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Moohoun Song
Korea Energy Economics Institute

Peter F. Orazem
Iowa State University, pfo@iastate.edu

IOWA STATE UNIVERSITY

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The Roles of Mathematical and Verbal Skills by Major

Moohoun Song[a] and Peter F. Orazem[b]

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Students in majors with higher average quantitative GRE scores are less likely to attend graduate school while students in majors with higher average verbal GRE scores are more likely to attend graduate school. This sorting effect means that students whose cognitive skills are associated with lower earnings at the bachelor's level are the most likely to attend graduate school. As a result, there is a substantial downward bias in estimated returns to graduate education. Correcting for the sorting effect raises estimated annualized returns to a Master's or doctoral degree from about 5% to 7.3% and 12.8% respectively. Estimated returns to professional degrees rise from 13.9% to 16.6%. These findings correspond to a large increase in relative earnings received by postgraduate degree holders in the United States over the past 20 years.

JEL: J3

KEYWORDS: Postgraduate, Rate of return, Demand for schooling,Quantitative skills,Qualitative skills, Sorting

[a] Korea Energy Economics Institute
[b] Iowa State University, Department of Economics, Ames, IA 50014.
Corresponding author is Peter F. Orazem, pfo@iastate.edu (515) 294-8656
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I. Background

A wealth of economic research has documented an increase in the returns to education in the 1980s. Most of this research has concentrated on the relative returns to a bachelor's degree relative to lower levels of education. Since the 1980s, there has been a well-documented increase in returns to a college education relative to lower levels of schooling. The trend in relative earnings for bachelor's degree holders relative to high school graduates between 1976 and 1998 is illustrated in Figure 1. The bachelor's degree premium over a high school degree rose from 25% in 1976 to 45% in 1998 with the gains beginning in the early 1980s. Not as commonly known is that returns for those who entered or completed some postgraduate training rose even more rapidly. Over the period, the premium earned by graduate degree recipients above the average for those with bachelor's degrees rose from 32% to 67%.

This study has two objectives. The first is to measure the returns to postgraduate training, controlling for likely joint choices of years of schooling and their associated returns. Past estimates reported by Jaeger and Page (1996) and Graham and Smith (2005) imply very low annualized returns to graduate education of around 5% per year. However, those estimates may be clouded by nonrandom sorting on ability. The second objective is to determine if the increase in returns to postgraduate training can be explained by changes in the quality of more recent cohorts of graduate students relative to their older colleagues or if we need to seek other explanations for the rising returns to graduate education.

We focus on the roles of quantitative and verbal skills on education choice and observed returns to those choices. Several studies have documented changes in the returns to quantitative skills in the 1980s. Murnane, Willett and Levy (1995) found that rising returns to mathematics skills can explain a substantial fraction of the observed increase in returns to college between 1978 and 1986. Grogger and Eide (1995) and Levine and Zimmerman (1995) also reported that standardized mathematics scores or having taken more mathematics classes had a significant positive impact on women's wages but not men's wages.

The mechanism by which mathematical skills influence wages is not clear. It is likely that stronger quantitative skills are complementary with the use of information technologies that are widely suspected to have raised worker productivity and wages. However, quantitative skills may also affect the type of training individuals receive. Willis and Rosen (1979), Murnane, Willett and Levy (1995) and Taber (2001) all found that stronger mathematical skills in high school increased the likelihood of attending college. Paglin and Rufolo (1990) found that quantitative skills influenced choice of graduate major.

There is a presumption that quantitative and verbal skills increase in importance as the education level rises, and so changes in the value of these skills would be expected to affect the measured returns to post-graduate training. Two effects are potentially at work:

1) Rising returns to cognitive skills may have increased the opportunity costs of attending graduate school, limiting incentives to pursue post-graduate education in the areas where the returns are rising the most rapidly. Consequently, the most able students opt not to pursue graduate education in favor of capturing returns to those skills in jobs they can acquire with a bachelor's degree.

2) The marginal product of cognitive skills may have risen atypically in post-graduate training, raising the returns to graduate training relative to lower education levels.

These two possibilities would have opposite effects on incentives to attend graduate school and on observed wages. The former would suggest that the observed wage differentials between graduate and undergraduate degree holders would understate the true returns to graduate education because the earnings of those stopping at the bachelor's degree exceed the opportunity costs of those who attended graduate school. The latter would suggest the most able would attend graduate school, suggesting that the observed wage differential between graduate and undergraduate degree holders is an upward biased measure of the returns to graduate school. The comprehensive review by Card (1999) suggests that studies that control for nonrandom sorting into lower levels of education routinely obtain higher estimated returns to schooling when employing instrumental variables than from ordinary least squares estimation.[1] To our knowledge, previous studies of returns to graduate education have not explored the direction of bias from nonrandom sorting into graduate school.

There are many studies that examine incentives to enter individual majors and the returns to those decisions. However, more general studies of returns to graduate education are rare.[2] The main advantage to a general study of returns to graduate education is that if quantitative or verbal skills sort individuals across degrees, we need to have the sample cover the universe of students and not just a specific field or major. In addition, it is easier to compare estimated returns to an education level to the literature on returns to high school or college that do not distinguish by field than it is to compare returns to a specific graduate degree in, say, law or sociology.

Our findings suggest that least squares estimates of the returns to graduate education are strongly biased downward by nonrandom sorting into graduate school. The nonrandom sorting occurs on both verbal and quantitative skills: bachelor's degree recipients in majors with stronger quantitative skills and weaker verbal skills are more likely to take a job after the bachelor's degree rather than going for further schooling. Consequently, the observed average earnings for those opting for employment with a bachelor's degree overstate the average earnings of those opting to enter graduate school. Rising returns to quantitative skills and falling returns to verbal skills suggest that the downward bias in least squares estimates of returns to graduate education has been increasing over time. Correcting for nonrandom sorting raises estimated returns to levels similar to or larger than the returns to a bachelor's degree.

II. Estimation Model

Our analysis begins with the standard log-earnings framework:

1) $$\ln y_i = S_i\beta_S + X_i\beta_X + \mu_i\beta_\mu + u_i ,$$

where $\ln y_i$ is the observed earnings of the i^{th} individual; S_i is the observed schooling level, taken as a vector of dummy variables with the value of one indicating the individual's highest degree earned; X_i is a vector of individual characteristics; μ_i is an individual-specific ability component that influences earnings; and u_i is a random error term that is uncorrelated with S_i , X_i and μ_i. The β_S and β_X represent the estimated returns to schooling levels and individual attributes, respectively.

If μ_i is not observable by the econometrician, then (1) becomes

1′) $$\ln y_i = S_i\beta_S + X_i\beta_X + \varepsilon_i ; \varepsilon_i = \mu_i\beta_\mu + u_i ,$$

where the error term ε_i will include both purely random components and unmeasured individual ability. If that ability is correlated with schooling success, then exclusion of μ_i from the estimating equation will lead to $\mathrm{E}(S_i\varepsilon_i) = \mathrm{E}(S_i\mu_i\beta_\mu) \neq 0$, and so the estimates of β_S and β_X will be subject to missing variables bias.

In our application, individuals decide between stopping at the bachelor's degree or continuing on for additional schooling. The choice set at the time the individual finishes undergraduate training includes four schooling levels: Bachelor's, Master's, Doctorate and Professional degree (mainly law or medicine). These choices are denoted respectively by subscripts B, M, D, and P. For simplicity, we consider these choices mutually exclusive, and so we only consider the choice of the highest degree earned. This avoids complications related to sequential educational choices.

The schooling decision involves selecting the option that maximizes utility. This can be written as $S_i = max\ (S_{Bi}, S_{Mi}, S_{Di}, S_{Pi})$ where S_{li} is the utility from schooling choice l. Although the utility levels are not observable, we can observe how the elements of S_{li} affect the probability of selecting schooling choice l.

Suppose that the individual selects schooling level S_i at least in part on the basis of expected earnings at that education level. Then the individual will use knowledge of X_i and μ_i to forecast what he expects to earn from each of the four educational choices. Suppose also that there is a vector Z_i that contains factors that shift the individual's taste for or cost of schooling choice l. Then utility from each choice S_{li} can be approximated by

$$(2) \qquad S_{li} = X_{li}\,\theta_X + Z_{li}\,\theta_Z + \mu_{li}\,\theta_\mu + v_{li} \quad ; \quad l = B, M, D, P,$$

where v_{li} may include omitted variables, measurement errors, or specification errors of functional choice, and it is assumed to be independent of observed variables.

Now, even if $\mathrm{E}(S_i \mu_i \beta_\mu) = 0$, direct estimation of (1) will yield biased estimates if $\mathrm{E}(v_{li}\ u_i) \neq 0$. This endogeneity bias is caused by the joint selection of years of schooling with the expected returns from that schooling. A large literature on returns to schooling suggests that both sources of bias, missing measures of ability and endogeneity of the schooling choice, are likely to exist. However, the past literature has not established the magnitude of these biases in the context of estimated returns to postgraduate education. Consequently, we need to derive a mechanism to address the two potential sources of bias.

A. Instruments

To solve the problem, we follow two strategies commonly employed in the literature. First, we use measures of the direct cost of postgraduate education such as tuition levels or the likelihood of getting support graduate students in the year of receipt of the bachelor's degree.[3] These measures are included as elements of Z_i that are believed to alter the probability of continuing in school but may not affect what individuals expect to earn after completing school.

We also included measures of parental education as elements of Z_i. Card (1999) argued that parental education might not be a legitimate instrument for years of schooling because parental education is correlated with unobserved individual ability, even if parental education does not directly affect earnings. His argument suggested that when parental education is used as an instrument for years of schooling, the estimated returns would be biased upward. We found that when parental education was treated as an element of X_i that enter both the schooling and earnings equations, estimated returns were even larger when parental education was used as an instrument, although the differences were not large. Consequently, use of parental education as an instrument for years of schooling does not appear to bias upward estimated returns. Joint test of overidentification failed to reject our use of the tuition measures and parental education variables as instruments, and so we report the estimates that exclude parental education from X_i. Results from other specifications are available on request.

B. Major-level versus individual-level ability

One reason our measures of parental education appear not to cause problems may be that we are able to incorporate measures of verbal and quantitative ability into equations (1) and (2) that are typically missing in other studies. Let individual ability be given by

(3) $$\mu_{li} = \mu_l^M + \eta_i$$

where μ_l^M is the vector of average mathematical and verbal skills associated with the individual's undergraduate major and η_i is an individual-specific ability component that does not vary in productivity across schooling levels. The η_i would not affect choice of schooling level. However, verbal and mathematical skills can have different productivities at different schooling levels. Variation in μ_l^M across majors at one point in time or across cohorts can affect the graduate school entry decision. Elements of Z_i can still serve as legitimate instruments for years of schooling provided that $E(Z_i \eta_i) = 0$.

Inserting equation (3) into equation (2), we obtain

(4) $S_{li} = X_{li}\theta_x + Z_{li}\theta_Z + (\mu_l^M + \eta_i)\theta_\mu + v_{li},$

$= V(X_{li}, Z_{li}, \mu_l^M) + \zeta_{li}$; $V(X_{li}, Z_{li}, \mu_l^M) = X_{li}\theta_x + Z_{li}\theta_Z + \mu_l^M\theta_\mu$, $\zeta_{li} = v_{li} + \eta_i\theta_\mu$, $l =$ B, M, D, P.

Therefore an individual chooses an alternative l over B if $I_{li}^* \geq 0$ where

(5) $I_{li}^* = g(X_{li}, Z_{li}, \mu_l^M) - \omega_{li}$; $g(X_{li}, Z_{li}, \mu_l^M) = V(X_{li}, Z_{li}, \mu_l^M) - V(X_{Bi}, Z_{Bi}, \mu_B^M)$, $\omega_{lu} = v_{Bi} - v_{li}$.

The probability an individual chooses a schooling level l over B is

(6) $\Pr[I_{li}^* \geq 0] = \Pr[g(X_{li}, Z_{li}, \mu_l^M) - \omega_{li} \geq 0]$

$= \Pr[\omega_{li} \leq g(X_{li}, Z_{li}, \mu_l^M)]$.

If the ω_{li} are drawn independently from an extreme value distribution, then (4) can be estimated using multinomial logit. The parameter estimates will generate predicted probabilities that individual i will select any of the four options S_{Bi}, S_{Mi}, S_{Di}, and S_{Pi}. Three of these are inserted into (1) in place of the endogenous S_i to generate unbiased estimates of β_s under the maintained hypothesis that $E(Z_i v_{li}) = E(Z_i \eta_i) = 0$.[4]

This two-step procedure is inefficient because it does not incorporate the sampling errors in the parameter estimation of the multinomial logit estimates of (4) into the estimation of the log earnings equation (1). We correct the second-stage standard errors using a bootstrapping procedure in which the two-step estimation was replicated 100 times, sampling with replacement, and sampling variation in the resulting estimates used to compute the second-stage standard errors.

If major-specific skills at the bachelor's degree level are increasing in market value, then they will tend to lower incentives to pursue graduate work in that field. Conversely, majors whose skills are falling in value at the bachelor's level will have disproportionately high numbers of graduate students. If this sorting effect drives lower earning bachelor's degree recipients into graduate school and drives higher earning bachelor's degree recipients out of graduate school, it would tend to depress estimated returns to graduate work. If true, then least squares estimates of the returns to graduate school that ignored the role of major-specific ability measures would tend to understate the true returns. Our empirical work provides evidence consistent with this sorting story.

III. Data

The primary data source for this study is the Scientist and Engineer Statistics Data System (SESTAT) collected by the National Science Foundation (NSF). The 1993 wave of SESTAT also incorporated the 1993 National Survey of College Graduates, a once-per-decade survey that also covered fields outside of the sciences and engineering. The full sample includes 133,399 individuals who received a bachelor's degree between 1939 and 1992. Our working sample excludes individuals who received the bachelor's degree before 1963 or after 1986. The

1963 limit was necessitated by the lack of information on Graduate Records Exam (GRE) scores by major before 1963. The 1986 limit was imposed because we needed to give bachelor's degree recipients sufficient time to enter and complete higher degrees. Of the 84,595 individuals whose bachelor's degrees are between 1963 and 1986, we exclude 20% because of missing information required for the analysis, with three-quarters of these dropped because of missing salary information. That leaves us with a working sample of 67,565 individuals who received a bachelor's degree between 1963 and 1986. We use sample weights so that our subsample can replicate means for the relevant universe: the population of all bachelor's degree recipients in the United States between 1963 and 1986.

Table 1 includes summary statistics on the variables included in the analysis. The dependent variables include the natural logarithm of annual salary in 1993 and a series of dummy variables indicating highest degree earned. Earnings of all college graduates in 1993 averaged just under $54,000. Bachelor's recipients averaged $48,000 while Master's recipients averaged $53,000, Ph.D.s averaged $60,000 and those with professional degrees averaged $84,000. Fifty-five percent of the college graduate population did not earn a degree beyond the bachelor's level. Twenty-nine percent had a Master's degree, 10 percent held professional degrees, and 6 percent had doctorates.

Variables included in the demographic vector X_i are potential work experience (1993 – graduation year of highest degree), gender, citizenship, and racial and ethnic dummy variables. We also included information on whether the individual was raised in a rural area. Tastes for graduate education as well as the opportunity costs and anticipated returns from postgraduate training are likely to vary across these demographic factors. [5]

The vector Z_i includes average real medical school and graduate school tuition, and the percentage of self-supporting graduate students for the year the individual received the first undergraduate diploma. Due to data availability, these measures are averaged across all postgraduate degree programs. This means that we only have time series and not cross sectional variation in the direct costs of postgraduate schooling.[6] Even so, because undergraduates in a given major can select from many different graduate degree programs, major-specific information would be endogenous. Data on tuition and availability of graduate support were collected from the National Center for Education Statistics. The probability of pursuing postgraduate education should be lower for those receiving their bachelor's degrees in years where real tuition levels are high or the probability of receiving support is low.

Because information on individual bachelor's degree major and year of graduation, we can append information on the average GRE mathematics and verbal score for the college major in the year of graduation.[7] The GRE scores are used to approximate the skill content of the major. These measures are not fixed over time, as can be seen in Figure 2. Average verbal scores rose until 1975 and then fell thereafter. Average quantitative scores rose about 12 percent until 1975, retreated slightly over the next ten years, and then resumed modest growth.

Over time, the fraction of test takers from foreign countries has increased, and this may artificially change the average verbal and mathematics scores. To hold constant the composition of foreign graduate students taking the GRE, we regressed the GRE scores by major on the proportion of foreign doctoral graduates in the major six year earlier.[8] The residual represents changes in the skill content of college graduates holding fixed the proportion of foreign test takers. These corrected GRE time paths are also shown in Figure 2. The corrected verbal GRE path lies above the observed path as one would expect, but the shape is very similar to the uncorrected path. However, the corrected quantitative GRE path shows a much steeper decline in average scores after 1975 and a much steeper rebound after 1986. The timing of the decline in verbal and quantitative GRE scores occurs about four years after the decline in 12^{th} grade scores on the Iowa Test of Basic Skills reported by Bishop (1989).

Average GRE scores vary across majors, genders, races, and education levels. This variation provides cross-sectional variation in the skill content of bachelor's degree recipients. As shown in Table 2, students whose highest degrees were at the bachelor's level were in majors with the highest quantitative scores and the lowest verbal scores. This is consistent with the speculation that the sorting into graduate school may be based in part on cognitive skill content of majors as proxied by GRE scores. Undergraduate majors in the sciences and engineering had markedly higher average quantitative scores while Engineering and Business had markedly lower average verbal scores. If returns to these skills have changed over time, there will be asymmetric changes in the relative incentives to seek post-graduate training across majors. Because demographic groups concentrate in different majors, there is cross-sectional variation in major GRE scores by race, ethnicity and gender. Men tended to be in majors with higher average quantitative GREs and marginally lower verbal GREs. Asians also concentrate in majors with high quantitative and low verbal scores.

Together, the time series and cross-sectional variation in GRE scores should be sufficiently large to assess whether changes in cognitive skills developed in undergraduate programs have a role in explaining changes in the returns to post-graduate education in the United States. We proceed to that exercise in the next section.

IV. Estimation Results

A. Schooling Choices

Our primary interest is in deriving estimates of equation (1), but we also have an interest in assessing how bachelor degree recipients decide to continue on in school. Results from the weighted multinomial logit estimation of the schooling choice equation are reported in Table 3. The estimation uses the bachelor's degree as the reference group, and so positive (negative) signs indicate an increased (decreased) probability of the educational choice relative to stopping at the B.A. level.

Family background variables are highly significant in influencing the choice of whether or not to pursue and advanced degree. As mother's and father's education levels rise, the probability of seeking an advanced degree increases. The effect is strongest at the PhD level. B.A. recipients who grew up in rural areas are less likely to pursue an advanced degree. U.S. citizens are less likely to seek a Master's or doctorate but are more likely to pursue a professional degree. Asians are more likely than whites to pursue a Master's or Ph.D., while Hispanics and Blacks are less likely to pursue the doctorate.

Measures of expected cost of pursuing a graduate degree performed as expected. Individuals who received the bachelor's degree in years with higher real graduate and medical school tuition levels were less likely to pursue an advanced degree. However, the negative effect is only statistically significant for the effect of graduate school tuition on PhD or Professional degrees. The percentage of self-supporting graduate students significantly decreased the probability of pursuing all three advanced degrees. We also interacted the probability of self-support with a measure of parental education with the expectation that parents with higher education levels might moderate the adverse effects of a low probability of receiving graduate support.[9] That expectation was also realized in that all signs on the interacted terms were positive, although only marginally significant in predicting the likelihood of obtaining a professional degree. The joint significance test of the six elements of Z_i easily rejects the null hypothesis of no effect. Later, we found modest evidence that real graduate tuition may not be a legitimate instrument. Although our results are not changed when we treat it as an instrument, we restricted our set of instruments to the remaining five. These also easily passed joint tests of significance.[10]

GRE scores have an interesting impact on the probability of pursuing a higher degree. The simulations in Figure 3 show how the probability of selecting each degree level changes with the average GRE scores for undergraduate majors. Undergraduates in majors with higher verbal scores are more likely to pursue the doctorate or professional degrees. However, undergraduates in majors characterized by stronger quantitative skills are much more likely to complete their schooling at the bachelor's degree level. In separate regressions, we found that the impact of the quantitative score on schooling choice has been stable over time. If returns to quantitative skills have risen, the impacts must have been neutral across education levels. The marginal effects of GRE verbal scores increased slightly over time, but the effect is much smaller than the quantitative score.

We show how changes in average quantitative and verbal skills have affected postgraduate degree attainment in Figure 4a-c. These simulated effects of the multinomial logit model hold all factors at their sample means except for the GRE scores which are allowed to vary at historical levels. Simulations are carried through to 1993 because all necessary information was available, although the parameter estimates are based on data just through 1986.

The most dramatic changes are due to changes in the GRE quantitative score. As shown in Figure 4a, rising average quantitative GRE scores have led to an increasing proportion of students stopping at the bachelor's degree since 1985 while fewer students have sought doctoral or professional degrees. The finding that the marginal impact of the GRE quantitative score does not vary across graduation cohorts suggests that this is a result of rising quantitative skills and not rising returns to those skills. Because verbal scores raise the likelihood of seeking advanced degrees, rising GRE verbal scores in the 1960s and 1970s tended to increase the likelihood of entering graduate school. However, the erosion in verbal skills since 1975 has reversed the pattern. By 1993, most of the increase in predicted probability of seeking advanced degrees associated with verbal skills had disappeared.

Putting the two effects together, we show in Figure 4c that the net impact of falling verbal skills and rising quantitative skills has been to lower the supply of doctorates since the late 70s and to lower the supply of professionals since the mid 80s.

B. Estimated Returns to Postgraduate Education

Table 4 reports the results from Ordinary Least Squares and Two-stage estimation of the log earnings equation (1). Both sets of results correct for sample weights. Least squares estimates of returns to graduate education are positive and significant. However, the implied annual returns are small. Assuming a Master's program takes two years and a PhD program takes 6, implied annual returns are only 5.6% and 4.1% respectively.[11] Annualized returns to professional degrees are more reasonable at 13.9%, assuming a four year program. There is a significant positive return to majors with higher GRE mathematics scores but a significant reduction in earnings from majors with higher GRE verbal skills. There is a significant premium for postgraduate degrees in business and a significant discount for postgraduate degrees in the sciences.

Controlling for the likely endogeneity of the schooling choices raises the measured returns to advanced degrees.[12] The implied annual return to a Master's degree rises to 7.3%, about the lower bound of the corrected returns reported by Card (1999). The returns to a Ph.D. rise to 12.8%, toward the upper bound of the corrected returns reported by Card. The annualized return to a professional degree rises to 16.6%.[13] These estimates seem much more plauisible than the very low returns obtained from least squares estimates and seem more consistent with the presumption that technological change has led to rising returns to skill.

Returning to the two alternative possibilities discussed at the beginning of the paper, our findings suggest that least squares estimates of returns to postgraduate training are biased downward. Those who do not go on to graduate school are drawn atypically from the upper tail of the GRE quantitative distribution and the lower tail of the GRE verbal distribution, both of which are expected to raise their earnings. On the other hand, those who go on to graduate school are drawn disproportionately from the lower tail of the quantitative GRE distribution and from the upper tail of the GRE verbal distribution, both of which lower their opportunity costs of graduate school. Consequently, average earnings of bachelor's degree recipients overstate the opportunity cost faced by those opting to pursue advanced degrees, and so the observed premium of average earnings for postgraduate degree holders over bachelor's degree recipients understates the true returns to graduate school. Correcting for the sorting raises the estimated returns, as found in Table 4.

To illustrate the impact of changing GRE scores on observed returns to schooling, we simulate how GRE scores alter log earnings directly through estimates in Table 4 and and indirectly through their implied impact on the probability of receiving an advanced degree estimated from Table 3. The results of the simulation are shown in Figure 5. The direct effect of a 10 point increase in the quantitative GRE score is to raise earnings by 2%. However, the increase in average quantitative GRE score also lowers the likelihood of attending graduate school, which counteracts the positive direct returns to quantitative scores almost exactly.

Although the direct effect of average verbal GRE score on earnings is insignificant, there is an indirect impact on earnings through its influence on postgraduate training. When verbal scores were rising, they had a substantial effect on earnings which has since reversed with the more recent slide in verbal GRE scores. Combining the two effects, changes in verbal and quantitative GRE scores are responsible for only a 2% increase in relative postgraduate earnings between 1963 and 1993, a small fraction of the 35% increase in relative earnings for graduate degree holders shown in Figure 1.

C. Unobserved Ability

In equation (3), we proposed that there would also be individual abilities within the major as well as the major average. These unobserved individual abilities may also affect the likelihood of pursuing an advanced degree. To test that hypothesis, we follow Rosenzweig and Schultz (1983) by collecting the residuals from the earnings equation. These residuals represent individual earnings of BA major recipients that are uncorrelated with education level, average verbal and quantitative skills in their major, or other demographic variables included in the earnings function. They will also include random noise in the earnings function, so they will measure the unobserved ability with error. An auxiliary multinomial logit estimation of education choices on the earnings residuals will illustrate the direction of the effect of unobserved ability to earn income on the probability of seeking graduate or professional education. Note that the measurement error inherent in this method will tend to bias the coefficients toward zero.

Table 5 reports the estimated marginal effect of the earnings residual on the probability of pursuing each degree. Those with higher unobserved ability to earn income were more likely to pursue advanced degrees of all types, especially professional degrees. Consequently, unobserved abilities sort BA recipients in the opposite direction as sorting on observed quantitative skills, and in the same direction as sorting on observed verbal skills. These individuals with atypically large unobserved skill endowments particularly sort toward law and medical schools.

D. Returns by Undergraduate Major

We can also apply our procedure to estimate returns to postgraduate education for individual undergraduate majors. Our degree levels are technically identified by parental education and time series information on fees and support. However there is less variation in opportunity costs or returns within majors which may make it more difficult to generate precise estimates. The results of the exercise are shown in Table 6. In general, our findings confirm those of Table 4 that least squares estimates of postgraduate returns are biased downward, but our corrected estimates are frequently not precisely estimated.[14]

V. Conclusions

Returns to advanced degrees are positive and significant. Least squares estimates for returns to Master's or doctoral education are quite low, on the order of 5% per year. Estimates increase in magnitude after controlling for likely endogeneity of the choice of pursuing an advanced degree. Our estimates of 7.3% return per year for a Master's degree and 12.8% return per year for a doctoral degree are of comparable size to those estimated for lower levels of schooling. Our finding of downward bias in least squares estimates of returns to graduate education are similar to the conclusions from estimated returns to lower levels of schooling.

Our study points out an interesting role for cognitive skills in the market for advanced degrees. Students in majors with higher average quantitative GRE scores are less likely to attend graduate school, even though such students presumably are more likely to be successful in graduate education. The opposite happens for verbal skills—students in majors with higher average verbal GRE scores are more likely to attend graduate school. This leads to a sorting effect whereby students whose cognitive skills would suggest lower earnings at the bachelor's level are more likely to attend graduate school. This sorting effect appears to be part of the cause of the downward bias in estimated returns to graduate education—the average earnings of those who do not go to graduate school overstate the opportunity costs of graduate education for those who do pursue advanced degrees.

Nevertheless, changes in verbal and quantitative skills over time as indexed by the changes in average GRE scores play only a minor role in explaining the large increases in relative returns to graduate and professional education since 1980. While quantitative skills have large and significant returns, the positive direct effect of rising GRE scores on earnings is counteracted by the negative effect of improving quantitative skills on the probability of seeking advanced degrees. Verbal skills have no significant direct effect on earnings and declining skills have tended to reduce the probability of seeking advanced degrees since 1980.

These conclusions are subject to the usual caveat that our instruments may not be valid, although our measures of the costs of graduate education perform as expected and pass overidentification tests, and we do try to control for unmeasured ability to a greater extent than has been possible in most studies. Nevertheless, our results may still be subject to biases that we cannot control with the data at hand.

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Table 1. Descriptive Statistics: 1963-1986 (N = 67565)

	Variable	Mean	Std. Err.
Demographics	Age	41.2	(0.027)
	Experience	17.4	(0.025)
	Male	0.723	(0.002)
	US Citizen	0.956	(0.001)
	Rural Background	0.319	(0.002)
Education	BA	0.549	(0.002)
	MA	0.287	(0.002)
	Ph. D.	0.063	(0.001)
	Prof. Degree	0.101	(0.001)
	Posdoc	0.004	(>0.001)
Race	Hispanic	0.031	(0.001)
	White	0.849	(0.001)
	Black	0.052	(0.001)
	Asian	0.066	(0.001)
	Native Am.	0.002	(>0.001)
BA Major Field	Science Majors	0.342	(0.002)
	Engineering Majors	0.205	(0.002)
	Social Sci. Majors	0.326	(0.002)
	Business Major	0.032	(0.001)
	Other Majors	0.095	(0.001)
Earnings (1993 dollar)	Overall	53,864	(113.319)
	BA	47,900	(161.490)
	MA	53,325	(208.694)
	Ph.D.	59,657	(165.362)
	Professional Degree	84,155	(727.269)
Parents' Education	Mother's Education (years completed)	13.2	(2.45)
	Father's Education (years completed)	13.8	(2.86)
Schooling Costs	Med. School Tuition (1983 dollar)	7,371	(2710)
	Grad. School Tuition (1983 dollar)	2,423	(278)
	% of Grad. Students Self-Supported	26.3%	(5.39)

Data Source: NSF 1993 SESTAT

Table 2: Average GRE Score for the major, by attributes of individuals in the major

Individual Attribute	Verbal GRE	Quantitative GRE
BA	500.8	581.9
MA	502.4	568.7
PhD	508.2	573.0
Professional Degree	515.4	555.7
Science Majors	512.0	606.0
Engineering Majors	469.2	649.5
Social Science Majors	518.6	518.5
Business Major	475.4	542.3
Other Majors	502.4	507.5
White	503.6	573.9
Black	504.9	553.2
Asian	497.1	604.0
Native American	506.9	563.2
Male	501.0	585.3
Female	509.0	547.8

Data Source: NSF 1993 SESTAT, Educational Testing Service

Table 3. Multinomial Logit Estimation of Higher Education Choices

Variable	MA		PhD		Professional	
Family Background						
Mother's Education[a]	-0.044	(0.019)	0.039	(0.019)	0.031	(0.03)
Father's Education[a]	-0.010	(0.018)	0.057	(0.018)	0.101	(0.03)
Schooling Costs						
Medical School Tuition/100[a]	-0.555	(0.54)	-0.003	(0.006)	-0.003	(0.009)
Graduate School Tuition/100	-1.76	(2.28)	-0.104	(0.025)	-0.06	(0.04)
% Self-Supported[a]	-.087	(0.019)	-0.067	(0.02)	-0.072	(0.03)
Parent Ed 16+*% Self-Supported[a]	0.004	(0.001)	0.002	(0.001)	0.003	(0.002)
Graduate Records Exam						
Verbal mean/100	0.350	(0.098)	1.38	(0.10)	1.84	(0.14)
Quant. Mean/100	0.033	(0.056)	-0.51	(0.05)	-1.58	(0.09)
Foreign Student Ratio	-0.442	(0.157)	1.59	(0.12)	1.64	(0.18)
Undergraduate major						
Science Majors	-0.658	(0.069)	0.052	(0.07)	2.202	(0.15)
Engineering Majors	-0.353	(0.096)	-0.288	(0.10)	1.257	(0.24)
Social science Majors	-0.527	(0.056)	-0.825	(0.06)	0.889	(0.13)
Business Major	-0.456	(0.095)	-1.420	(0.18)	-1.368	(0.55)
Demographics						
Experience/100	0.434	(5.31)	0.234	(5.43)	7.73	(8.39)
Experience squared/100	0.010	(0.12)	0.081	(0.12)	-0.337	(0.19)
Rural background	-0.172	(0.03)	-0.208	(0.04)	-0.380	(0.06)
Male	-0.244	(0.04)	0.333	(0.04)	0.667	(0.06)
Citizen	-0.411	(0.06)	-1.566	(0.06)	0.346	(0.12)
Hispanic	0.006	(0.06)	-0.208	(0.08)	0.098	(0.09)
Black	0.002	(0.05)	-0.241	(0.09)	-0.138	(0.09)
Asian	0.261	(0.04)	0.429	(0.05)	-0.076	(0.08)
Native Am.	0.129	(0.15)	0.277	(0.17)	-0.550	(0.27)
Constant	0.704	(0.87)	-2.976	(0.93)	-4.057	(1.38)

Pseudo $R^2 = 0.078$

Standard errors in parentheses. Tuition is in constant 1983-84 dollars.

[a] Instrument used in second stage estimation

Joint test of significance of five instruments: $X^2(15) = 725.6$

Data Source: NSF 1993 SESTAT, Educational Testing Service

Table 4: Ordinary Least Squares and Two-Stage Estimation of the Log Earnings Function

Equation Variables	OLS Estimates Coefficient	OLS Estimates Std. Err.[a]	IV Estimates Coefficient	IV Estimates Std. Err.[b]
Degree				
MA	0.112	(0.007)	0.146	(0.118)
PhD	0.243	(0.008)	0.766	(0.103)
Professional Degree	0.554	(0.013)	0.662	(0.081)
Graduate Records Exam				
Verbal mean/100	-0.070	(0.020)	-0.129	(0.301)
Quant. mean/100	0.181	(0.012)	0.210	(0.008)
Foreign Student Ratio	-0.020	(0.028)	-0.098	(0.038)
Undergraduate Major				
Science Majors	-0.036	(0.014)	-0.055	(0.012)
Engineering Majors	0.031	(0.012)	0.023	(0.009)
Social Science Majors	0.037	(0.011)	0.055	(0.012)
Business Major	0.118	(0.018)	0.140	(0.033)
Demographics				
Experience/100	2.42	(0.331)	2.722	(2.32)
Experience Squared/100	-0.027	(0.008)	-0.039	(1.09)
Rural	-0.084	(0.007)	-0.075	(0.108)
Male	0.170	(0.007)	0.158	(0.012)
Citizen	0.108	(0.013)	0.176	(0.021)
Hispanic	-0.061	(0.011)	-0.050	(0.032)
Black	-0.094	(0.009)	-0.083	(0.030)
Asian	-0.088	(0.009)	-0.100	(0.019)
Native Am.	-0.127	(0.034)	-0.141	(0.025)
Posdoc	-0.369	(0.011)	-0.262	(0.040)
Graduate School Tuition/100	-0.010	(0.002)	-0.008	(0.008)
Constant	9.698	(0.109)	9.660	(0.022)
R^2	0.234		0.144	
N	67,565		67,565	

Robust[a] or bootstrapped[b] standard errors in parentheses.

Overidentification test: $X^2(5) = 3.38$. Critical value at 0.10 level is 9.24.

Data Source: NSF 1993 SESTAT, Educational Testing Service

Table 5. Marginal Effect of Individual Heterogeneity on Probability to Pursue Advanced Degree

Dependent Variable	Marginal Effect	Std. Err.
BA	-0.224	(0.007)
MA	0.029	(0.007)
Ph.D.	0.038	(0.002)
Professional Degree	0.157	(0.004)
Data Source: NSF 1993 SESTAT		

Table 6: Estimated returns to advanced degrees relative to the bachelor's degree, by undergraduate major

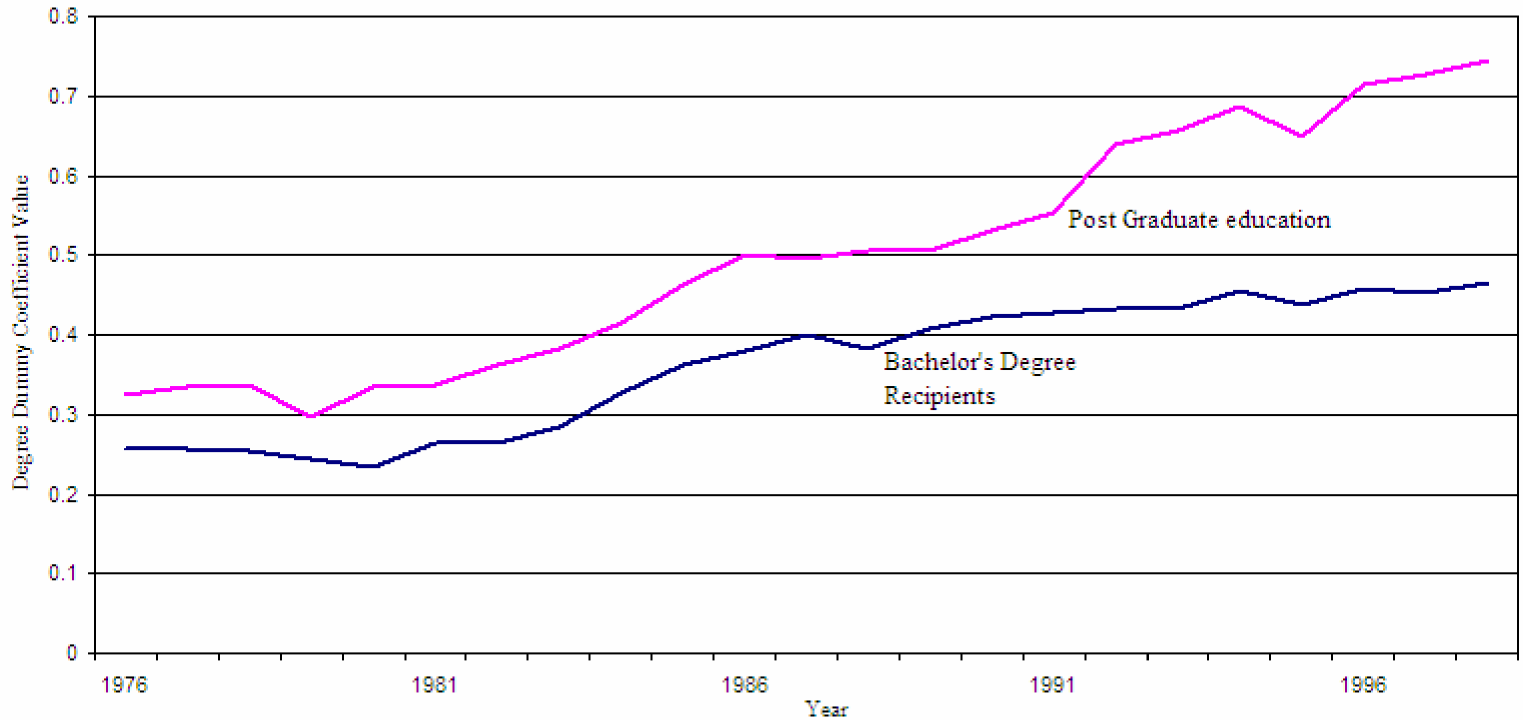
	Exogenous Degree Assumption				Endogenous Degree Assumption		
Major	Master's	Doctorate	Professional		Master's	Doctorate	Professional
Biological Sciences	**0.07**	**0.27**	**0.65**		-0.41	0.68	**0.68**
	(0.02)	(0.02)	(0.02)		(0.32)	(0.35)	(0.13)
Business/Social Science	**0.13**	**0.26**	**0.49**		**-0.52**	**0.94**	**0.85**
	(0.01)	(0.02)	(0.02)		(0.24)	(0.37)	(0.14)
Education	-0.03	**0.17**	**0.22**		0.11	0.21	0.76
	(0.05)	(0.06)	(0.07)		(0.23)	(0.64)	(0.53)
Engineering	**0.13**	**0.25**	**0.35**		**0.51**	**0.63**	-0.58
	(0.01)	(0.01)	(0.06)		(0.17)	(0.27)	(0.61)
Humanities	**0.11**	**0.18**	**0.51**		0.39	0.24	0.96
	(0.03)	(0.03)	(0.07)		((0.37)	(0.68)	(0.54)
Mathematical Disciplines	**0.06**	**0.17**	**0.57**		0.16	0.21	**1.33**
	(0.02)	(0.02)	(0.08)		(0.22)	(0.29)	(0.37)
Physical Sciences	**0.08**	**0.20**	**0.44**		**0.98**	0.45	0.59
	(0.03)	(0.03)	(0.09)		(0.44)	(0.31)	(0.33)

Notes: Returns are coefficients on degree levels from weighted regressions of the form reported in Table 4 estimated over samples including only bachelor's degree recipients from the specified major

Standard errors in parentheses. Estimates in bold indicates significance at the 0.05 level.

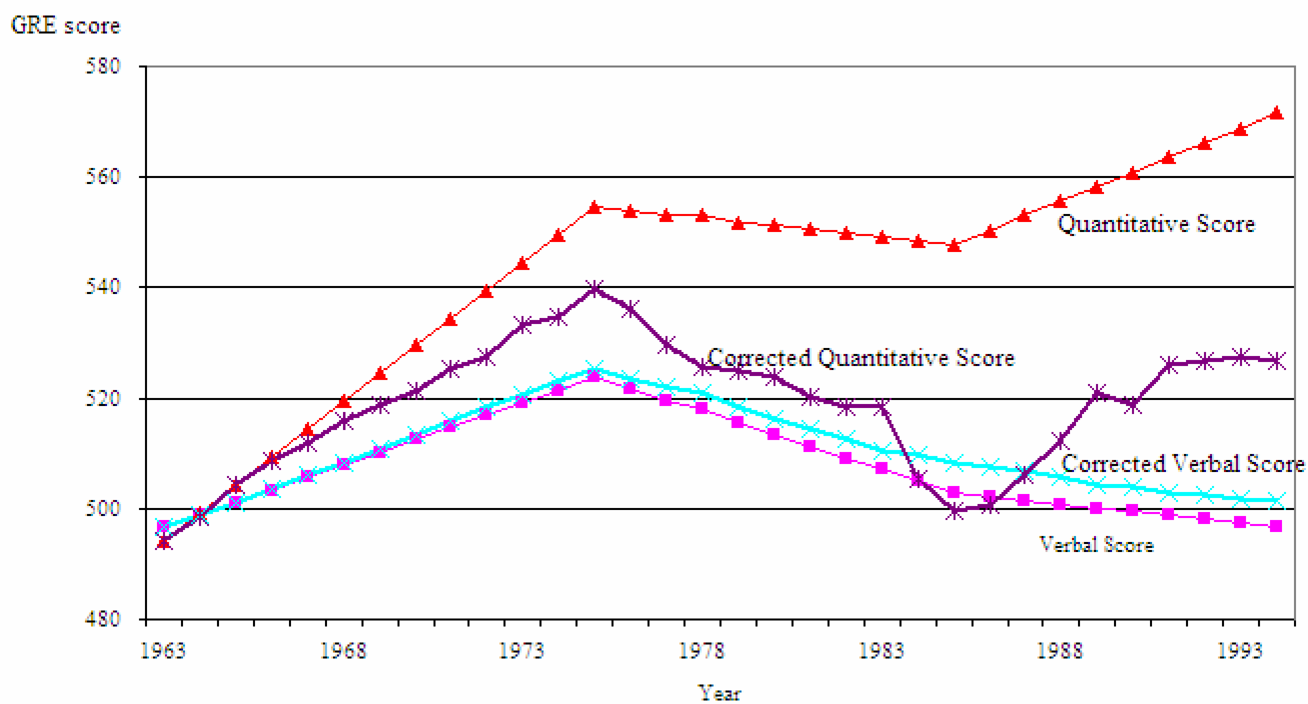
Data Source: NSF 1993 SESTAT, Educational Testing Service

Figure 1. Estimated Returns to Schooling Relative to High School Graduates: 1976-1998



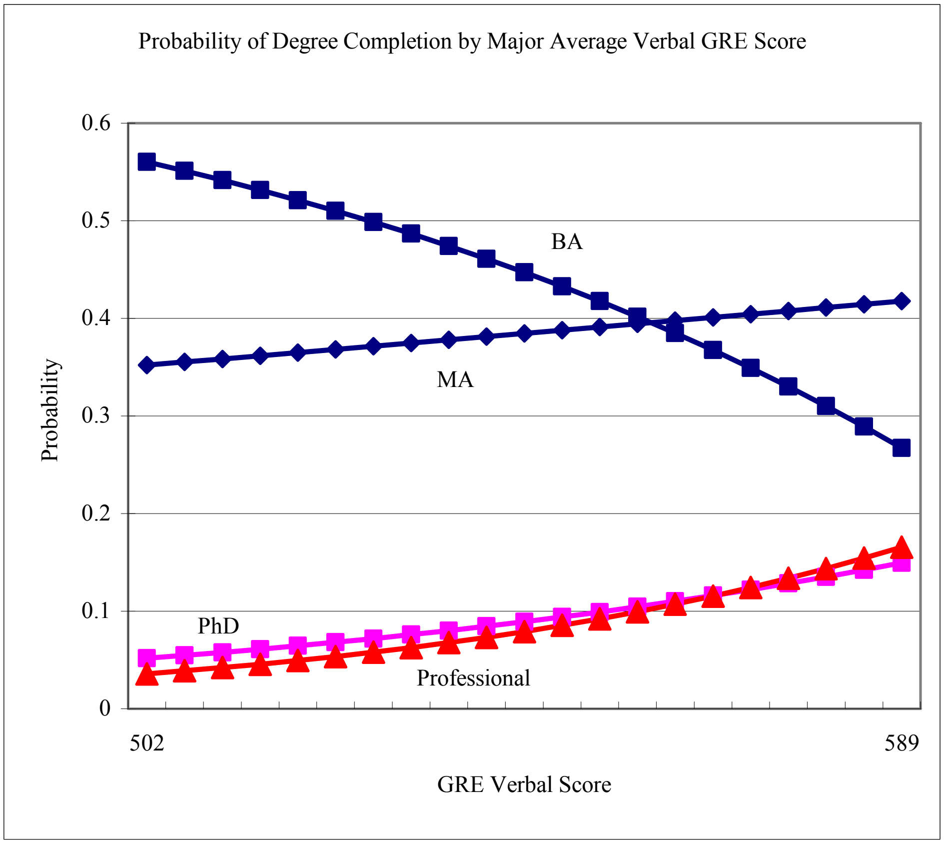
Notes: Values based on coefficients from annual regressions of log weekly wage on a vector of dummy variables indicating educational attainment, age, age squared, and a vector of demographic dummy variables. Data taken from the March Current Population Survey (1976-1998).

Figure 2: Trends of Observed and Corrected GRE Verbal and Quantitative Scores, 1963-1997



Note: Corrected Scores remove the estimated effect of foreign test takers from the mean score. Data taken from the Educational Testing Service and the Survey of Earned Doctorates, various years.

Figure 3: Simulated probability of selecting each degree type by average GRE score of the undergraduate major, holding all other variables at sample means, based on the estimated multinomial logit model. Data Source: NSF 1993 SESTAT, Educational Testing Service



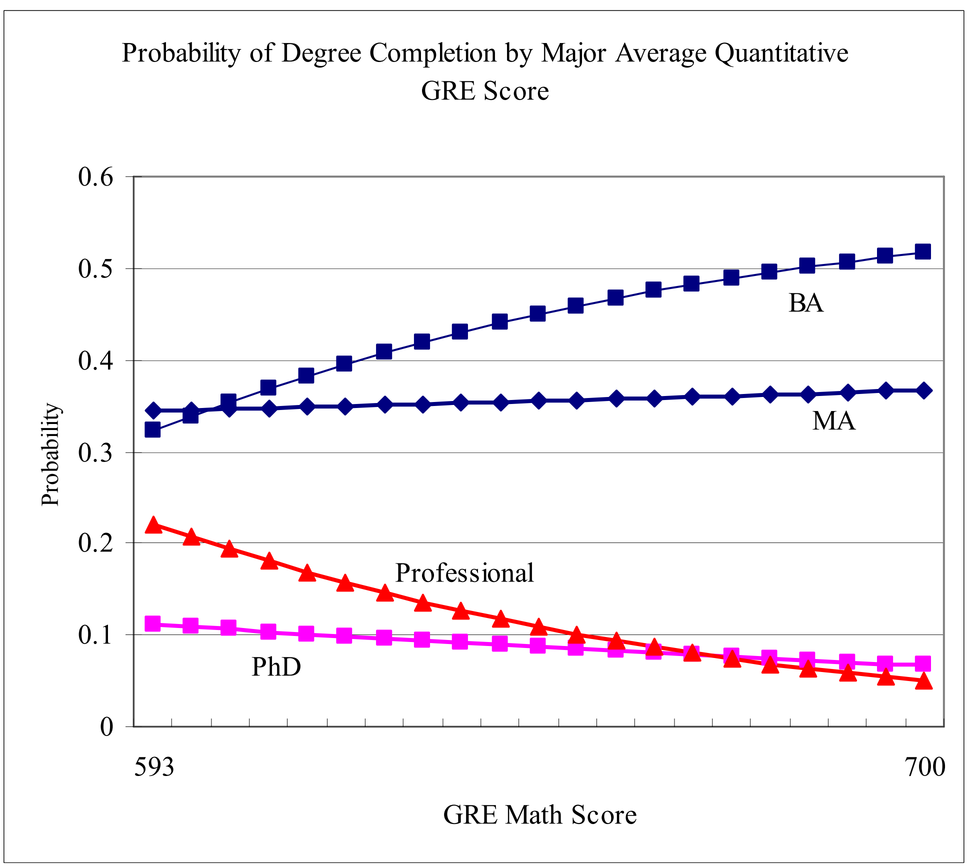


Figure 4A: Simulated probability of selecting each degree type by historical change in average quantitative GRE score, all else equal
Data Source: NSF 1993 SESTAT. ETS (1963 normalized to 1)

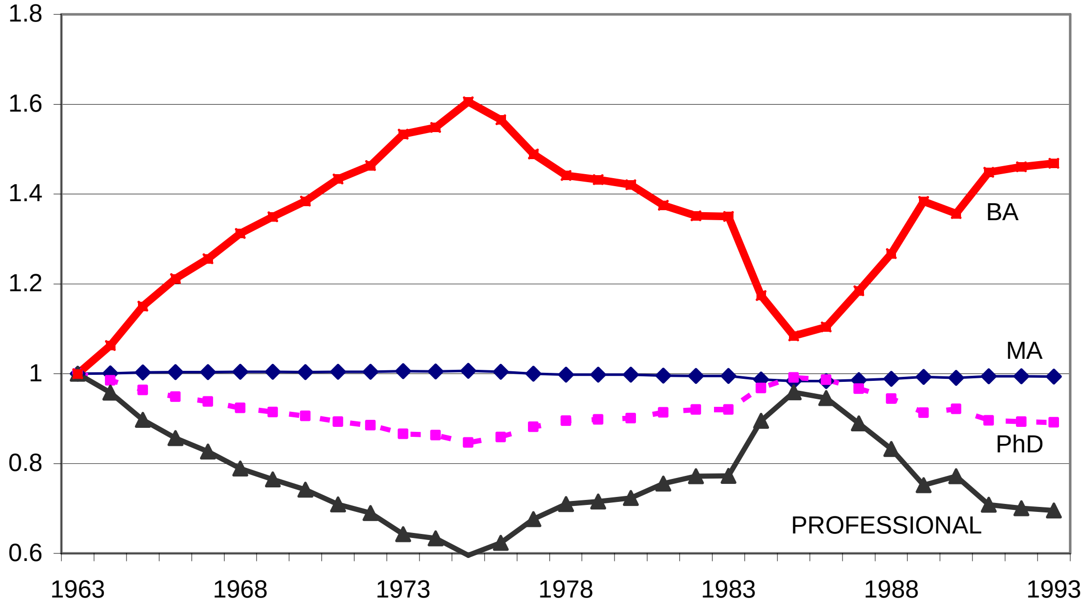


Figure 4b: Simulated probability of selecting each degree type by historical change in average verbal GRE score, all else equal
Data Source: NSF 1993 SESTAT. ETS (1963 normalized to 1)

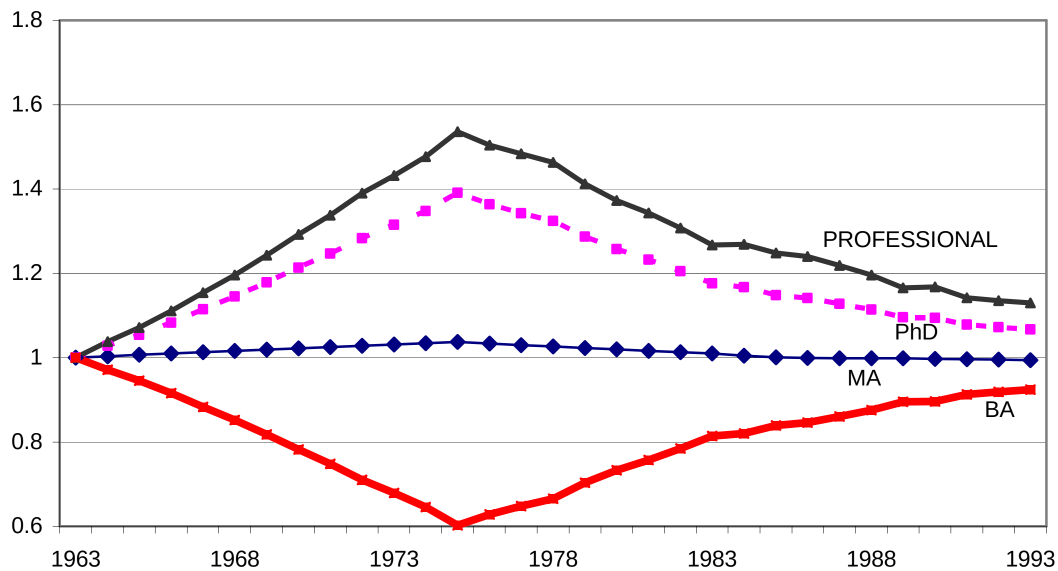


Figure 4c: Simulated probability of selecting each degree type by historical changes in average quantitative and verbal GRE score, all else equal
Data Source: NSF 1993 SESTAT. ETS (1963 normalized to 1)

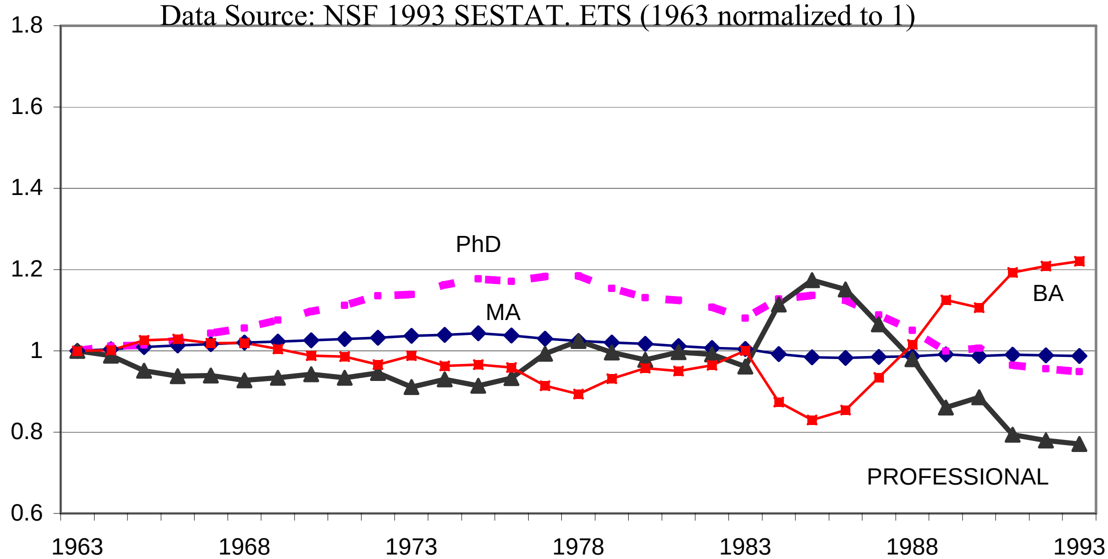
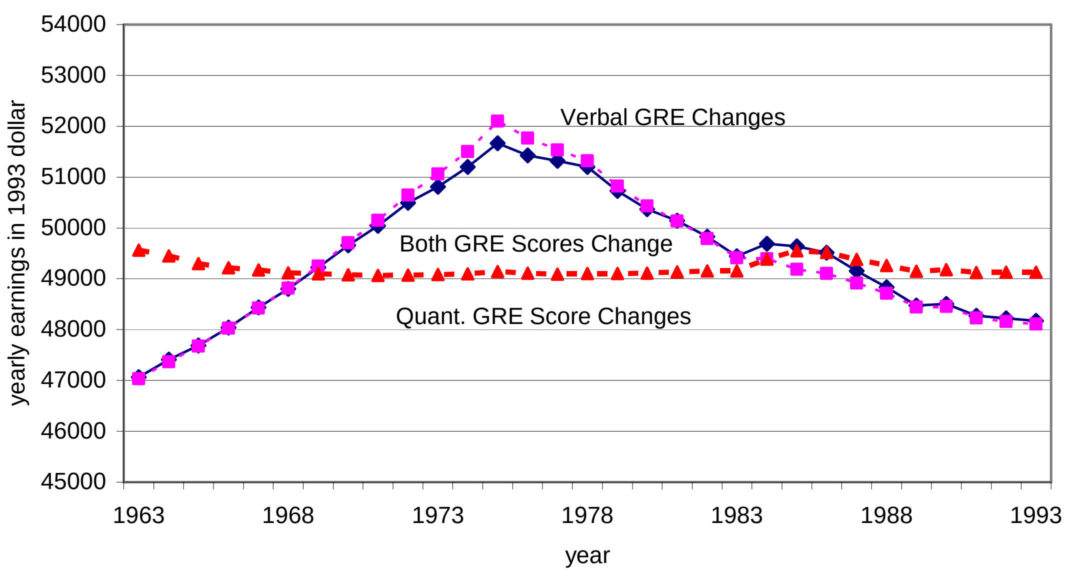


Figure 5: Simulated Direct and Indirect Impact of Changes in GRE Scores on the Average Earnings of Bachelor's Degree Recipients, 1963-1993
Data Source: NSF 1993 SESTAT. ETS (in 1993 dollars)



ENDNOTES

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[1] Past studies using instrumental variables have been criticized for the use of potentially invalid instruments. For example, frequently used family background variables (Willis and Rosen (1979), Altonji and Dunn (1996), Deschenes (2002)) may be correlated with unmeasured ability, rendering them invalid. In their study using twins data, Ashenfelter and Rouse (1998) found that family background variables strongly affected educational choices but did not affect earnings, exactly what one would want in an instrument. However, as Card (1999) argues, even that is not sufficient to validate family background measures as instruments if family background is correlated with unobservable ability.

[2] See Ehrenberg (1992) for a review. The most recent studies of which we are aware are Jaeger and Page (1996) and Graham and Smith (2005). Earlier studies include Ashenfelter and Mooney (1968) and Taubman and Wales (1973). There is a vast literature on incentives to enter and returns to specific graduate degrees, pioneered by Richard Freeman (1976 a, b; 1999).

[3] In the end, we drop graduate turtion as an instrument because it fails some of the diagnostic tests we employed to investigate whether it had explanatory power for earnings. The other instruments we discuss passed all the diagnostic tests.

[4] We also investigated the performance of an ordered probit formulation which would relax the independence assumption. The problem is that there is no natural ordering of professional degrees versus Master's or doctoral degrees. In practice, the ordered probit specification performed poorly. It was unable to to distinguish between bachelor's degree and Master's degree recipients or between doctoral and professional degree programs. The resulting predicted degree levels yielded unreasobable returns. Consequently, we concluded that the independence restrictions implied by the multinomial logit specification were more consistent with the data than ordered alternatives. Note that a nested logit that split out profession degrees from the other two might be the more appropriate specification but it would require information that would allow us to distinguish between the opportunity costs of and tastes for Master's versus doctoral degrees, information that was not available to us.

[5] We concentrate on pecuniary returns to schooling, but we acknowledge that nonpecuniary returns to schooling are an important factor leading individuals to pursue graduate degrees. The NSF SESTAT data does contain many variables that could potentially proxy for tastes, but it is not clear whether tastes are acquired from schooling oir whether they drive schooling. The high correspondence between parents' and child's educatoin suggest that some of the demand for postgraduate education is nurtured.

[6] Note that even if available, the use of major-specific information on graduate tuition or support would reflect the individual's decision of which graduate program to select, and so the major-specific information would be endogenous. It would also leave undefined the relevant expected postgraduate schooling costs for those deciding not to pursue postgraduate degrees. Because undergraduates in a given major can select from many different graduate degree programs, the averaged information across degree programs is the more appropriate measure of the direct costs of additional schooling.

[7] The Educational Testing Service provided this data for selected years:1963, 1974 to 1976, 1983 to 1986. The number of majors included in the report varied from 21 majors in 1963; 92 majors in 1974 – 76; and 98 majors in 1983 – 86. These were aggregated into 28 major groups to correspond with the majors reported in the SESTAT. The GRE did not report data on 9 of the majors 1963, and so the nearest included major was used: e.g. computer science was placed in mathematics; agricultural and food science was placed in biology; and so on. Once consistent data series were generated for the four reporting dates, the values were interpolated to generate continuous values for the intervening years. As most average scores change very slowly, this process is unlikely to generate wildly inaccurate estimates of average scores by major.

[8] The proportion of foreign doctorate recipients by major for each year in the sample period is reported by the Survey of Earned Doctorates. We presume that the average doctoral program takes six years and that the percentage of foreign graduates completing the program is proportional to the percentage taking the GRE exam six years earlier.

[9] Parents education level variable is 1 if both parents are more than college graduate, ½ if either one of them is more than college graduate, and 0 if both are less than college graduate.

[10] Our estimated returns in the second stage did not change substantially when we altered the set of instruments.

[11] Jaeger and Page (1996) estimate similarly small returns to Master's and PhD degrees under the assumption of exogenous education levels. Their estimation method includes both years of schooling as well as dummy variables indicating degree, so our annualized results are not directly comparable to theirs. Our OLS estimates are also very similar to those reported by Graham and Smith (2005) under the assumption of exogenous education levels. Their focus is not on returns to graduate education, and so they do not discuss the low implied annual rate of return to Master's or doctoral training.

[12] Estimates that also included parental education in the second-stage earnings functions yielded comparable estimates of returns to graduate and professional education.

[13] These are likely to be overstated in that we do not incorporate tuition costs into the estimated return to professional degrees, and so these returns are gross of tuition costs. In contrast, tuition is often waived in doctoral programs, so those estimates are presumably closer to the true net return.

[14] The only conflicting estimate is that engineering bachelor degree recipients with professional degrees are estimated to earn less than those who stopped at the bachelor's degree, although the coefficient estimate is smaller than its standard error. However, less than one percent of engineering bachelor degree recipients completed a professional degree.