 342,289 observations lying within the interquartile range of class sizes; the second, IQ2, uses the 271,941 observations lying within the interquartile range of grades. This model, using these three subsets of data explains the observed data well. The "G" statistic, a ratio of the likelihoods, is distributed chi square with 15 degrees of freedom. The critical value at $P_R = 0.005$ is 32.801, and our G values greatly exceed this (see Table 1). Note that we also estimated this model stepwise and all the reported variables entered into the model and contribute significantly to the likelihood value. The c statistic's theoretical range is from 0.0 to 1.0 (0.5 or lower indicates that the model's predictions are no better than chance). Our regression results are 0.765, 0.773, and 0.731 (see Table 1) indicating a high discriminatory power of the model. The Tau-a is a test of the null hypothesis that we have an improperly specified model. Calculated Tau-a values of under 0.05 indicate failure to reject the null hypothesis. The calculated values are 0.450, 0.465, and 0.389. In summary, the model explains the observed data very well indeed

Turning next to the individual parameters from the logistics regression we find that all independent variables (with one exception for the time variable), including class size, have a statistically significant influence on grades, as all the p values are less than .0001. Note that Table 1 reports standard errors. Experience and ability are positively related to grade. Minority students do less well than non-minorities, females and those with high SAT scores do better but females do worse in larger classes (CS*G is negative). The departmental mean grade has the largest single impact on grades. This indicates that further work in this area should account for departmental grading culture, traditions, and the material presented as McKeachie suggests.

The chief result is that class size enters all estimations with a negative value (-0.007, -0. 012, -0.008 for each of the three datasets (see Table 1)). Note also the positive estimates of the squared term, CS^2, are consistent with the concave model suggested by Glan et.al. Therefore, the null hypothesis that class size does not matter can be rejected. We also found this result to be robust as to variations in other proxies for experience, ability, department, faculty and for other classroom environmental variables. Further, the standard errors on the class size terms are relatively small (.00022, .000102, and .000038 respectively). The coefficients at plus or minus two standard errors for class size thus range from –0.002014 to –0.001926, -0.004964 to –0.004556, and –0.002306 to –0.002154; all negative and relatively narrow ranges.

One could argue that the results are determined by the differing social structures in small versus large classes and that faculty are reluctant to give poor grades in small classes but more willing to award low grades to more anonymous students in large classes. To test if this is what drives our results, we re-estimated our model for other subsets of the data (the mid 90% and 80%, as well as for successively larger minimum class size cut-offs, and again for successively smaller maximum class size cut-offs). These results (Table 2) show the parameters on CS are consistently statistically significantly negative, ceterus paribus.[8]

The analysis, using an abbreviated model, was next extended to ten diverse departments, Economics, Psychology, Political Science, Chemistry, Computer Science, English, History, Management, Mathematics and Music. These results also indicate class size has a negative impact in seven and a non-significant effect in the other three departments (see Table 3). Note further, the significant coefficients on class size are approximately of the same magnitude across departments, ranging from 0.001 to 0.007 (Mathematics to Music). Note also, while women do better overall (see Tables 1 and 3), they do worse in Economics and Chemistry.

In summary, all of these results sustain the view that the effect of class size on grades is negative over a wide range of class sizes and departments, holding other demographic and student variables constant.

Next we show the results of analyzing a subset of data graphically. Figures 1 and 2 show average GPA by class size for total enrolment. The first deals with all classes, the second with classes sized greater than five. Again, the message is that large classes have a high probability of lower grades than smaller classes. Note that the probabilities fall rapidly for classes up to about 20 to 40 students and much more gradually thereafter. Thus, if grades are important, there is less of a decline in the probability of high grades when moving from classes of size 60 to 70 than for increasing class sizes from ten to twenty.

The Fixed Effects Model

If one treats the data as a panel data set, where the individual student is the unit of observation then a fixed effects model can be given as:

$$(3) \qquad W_{itj} = \beta_0 + \beta_1 + \beta_t + \beta_1 E_{it} + \beta_2 A_{it} + \beta_3 CS_j + \beta_4 \overline{W}_{DJ}$$

Here β_i is the student fixed effect and β_t the semester fixed effect. These two variables allow us to control for individual attributes not explicitly contained in the experience (level) and relative ability variables (which probably evolve over time), and time fixed effects, which control for grade inflation, if present. Initially, we estimate the model using the proportional odds assumption for ordinal logistic regression. That is, the marginal effects between an A minus and a B plus is the same as the marginal effects between any other grade pair, say B minus and C plus.

We estimate a polynomial variant of Equation (3) in both fixed effects and no fixed effects sub-variations. These are Models 1 and 2 of Table 4. In the first Model, the data was for 10,000 students covering 167,928 student grades. The data was differenced by subtracting the average grade the student received from the individual grade; hence, a fixed effects model. Model 2 in Table 4 is for the individual student-grades for the 10,000 students and is shown for comparison. The chief result is that class size again is strongly negative with coefficient values that are one order of magnitude larger than ability or experience. A test of the proportional odds assumption however fails with a p-value of less .0001.

Next, we relaxed the assumption of proportional odds and we estimated a binary fix effects model of equation (3) for a different random sample of 10,000 students chosen from the 167,928 observations. The results are reported in Table 5. Again, the model includes an experience variable, an ability variable to allow for time varying student ability, a departmental variable, and a class size variable. All fixed student characteristics are differenced out against the individual students' mean value. The binary logit estimates the probability at each grade level. For example, the probability of getting a B plus or better versus the probability of getting a B or lower. Note that the three runs bifurcating the probabilities at F versus D or better, D or lower versus C minus or better, and C minus or lower versus C or better did not converge and are thus not reported. We believe that this has to do with the smaller number of observations in this subset at those grade levels. Note that again, the log of class size has a negative coefficient that the departmental mean grade has the largest impact on grades, and that better students improve with experience. Both of these results of fixed effects models are consistent with and confirm the results from the ordinal logit estimation reported above in Tables 1, 2, and 3.

DISCUSSION

This study of grades in higher education, using various models relating environment, ability, and experience to undergraduate course grades, shows that class size has a negative relationship to grades and that while the value of the class size coefficient differs across different departments and subsets of data, it is negative in all cases.

Though we have found a negative relationship between grades and class size, we cannot conclude to the extent that grades are but a proxy for knowledge, that students learn more in smaller classes.[9] Nor do we offer a reason for our result. As Glan et al (1982) argued, attitudinal changes among faculty and students may account for the observed results. Recall that

McKeachie (1999) suggests that optimal teaching methods and class sizes vary by subject matter and level. He also reminds us that students may self select class sizes whenever possible. Alternatively, as the K-12 literature suggests, the attention faculty can give to individual students and the intensity of engagement in learning that occurs in small classes could account for the results. We do observe however, that the negative relationship persists even when we account for variations in data subsets, models, included variables, and a statistical methodology: a robust result.

Most importantly, from an economic perspective, we have not addressed the marginal costs of moving to smaller classes. Nor have we quantified the cost of lower grades. If large classes negatively affect student persistence as well as grades, this might suggest an additional non-market cost exists for relying on large classes; lost revenue due to the decrease student retention and the loss of reputation caused by lower graduation rates. Indeed, if we could quantify the indirect costs associated with loss of reputation, and the direct costs of losing tuition and other revenue because of lower retention rates, as well as the cost saving of using larger classes to teach courses, we might estimate an optimal class size for the institution. From society's point of view, any institutional net benefits must be set against the long-term costs associated with poorer course performance resulting from larger classes. The evidence presented in this paper suggests class size mostly influences the likelihood of getting an A; the increase in the likelihood of failing rising only modestly as class size increases. So it is likely that if class size does greatly influence persistence, it will do so by promoting voluntary rather than non-voluntary dropping out. Consequently, future studies might look at the effect class size has on both kinds of attrition.

TABLE 1

Estimated Coefficients via Maximum Likelihood-Logistics Procedures
Dependent Variable: Grade (W)

Variable/Statistic	All Data		IQ1		IQ2	
	COEF	SE	COEF	SE	COEF	SE
Relative Ability (A_r)	0.502	0.001	0.532	0.002	0.428	0.002
Relative Ability Squared (A_r^2)	-0.008	0.0003	-0.007	0.0004	-0.022	0.0005
Class Mean $(\overline{W}_c)$	1.376	0.005	2.762	0.009	1.448	0.008
Dept. Mean Grade $(\overline{W}_D)$	1.253	0.010	0.640	0.015	1.297	0.015
Class Size (CS)	-0.007	0.00007	-0.012	0.0005	-0.008	0.0001
Class Size (CS^2)	0.00002	1.6×10^{-7}	0.00006	3.4×10^{-6}	0.00002	2.9×10^{-7}
Math SAT (SATM)	0.098	0.003	0.089	0.004	0.054	0.004
Entered as Freshman (F)	0.194	0.006	0.129	0.008	0.240	0.010
Verbal SAT (SATV)	0.077	0.002	0.082	0.003	0.053	0.004
Female (G)	0.278	0.007	0.343	0.014	0.198	0.010
Minority (M)	-0.228	0.008	-0.200	0.011	-0.228	0.012
Level (L)	0.037	0.001	0.006	0.002	0.019	0.002
Time (Y)	0.002	0.0003	0.001*	0.0044*	0.004	0.0006
AP	0.240	0.005	0.240	0.007	0.144	0.008
CS*G	-0.001	0.00004	-0.003	0.0002	-0.0009	0.00007
N	672,489		342,289		271,941	
Tau-a	0.450		0.465		0.389	
c	0.765		0.773		0.731	
Difference (G)	359,295		197,658		105,486	
P_R > Chi Squared	0.0001		0.0001		0.0001	

IQ 1: Interquartile class size data.
IQ 2: Interquartile grade data.
* Not statistically significant by an X^2 test.

TABLE 2
Class Size Coefficients for Various
Subsets of Data
(Standard Errors in Parenthesis)

Dataset	No. of observations	CS	CS^2
Total Dataset	72,489	-0.00700	0.000015
	(100%)	(0.00007)	$(1.64x10^{-7})$
Inter			
90%	611,330	-0.00851	0.000024
	(90.9%)	(0.00012)	$(3.85x10^{-7})$
80%	543,965	-0.00955	0.000032
	(80.9%)	(0.00017)	$(6.64x10^{-7})$
Quartile	342,289	-0.0123	0.00006
	(50.9%)	(0.00054)	$(3.42x10^{-6})$
For all classes greater than			
5 students	657,253	-0.00566	0.000012
	(97.7%)	(0.00007)	$(1.65x10^{-7})$
10 students	642,250	-0.00507	0.000011
	(95.5%)	(0.00007)	$(1.67x10^{-7})$
15 students	617,071	-0.00455	$9.57x10^{-6}$
	(91.8%)	(0.00007)	$(1.69x10^{-7})$
20 students	583,815	-0.00412	$8.69x10^{-6}$
	(86.8%)	(0.00007)	$(1.73x10^{-7})$
Less than			
500 students	672,010	-0.00717	0.000015
	(99.9%)	(0.00007)	$(1.68x10^{-7})$
450 students	664,322	-0.00811	0.000019
	(98.7%)	(0.00008)	$(1.99x10^{-7})$
400 students	655,164	-0.00902	0.000022
	(97.4%)	(0.00008)	$(2.43x10^{-7})$
350 students	638,186	-0.0117	0.000033
	(94.9%)	(0.00011)	$(3.48x10^{-7})$
300 students	622,365	-0.0145	0.000045
	(92.5%)	(0.00013)	$(4.72x10^{-7})$
250 students	602,641	-0.0171	0.000058
	(84.6%)	(0.00015)	$(5.84x10^{-7})$
200 students	530,056	-0.0238	0.000101
	(78.8%)	(0.00021)	$(1.04x10^{-6})$
150 students	487,061	-0.0360	0.00020
	(72.4%)	(0.00031)	$(2.04x10^{-6})$

TABLE 3
Estimated Coefficients by Department

	Economics	Psychology	Political Sc.	Chemistry	Computer Sc.	English	History	Mgmt	Math	Music
Relative Ability	0.618	0.540	0.556	0.585	0.531	0.417	0.501	0.642	0.562	0.211
Class Size	-0.003450	-0.000289	0.0001*	-0.00137	-0.0002*	-0.0025	0.0002*	-0.00097	-0.00055	-0.00722
Entered as Freshman	0.297	0.597	0.312	0.424	0.197	0.217	0.296	0.294	0.257	0.490
Female	-0.073	0.162	0.029*	-0.259	0.511	0.200	0.183	-0.001*	0.189	0.151
Minority	-0.657	-0.625	-0.588	-0.556	-0.574	-0.517	-0.401	-0.556	-0.239	-0.513
Level	0.039	0.139	0.143	0.108	0.105	0.018	0.118	0.053	0.024	0.068
Year	-0.012	0.001*	0.006	0.006	0.0*	0.010	-0.004	0.005	-0.015	0.010
N	38,199	60,392	23,601	31,028	26,806	67,014	36,953	70,122	38,044	28,994
Tau-a	0.421	0.419	0.384	0.428	0.378	0.297	0.364	0.375	0.401	0.265
C	0.737	0.742	0.726	0.744	0.719	0.687	0.713	0.722	0.724	0.712

* Not statistically significant.

TABLE 4

Ordinal Logit Estimation of Data by Students: Dependent Variable is Grade
Estimated Coefficients via Maximum Likelihood-Logistics Procedure
(Values in Parenthesis are Standard Errors)

Variable/Statistic	Model 1: Fixed Effects		Model 2: No Fixed Effects	
Experience	0.184	(0.035)	0.329	(0.031)
Experience Squared	-0.024	(0.008)	-0.067	(0.008)
Experience Cubed	0.002*	(0.001)	0.005	(0.001)
Ability	0.183	(0.011)	0.871	(0.009)
Ability Squared	-0.018	(0.005)	-0.102	(0.004)
Ability Cubed	0.002	(0.001)	0.005	(0.0004)
Class Size	-2.195	(0.209)	-2.341	(0.190)
Class Size Squared	0.324	(0.052)	0.361	(0.048)
Class Size Cubed	-0.017	(0.004)	-0.019	(0.004)
Department	2.577	(0.021)	2.205	(0.017)
Proportion of fixed Effects significant at <.005 or better	0.673			
N	167,928		167,928	
-2 Log Likelihood				
Intercept only	625,261		625,261	
Full Model	512,487		547,065	

All Wald Chi square statistics <0.005 except as noted below.

* Chi Square = 0.0130; marginally significant

Note: a modified dataset with fewer observations was used for this test.

TABLE 5

Estimated Coefficients via Fixed Effects Binary Logit Model
(t - statistics in parentheses)

Variable/statistic	C or lower Versus C+ or better	C+ or lower Versus B- or better	B- or lower Versus B or better	B or lower Versus B+ or better	B+ or lower Versus A- or better	A- or lower versus A	Ordinal Non-fixed effects
Ability	0.176 (6.50)	0.184 (7.14)	0.149 (6.13)	0.169 (6.89)	0.153 (5.91)	0.142 (4.68)	0.620 (219.75)
Experience	NS	0.027 (1.29)	0.57 (3.09)	0.069 (4.08)	0.076 (4.48)	0.063 (3.33)	0.067 (32.25)
Log class size	-0.445 (-9.38)	-0.450 (-10.62)	-0.401 (-10.79)	-0.426 (-12.38)	-0.441 (-12.85)	-0.504 (-13.11)	-0.338 (-68.6)
Department	3.060 (17.59)	3.257 (20.22)	2.843 (20.09)	2.762 (21.08)	2.370 (18.63)	1.958 (14.12)	2.174 (127.84)
N	10,000	10,000	10,000	10,000	10,000	10,000	167,928
Percent β_I significant at							
0.01	42	71	80	88	89	81	
0.05	48	71	80	88	89	81	
0.10	51	71	80	88	89	81	

NS = not statistically significantly different from zero.

Figure One
Cumulative Probabilty of Grades Received vs. Class Size

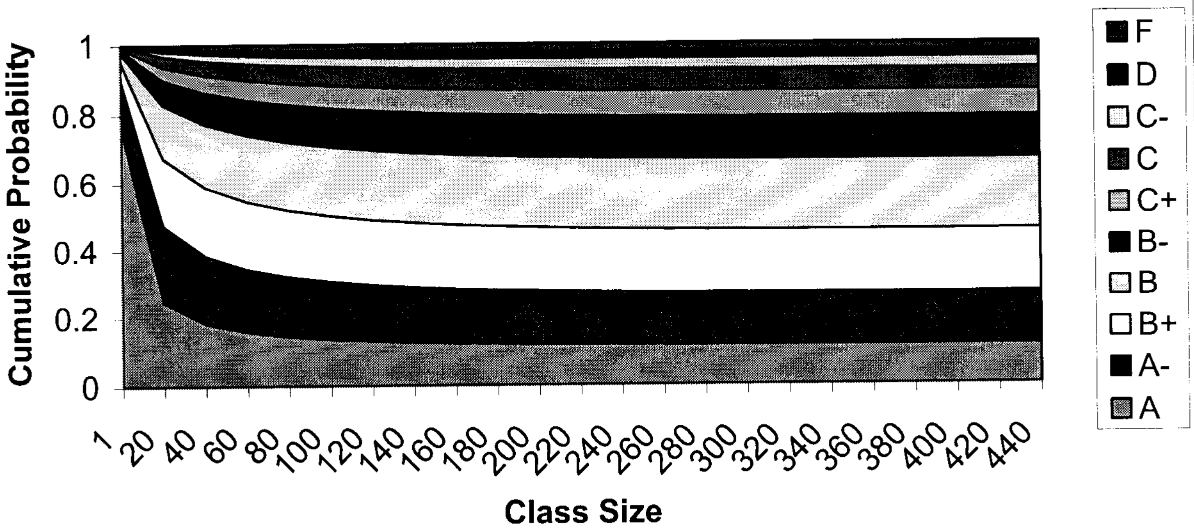
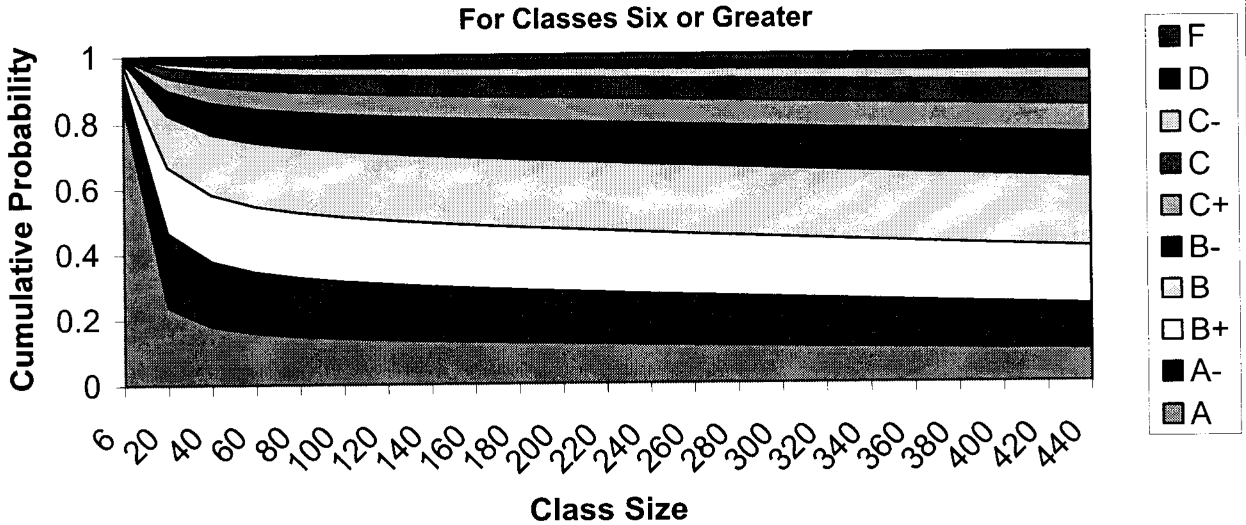


Figure Two
Cumulative Probabilty of Grades Received vs. Class Size
For Classes Six or Greater



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APPENDIX A
DATA

The data comes from a wide variety of courses taught by over 40 academic departments listed in Table A-1. The overall grade distribution is listed in Table A-2.

Relative Ability: Normalized grade point average of all other courses student is taking in a given semester relative to that of other students in the course in question. We also tested scores, high school standing, and cumulative GPA from prior college work. The overall results are essentially the same. Note that in labor theory, ability is generally considered to be temporally invariant. We allow for temporal variation that can be thought of as a combination of specific ability, motivation and learning by doing.

GPA: Grade Point Average on 4 point scale.

Departmental Mean Grade: Average grade awarded by relevant department over entire time period covered by this study on a 4 point scale.

Class Size: Class size after add deadline or the third week of class.

Student Level: Student level based upon earned credit hours on scale of 1 to 8 where 1 and 2 are freshman, etc.

Female: Dichotomous variable, one if female, zero otherwise.

Minority: Dichotomous variable, one if under-represented minority (Black, Hispanic, Alaskan Native/American Indian), zero otherwise.

Grade: Numeric value of course grade student received in credit bearing section; F = 0, D = 1, C minus = 2, C = 3, C plus = 4, B minus = 5, B = 6, B plus = 7, A minus = 8, A = 9.

Cumulative GPA: Individuals cumulative GPA at the start of the relevant term; an alternative measure of ability, motivation and circumstances or prior success in college.

AP Credit: Dichotomous variable; one if student entered with Advanced Placement credit, zero otherwise.

Year: Scaled log of time variable.

Entered as Freshman: Dichotomous variable, one if so entered, zero otherwise.

Class Mean: Grade point average of peers enrolled in specific course of interest.
SAT Scores: normalized SAT scores (0,1).

TABLE A-1
(Origin of Department Course)

Department	Frequency	Percent
Africana Studies	214	0.44
Anthropology	1626	3.32
Art History	443	0.90
Art Studio	517	1.06
Biological Sciences	2932	5.98
Chemistry	1729	3.53
Cinema	361	0.74
Classics & Near Eastern Studies	118	0.24
Comparative Literature	676	1.38
Computer Sciences	1691	3.45
Economics	2159	4.41
Electrical Engineering	515	1.05
English, Gen. Lit. & Rhet	3951	8.06
Engineering Design	327	0.67
Geological Sciences	1204	2.46
Geography	786	1.60
German, Russian & East Asian Languages	601	1.23
Harpur – Dean's Office	174	0.36
History	2385	4.87
Human Development	1265	2.58
Judaic Studies	407	0.83
Latin American Studies	127	0.26
Linguistics	108	0.22
Management	3621	7.39
Mathematical Sciences	2488	5.08
Mechanical Engineering	643	1.31
Medieval Studies	41	0.08
Music	2198	4.49
Nursing	940	1.92
Off Campus College	234	0.48
Philosophy	1751	3.57
Physics, Applied Physics and Astronomy	1013	2.07
Physical Education	3043	6.21
Political Science	1393	2.84
Psychology	3471	7.08
Romance Languages	1142	2.33
Sociology	1066	2.18
Systems Science/Industrial Engineering	94	0.19
Theatre	1207	2.46
Women's Studies	225	0.46
Other*	106	0.22

* Other includes Asian Studies, Bioengineering, Education, Latin American Studies, Public Administration and certain courses assigned to administration totaling less than ¼ of 1%.

TABLE A-2

Letter Grade Distribution

s7grad	Frequency	Percent
A*	200,705	22.88
A-*	131,627	15.00
AU	792	0.09
B*	109,172	12.44
B+*	114,740	13.08
B-*	63,703	7.26
C*	41,648	4.74
C+*	43,146	4.92
C-*	23,121	2.64
D*	19,851	2.26
F*	24,479	2.79
I	1855	0.21
MG	507	0.06
P	92,720	10.57
R	145	0.02
S	513	0.06
U	8	0.00
W	8,160	0.93
WF*	63	0.01
WP	346	0.04
X	23	0.00
Total	877,294	100.00
Missing	111,604	

*Used in statistical analysis totaling 772,225. The pass grade (P) is assigned to any student earning a pass/fail option who earns a grade of D or better, and accounts for over 88 percent of the unusable grades.

TABLE A-3
Descriptive Statistics

	Sample Size	Min	Interquartile range	Max	Mean	5% Trimmed Mean	Standard Deviation	Median	Mode
Grade	772,225	0.0	4.000	9.000	6.474	6.673	2.450	7.000	9.000
Student Level	988,898	1.0	4.000	8.000	4.967	5.019	2.237	5.000	8.000
AP Credit	988,137	0.0	1.000	1.0	0.419	0.410	0.493	0.0	0.0
Relative Ability	772,225	-16.679	2.203	22.695	0.605	0.605	2.158	0.661	0.0
Class Size	988,898	1.0	117	547	97.419	97.419	105.161	48	25
Dept. Mean Grade	970,439	1.783	0.375	3.881	3.120	3.120	0.272	3.166	3.167
Female	988,137	0.0	1.000	1.00	0.538	0.538	0.499	1.000	1.000
Minority	988,137	0.0	0.0	1.00	0.109	0.109	0.312	0.0	0.0
Year	988,898	6.931	10.560	47.449	37.824	37.824	9.942	41.271	47.185
Class mean	772,225	0.0	0.609	3.949	2.953	2.953	0.531	3.000	NA
Entered as freshman	988,137	0.0	0.0	1.0	0.762	0.762	0.426	1.00	1.00
Verbal SAT	871,803	-5.594	1.022	3.163	-0.003	-0.003	1.092	0.0	0.0
Math SAT	871,803	-6.268	1.070	2.904	0.001	0.001	1.083	0.0	0.0
GPA	764,432	0.0	0.900	4.000	3.106	3.106	0.755	3.292	4.000
Cumulative GPA	836,536	1.000	0.693	4.000	3.102	3.102	0.484	3.135	3.000

Endnotes

[1] Student/pupil ratios in K-12 schools had been dropping since the 1950's without any marked increased in standardized test scores or other indicators of overall student performance, and the majority of the studies conducted at the classroom level showed either no or very modest affect of class size on student performance. The U.S. Department of Education reports that K-12 student teacher ratios fell from 26.9 in 1955 to 17.2 in 1998. Yet average class sizes remain at about 24. The increase in special education teachers is believed to be the principle reason for this apparent contradiction.

[2] The negative slope suggests that the ideal class size from the point of view of the student's learning is size one. The concavity suggests an optimal tradeoff might exist between the student and the school (society). If concave, the rate of fall off in student outcome decreases slowly at first, and then more rapidly. If the costs of providing student outcomes is typical, it may also decline per student as the numbers of students per class increase, but rapidly at first as the costs of facilities and faculty are distributed over more students, and less rapidly at larger numbers of students as marginal efficiencies diminish. Hence, there may be a societal optimum, assuming society bears the costs of education and receives its benefits, where the rate of dimunation in outcomes equals the rate of dimunation in per student costs.

[3] Lipman, 1990; Kennedy and Siegfried, 1996, 1997.

[4] Heavily weighting studies that they considered more experimental in design, and discounting those they considered non- or quasi-experimental, Glass et al. (1982) argued that the positive effect of smaller class sizes results from attitudinal changes in both teachers and students in that environment.

[5] The most extensive experiment was Tennessee's STAR project. (Word et al., 1990; Ritter and Boruch, 1999) The results of the STAR Project showed that students scored better on 3rd grade standardized tests in math and reading if they had attended smaller sized kindergartens (Finn and Achilles, 1990, 1999; Krueger, 1999). Follow up studies showed that those students who continued in small classes beyond kindergarten did better than those that did not (Nye et al., 1999), and that small classes seem to be most beneficial to those coming from disadvantaged backgrounds (Krueger and Whitmore 2000; Slavin 1990). Subsequently, the findings from the STAR program and more modest experiments elsewhere (Tillitski, 1990; Molnar et al., 1999;Weiss, 1990) heavily influenced California's decision to spend 6 billion dollars on class size reduction (Santa Barbara, 2001).

[6] The evidence suggests that average class sizes must be reduced to 15 to achieve significant improvement in test scores, yet it has been estimated that this would cost up to eleven billion dollars a year if enacted nationwide at the K-12 level (Brewer et al., 1999). In view of current total spending on K-12 education nationwide of $655 billion in 1998 and over $790 billion in 2002 (U.S. Census Bureau, 2005), this seems modest. While the STAR project does show significant improvement in students attending smaller sized kindergarten, the estimated beneficial effect of continuing in small classes is modest and its significance debatable (Harder, 1990; Slavin, 1990). Further, the implementation of the STAR experiment has been question. The attempts to randomly assign students to different sized classrooms may not have been perfect, given that some parents may have tried to get their child into the treatment group of smaller classes. For similar reasons, the morale of teachers and students in control groups might have been different than those assigned to the treatment groups (Hanushek, 1995, 1996, 1999a, 1999b). Indeed, in a recent sophisticated statistical analysis, Hoxby (2000) critiques numerous class size studies on the basis of how they assigned students to different size classrooms. Using an exogenous assignment model she found only sketchy evidence that class size positively influences performance. See also Akerhielm (1995), Borden and Burton (1999), Correa (1993), Ehrenberg et. al (2001), Gursky (1998), Hanushek and Taylor (1989), Hoff (1998), Mosteller (1999).

[7] Using another perspective, Lesser and Ferrand, 1998 reviewed student opinion and eliminated class size as a factor affecting the student's perception of instruction, attributing observed variations to majors, faculty ability and student preparation. McKeachie, 1999 gives further references on class size research differentiating among learning methods, types of material and student motivation.

[8] The model of Table 2 is the same as the model for Table 1 and the overall statistics are consistent with those of Table 1. Detailed results are available from the author upon request.

[9] Other tests are needed for that conclusion. For example, we could compare different sized sections in terms of how well their students performed in subsequent, more advanced, coursework in the same discipline. As long as students from differently sized courses take the same subsequent course, their grade in the subsequent course could be used to judge the effect of class size in preparing the students for future coursework.