AC 2012-4421: ECONOMIC VALUE ADDED OF ENGINEERING EDUCATION

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Economic Value Added of Engineering Education

Abstract

The economic value of engineering education is estimated by applying the theory of human capital given the costs reported by the Integrated Postsecondary Education Data System (IPEDS) and college-specific salary profiles derived from the world's largest database of self-reported incomes (that contains ~8% of the salary data for all U.S. engineers). Results indicate that the median bachelor degreed US engineer will earn \$4.2MM over the span of a forty year career, which corresponds to a net present value of \$1.8MM assuming an annual cost of capital equal to 4.1%. The national average internal rate of return for engineering education is 5.85% given average lost wages and total cost attendance of \$36,360 per year across the top 150 US engineering colleges; this internal rate of return increases to 6.5% if the average net student price of \$24,790 is used instead of total cost of attendance. These rates of return are much lower than those historically reported, which is indicative of salary compression and educational cost escalation. Correlations to rates of return were found to be greater for SAT of the admitted students than for college rankings. Taken collectively, the results indicate the need for new models of engineering education.

Keywords: Human capital; internal rate of return; engineering education; college rankings; salary profiles.

Introduction

The efficient utilization of human capital is of critical concern at the individual, institutional, societal, and global levels. For an individual and his/her family, decisions must be made regarding how to invest in their education relative to potential economic and other intangible returns. The decision to pursue alternative majors at increasing levels of higher education will introduce the possibility of pursuing new career options albeit at the loss of other unknowable professional and personal opportunities. Accordingly, the individual believes that they are making rational decisions about their choice of major and enrollment in a specific educational institution based on personal interests and/or expected economic returns of their investment of time and money. Prospective populations may include traditional students and, increasingly, returning students seeking to reinvest in their education.

At the institutional level, administrations seek to develop and offer programs that will attract the highest quality students who will pay the highest bearable tuition, perform to the highest levels, earn the highest salaries and recognitions, and thereby provide the greatest return to the institution. Institutions often perform an economic analysis regarding the allocation of their investments in human capital, especially the number and classification of faculty lines across departments. Administrations must also reason about staffing, facilities, and policies that will impact their constituents' future success; potential determinants of success may include class sizes, instructor quality, internship availability, research experiences, extracurricular activities, academic counseling, professional placement, and others.

At the societal level, the apportionment of tax revenues to public education is a long tradition of democratic societies by which governments seek to develop human capital to induce productive work, promote social stability, and advance the quality of life. In the United States, individual states have primary authority over their public educational systems. Here, legislatures also perform economic analysis regarding the needs of their constituents and the allocation of resources across educational institutions. At the federal level, Congress seeks to provide guidance to state legislatures through incentives and related policies offered through the U.S. Department of Education (DoED). Furthermore, state and federal governments have a significant impact on public and private education through directed program development and technology research grants. Some recent examples of federal investment include initiatives in science, technology, engineering, and mathematics (STEM) programs, info/nano/bio technology research, and more recently advanced manufacturing. Once again, government agents are explicitly or implicitly performing economic calculus to justify budget allocations.

At the global level, ethicists suggest the need to consider a just society that recognizes the dignity of every human being towards the allocation of resources to encourage labor equality and solidarity. This concept of “social justice” suggests a very different allocation of resources across societies. The reason for the different suggested allocation of resources is that rates of return on investments in education decrease on the margin, meaning that rates of return decrease with increasing levels of education and salary. Accordingly, global economic analyses [1-3] suggest that global resources are more equitably distributed through the offering of lower levels of education in poor countries rather than higher levels of education in rich countries. While some engineers may view such lines of inquiry as provocative, theories about the investment and depreciation of human capital have become well developed and can provide useful guidance regarding the economic value of engineering education.

It is the goal of this work to quantitatively evaluate the economic value added of engineering education. The approach is to apply the theory of human capital by considering the educational costs and career salary profiles of graduating engineers. Costs are modeled according to the publically available Integrated Postsecondary Education Data System (IPEDS) published by the U.S. Department of Education. Career salary information is procured in the form of statistical data from Payscale’s database, the world's largest collection of self-reported incomes. It is the goal that the resulting analysis will be used to evaluate elasticity of investments in human capital at increasing levels of education, assess rates of return from individual and societal perspectives, guide career strategies for reinvestment in human capital, evaluate the dynamics of alternative engineering careers with respect to labor supply/demand and human capital depreciation, characterize the sensitivity of rates of return relative to student ability, and ultimately suggest the determinants of a “quality” engineering education.

Literature Review

In corporate parlance, economic value added (EVA) is the profit earned by a firm less the cost of financing the firm’s capital [4]. The same concept may be applied at the individual level with respect to investment and returns on “human capital”, and such analysis of human capital has long been of interest to economists. With respect to the division of labor, Adam Smith [5] implied the existence of monetary value in human capital: “The acquisition of talents, by the maintenance of the acquirer during his education, study, or apprenticeship, always costs a real expense, which is a capital fixed and realized, as it were, in his person.” Pigou also suggested the importance of human capital with regard to trade-offs in its development [6]: “There is such a thing as investment in human capital as well as investment in material capital.”

The theory of human capital was more fully developed by various contributors [7-9]. By 1964, Becker’s Human Capital examined marginal rates of return on education by comparing additional output relative to investment levels in human capital [10]. Becker recognized that while human capital is substitutable with respect to development and utilization, it is not transferable like other assets such as land, labor, or fixed capital. Some early, explicit assessments of the economic value added of education include the justification of executive compensation [11] and the value of military experience by examination of World War II veterans [12]. By 1976, many such studies (including value of engineering courses) had been conducted as reviewed by Blaug in a meta-analysis [13].

As set forth by Mincer [9, 14-16], the basic earning function allows the estimation of rate of return through the fitting of a semi-log function using the logarithm of earnings as the dependent variable. Mincer used two forms of the earning function, parabolic and Gompertz. The gross annual earnings $E_{s,t}$ for a worker with s years of schooling and t years of experience is expressed with parabolic dependence as:

$$\ln E_{s,t} = \ln E_0 + r_s s + r_p k_0 t - \frac{r_p k_0}{2T} t^2 \quad (1)$$

where r_s and r_p are the rates of return on schooling and post-school investments, k_0 is the ratio of investment to gross earnings at the start of work experience, and T is the positive net investment period (career work span). The Gompertz earning function incorporates a sigmoidal transfer function to express the decline in value of up-front investment in education:

$$\ln E_{s,t} = \ln E_0 + r_s s + r_p k_0 t + \frac{r_p k_0}{\beta}(1 - \exp\{\beta t\}) \quad (2)$$

where β is the annual decline of the ratio k_0. Mincer used these functions to evaluate the rates of return on different investments in human capital, and thereby gain understanding of the earnings structure as a function of schooling and age. Mincer found very low correlation coefficients across broad populations, with approximately 30% of the observed behavior typically explained. A primary finding is that increased earnings are correlated with self-investment activities after the completion of formal schooling, though dollar profiles of earnings will tend to “fan out” later in life given increasing variances in self-investment.

Self-investments in education are staggered over time and so the marginal returns are continuously decreasing as the payoff period shortens with one's remaining lifespan. In addition, the direct cost of education tends to monotonically increase from elementary school, middle school, high school, undergraduate, and graduate degrees. At the same time, the opportunity cost of lost earnings also increases while the life span is decreasing. As a result, the marginal return on investment can become negative later in life giving rise to a concave earnings curve. For example, Psacharopoulos [1] conducted a global study while working for the World Bank in which he found that the lower income nations received an average rate of return of 11.2% with a median of 6.4 years of schooling while higher income nations received an average rate of return of 6.6% with a median of 10.9 years of schooling. Interestingly, this same study found that engineering provided the highest private rate of return of all professional undergraduate degrees, equal to 19.0%.

There are some major assumptions in this theory of human capital. Perhaps most significant is the assumption of constant rates of return across the span of a career. The theory thus fails to explicitly model dynamics such as varying levels labor supply and demand due to global recessions, offshoring trends, or technological obsolescence. In theory, it would be possible to develop an expanded model but the procurement of the requisite historical and broad salary data is difficult in practice. A second significant assumption is that the theory of human capital does not explicitly model the intellectual ability, emotional commitment, or educational quality at the individual level. Again, the influence of some of these determinants on the value of human capital and economic value added of engineering education may be studied, but is not the primary focus of the current work.

Analysis Methodology

Salary Data: Salary data was derived from the Payscale's database, the world's largest store of individual employee compensation profiles. Each compensation profile is provided by individuals motivated to gain access to peer salary comparisons for negotiation purposes. The database contains profile data for about 4% of the working population, though the proportion is higher in some (especially technical) disciplines. To avoid inadvertent disclosure of individual information in conflict with implemented privacy policies, a statistical abstract of salary data was analyzed. Here, population "buckets" were developed for working engineers according to degree level (from Associates to Doctoral), majors (14 most prevalent), engineering college (475 institutions), and year of graduation (six ranges including 1977-1986, 1987-1991, 1992-1996, 1997-2001, 2002-2006, 2007-2011). The top and bottom 0.5% of salaried earners were removed to reduce the likelihood of outliers; buckets exhibiting a coefficient of variation (σ/μ) greater than 100% were also discarded. The resulting database incorporated data for 75,036 individuals distributed across 11,149 unique buckets.

Table 1: Comparison of reported engineering salaries

	Median Salaries		Population			IRR
	US BLS	Payscale	US BLS	Payscale	%	%
Aerospace	$ 92,520	$ 70,442	71,600	2,677	3.7%	5.6%
Biomedical	$ 77,400	$ 76,470	16,000	6,472	40.5%	5.7%
Chemical	$ 84,680	$ 77,852	31,700	11,567	36.5%	6.6%
Civil	$ 74,600	$ 61,009	278,400	9,520	3.4%	5.0%
Computer	$ 97,400	$ 77,200	74,700	10,505	14.1%	6.3%
Electrical	$ 82,160	$ 79,203	157,800	13,834	8.8%	5.9%
Environmental	$ 74,200	$ 59,450	54,300	507	0.9%	6.1%
Industrial	$ 73,820	$ 70,635	214,800	4,345	2.0%	5.8%
Mechanical	$ 74,920	$ 68,677	238,700	20,302	8.5%	5.5%
Nuclear	$ 97,080	$ 92,695	16,900	865	5.1%	9.1%
All	$ 84,879	$ 72,500	1,571,900	75,036	4.8%	5.9%

A summary of the incorporated PayScale data is presented in Table 1 alongside data from the U.S. Bureau of Labor Statistics (USBLS) for validation purposes. It is observed that the size of the surveyed population used for this study relative to the USBLS varies significantly by engineering major, from 0.9% of environmental engineers to 40.5% of biomedical engineers. While the variances are interesting, the most important variance may be the upward bias in the median salaries reported by the USBLS. There are several possible explanations for this bias, the most likely of which is that the self-reported salary profiles incorporated in this study are from more recent graduates who tend to have lower salaries than engineers with greater experience. This skewed distribution of salary profiles is not problematic since the presented analysis explicitly models salary growth as a function of experience to evaluate the economic value added of engineering education.

There are, of course, issues of self-selection that may inadvertently alter the distribution of engineering salaries incorporated into the presented analysis and results. For example, engineers having left the field (such as homeless veterans) would likely not participate in the salary survey. Conversely, highly satisfied engineers with stable employment also would be less likely to participate in the salary survey. Still, the advantage of the incorporated database relative to the USBLS, ASEE, and other professional/institutional sources is that the incorporated data provides an objective view of the salaries along with degree characteristics across a large and diverse population.

Cost Data: Cost and other characteristic data for engineering colleges are provided by the Integrated Postsecondary Education Data System (IPEDS) maintained by the National Center for Education Statistics of the United States Department of Education. The characteristics incorporated into the analysis include tuition and fees, room and board charges, proportion of students seeking financial aid, average net price for students at each institution, and graduation rates. Figure 1 provides the statistical distribution of the annual cost data for the top 150 engineering colleges ranked by US News & World Report; salary profiles were available for graduates from every one of these institutions with the mean number of salary observations equal to 257 per college. Cost data for 2009 was used since this was the latest year for which average net prices[1] were reported, though average net prices were not available for all colleges.

[1] The National Center for Education Statistics defines the average net price as total cost of attendance less the average amount of federal, state/local government, or institutional grant or scholarship aid. Total cost of attendance is the sum of published tuition and required fees, books and supplies, and the weighted average for room and board and other expenses.

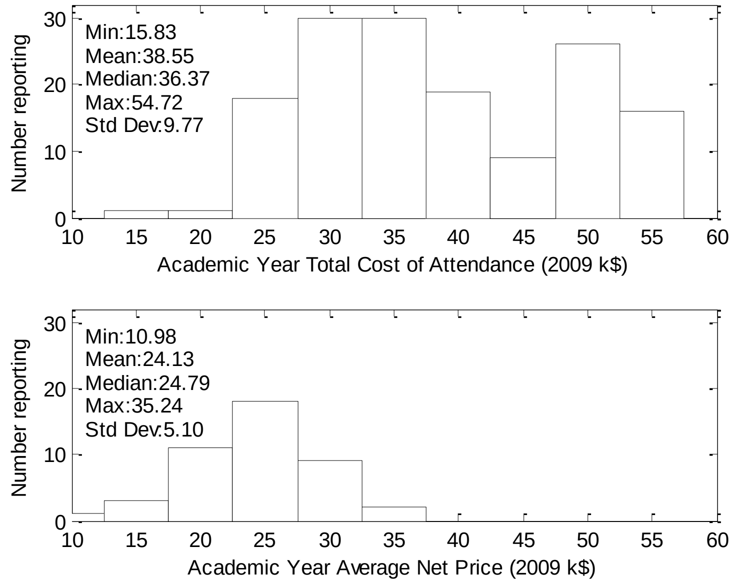

Figure 1: Total cost and net price distributions for top 150 engineering institutions

For public institutions charging different rates for in-state and out-of-state students, the out-of-state costs were used to provide a lower bound for rate of returns from an individual's perspective. Analysis incorporating net price data will provide an expected rate of return for the "average" student. Figure 1 indicates that the effect of financial aid is to not only lower the average cost of education, but also reduce the variation in cost between institutions. The reduction in both the mean and standard deviation from the total to the net cost suggest that there is significant negative demand elasticity in what students are willing to pay for higher education.

Evaluation: The subsequent analysis is restricted solely to recipients of bachelor's degrees of engineering. In evaluating the economic value of engineering education, it is important to develop a high fidelity model that provides an accurate representation of the evolution of engineering salaries as a function of experience. Furthermore, it is desirable that the developed model has a minimum number of coefficients and that those coefficients have a readily understandable meaning. As such, the following model was developed for salary, *s*, as a function of time, *t*, with a Gompertz type sigmoidal behavior:

$$s(t) = s_b(1 + r_s)^{t \cdot exp(t/\tau)} \tag{3}$$

where s_b is the base salary at the onset of engineering work, r_s is the annual rate of salary increase, *t* is the number of years of work experience, and τ is the half-life of the engineering salary function. The model coefficients were fitted using the Matlab function fminsearch to minimize the objective:

$$f = \sum \left(\left(s_{pre} - s_{obs} \right)^2 / n \right)^{1/2} \tag{4}$$

where s_{pre} is the predicted salary, s_{obs} is the observed salary, and *n* is the number of observations. The model was found to fit a very broad variety of observed behaviors including non-monotonic functions having low τ. These models can then be used to assess the net present value and internal rate of return as discussed in the next section.

Results

Figure 2 plots the aggregate annual salary profile as a function of years of experience for all 50,341 bachelor degreed engineers incorporated in the study. The data points represent the mean salaries of all engineers as grouped into buckets with varying years of experiences as previously defined; the vertical error bars represent one standard deviation of salaries. The thick dashed line in the figure represents the model of equation (3) with s_b equal to 48857, r_s equal to 7.5%, and τ equal to 37.8 years. It is observed that the standard error of the model (deviation between thick line and data points) is much lower than the standard deviation of the salaries represented by the error bars.

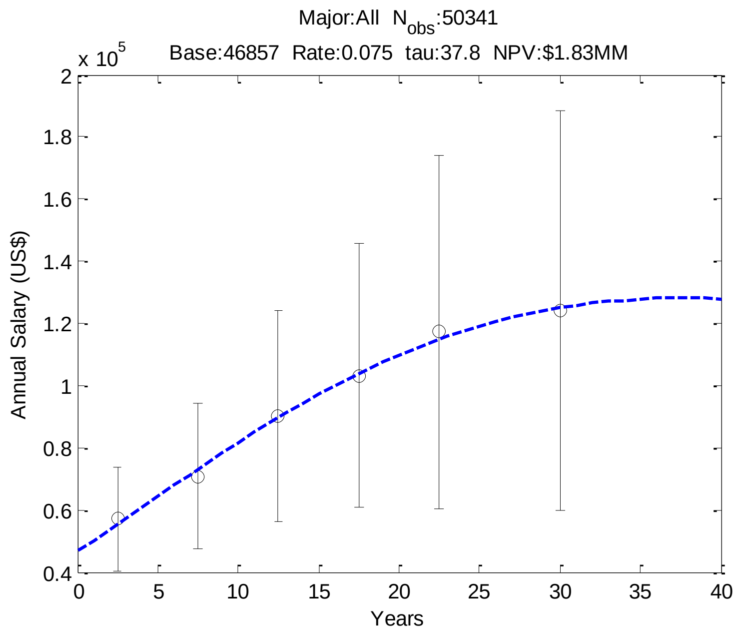

Figure 2: Projected salary profile for the aggregate of bachelor degreed engineers

The large variations in salaries are driven by a number of factors including type of engineering major, cost of living due to geographic disparities, years of experience within a population bucket, differences in work responsibilities, perceived quality of the engineer, negotiation capabilities, and others; the role of some of these determinants will be investigated in this and other papers. Salaries tend to increase with increasing years of experience and "fan out" as found by Mincer [9] who suggests that the widening of the salary distribution is related to self-investment in one's human capital. Analysis of many salary profiles supports this premise, but the behavior of salary profiles varies widely between different majors and institutions as later investigated. Somewhat counter intuitively, this fanning out of the salary profile has a reduced economic impact given the long time horizon and deep discounts to the present value associated with the time value of money.

A net present value (*NPV*) is calculated assuming a forty year engineering career span as:

$$NPV = \sum_{t=1}^{40} \frac{s(t)}{(1+i)^t} \tag{5}$$

For the aggregate salary profile plotted in Figure 2 for bachelor degreed engineers, the *NPV* is $1,830,000 assuming a cost of capital, i, of 4.1% per year (the present average national fixed rate for a thirty year mortgage). The salary model of equation (3) was fit to the bachelor degreed engineering graduates of all 150 of the top ranked US engineering colleges. The net present value for the earnings of each school's graduates is plotted in Figure 3 as a function of the annual total cost of attendance and average net price. It is observed that net present value has some positive correlation with annual cost of attendance as should be expected from economic principles. Net present value actually has a slight negative correlation with average net price.

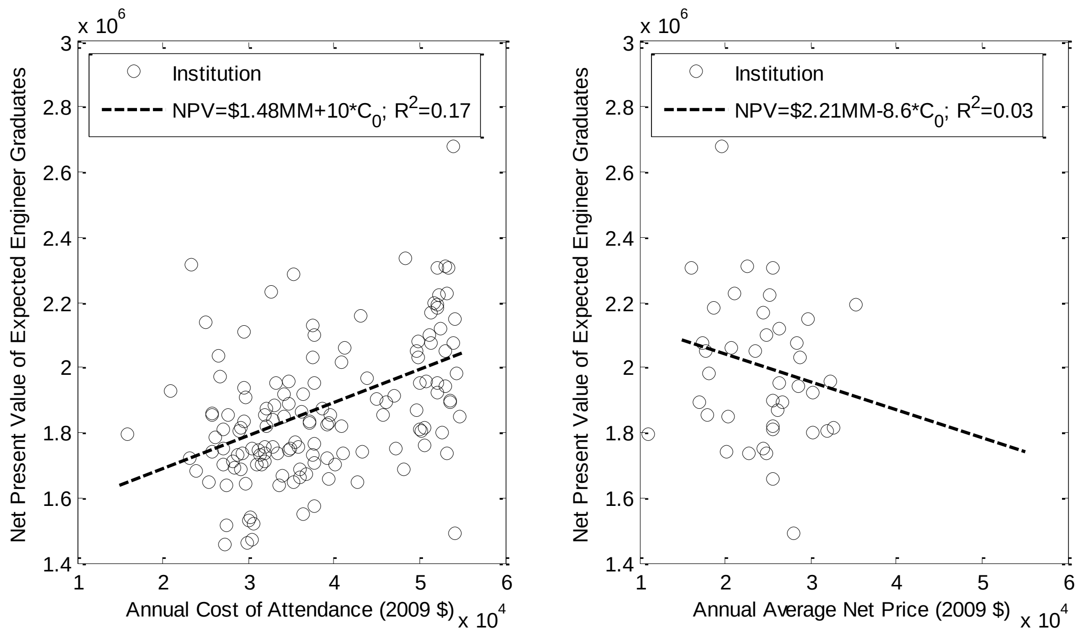

Figure 3: Net present value of engineer graduate salaries relative to institutions' list costs and net prices

While net present value is one common measure in engineering economics, it is more common in the literature to evaluate an internal rate of return, *irr*, such that future amounts are discounted so that the expected costs equal the expected returns. The education costs must consider not only the total cost of attendance or average net price (ref Figure 1) but also the lost compensation that would have otherwise been earned if the engineering education had not been undertaken. Similarly, the expected returns must not account for all of the engineering salary, but rather only that portion above the earnings that would be expected without an engineering degree. As such, the internal rate of return was found using the Matlab function `fminsearch` to solve the following equation for *irr*:

$$\sum_{t=1}^{4} \frac{C_0(1+r_C)^{2+t}+s_0}{p(1+irr)^t} - \sum_{t=1}^{40} \frac{s(t)-s_0}{(1+irr)^{t+4}} = 0 \qquad (6)$$

where C_0 is the 2009 total/net cost according to the IPEDS database, 40 is the engineering career span after graduation, 4 is the expected number of years to graduate, p is the reported proportion of students graduating within four years, s_0 is the expected salary without an engineering degree equal to 32252 [17], r_c is the annual rate of increase in education costs assumed equal to 4.5% [18], and $s(t)$ is the expected salary profile associated with an engineering degree and/or institution fit according to equation (3). In equation (6), the exponent $2+t$ is used to adjust the 2009 college costs to the present and future years. No adjustments with respect to cost of capital or merit increases are applied to $s(t)$ or s_0 since both variables are in 2011 dollars and $s(t)$ models the value of experience.

Equation (6) can be solved for the aggregate salary profile plotted in Figure 2 assuming a median total cost of attendance equal to $36,360 (ref Figure 1) and a median graduation rate *p* of 69% for the 150 top-ranked engineering schools. The national average internal rate of return for a bachelor's degree in engineering is 5.85%. Table 2 provides a sensitivity analysis of the internal rate of returns with respect to changing assumptions from average list price to average net price, graduation rates from 69% to 100%, and from average salary of high school diploma graduates to Fair Labor Standards Act (FLSA) minimum wage earners ($7.25/Hr). It is observed that the rate of return is most sensitive to assumptions in s_0, the salary earned should a student not pursue and engage in an engineering career.

Table 2: Comparison of reported engineering salaries

Condition	1	2	3	4	5	6	7	8
C_0	36360	36360	36360	36360	24790	24790	24790	24790
p	69%	69%	100%	100%	69%	69%	100%	100%
s_0	32252	15080	32252	15080	32252	15080	32252	15080
irr	5.85%	10.57%	6.44%	11.97%	6.46%	12.02%	6.92%	13.24%

These rates of returns are troubling. Mincer [14], Becker [10], and Psacharopoulos [1] indicated that rates of return on the order of 6% are quite typical for higher education. However, rates of return have historically been much greater for engineers: Psacharopoulos in 1972 found a rate of return for engineering education of 19%. The lower rates of return reported in Table 2 indicate that there has been significant salary compression for engineers, likely due to globalization/offshoring [19, 20], even while education costs have increased above inflation rates.

Given that rate of returns for engineering education are quite low, prospective engineering students as well as administrators should be considering the relative economic value added of different program options. Accordingly, the described methodology has been applied to all of the top 150 ranked engineering educational institutions. For each institution, the salary profiles for the graduated engineers were compiled and fit to equation (3). The average net price and graduation rates as reported by IPEDS were then used with equation (6) to solve for the engineering education rate of return for each institution. Table 3 provides the *irr* statistics for engineering colleges with C_0 in equation (6) equal to the total annual cost of attendance as well as the average net price for each school. It is observed that the change from the annual cost of attendance to the average net price increases the internal rates of return by about 1% while slightly reducing the standard deviation across engineering colleges.

Table 3: Statistics for internal rates of return (IRR) for engineering colleges using different cost assumptions

Assumption on C_0	Min	Mean	Median	Max	Std Dev
IRR for Total Cost of Attendance	6.10%	8.35%	8.23%	10.84%	1.02%
IRR for Average Net Price	7.20%	9.00%	9.05%	10.90%	0.94%

While the range of 6.1 to 10.9% listed in Table 2 and 3 may not seem so significant, these variances correspond to very large difference in lifetime earnings across the span of an engineering career. For example, Figure 4 plots the salary profiles for engineers graduating from two different engineering colleges providing relatively low and high rates of return. It is observed that the engineering graduates from the college associated with the lower rate of return experience lower salaries upon graduation as well as decreasing salaries later in their careers. By comparison, engineers from the college associated with the higher rate of return have not only higher starting salaries but much higher salaries later in their career. As a result, the net present value and sum of the career earnings vary drastically. The school having graduates with lower salaries also has a lower annual cost of attendance as would be expected from economic principles. However, the reduction in total cost of attendance in years 0 to 3 are not sufficient to significantly increase the rate of return given the relatively large lost wages $32,252 for high school graduate workers [17].

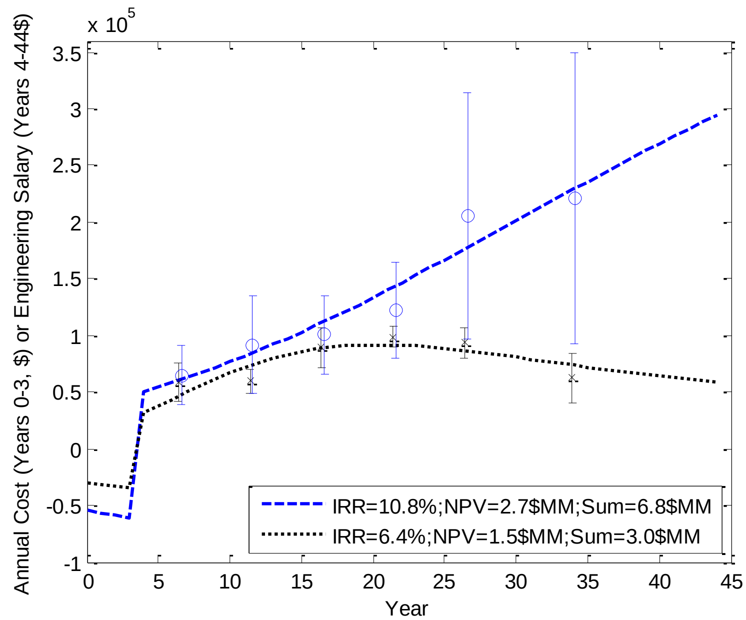

Figure 4: Projected costs and salary profiles for two engineering colleges

Discussion

Psacharopoulos indicated (p. 1333 of [1]) that “the issue of returns to investment in the quality rather than quantity of education continues to be the ‘holy grail’ and research frontier in this field [theory of human capital].” This line of inquiry introduces the issue of college rankings as a perceived measure of “quality”. The rates of return for the top US engineering colleges are plotted against US News & World Report’s engineering college ranking in Figure 5. It is observed that the correlations between college ranking and rates of return are quite low, with the graduates of many lower ranked schools far outperforming the graduates of more highly ranked schools with respect to salary; the use of average net price rather than annual total cost in the internal rate of return analysis slightly improves the correlation. In either case, however, the results indicate that college ranking is not a significant determinant of salary of the graduating engineers (top 25 schools have a (μ,σ) of (8.53%, 0.93%) compared to (8.32%,1.05%) for the remaining 125 schools).

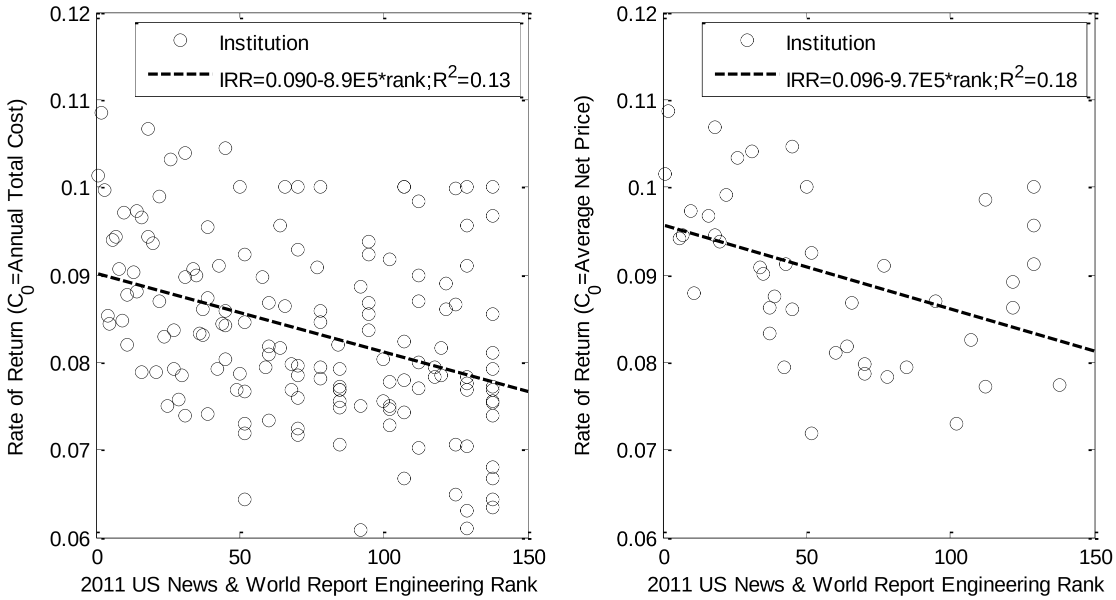

Figure 5: Correlation between engineering college rank and rate of return

Given this low correlation, one may wonder if the variation in the internal rates of return is due to the ranking or the abilities of the admitted students. Figure 6 plots the correlations between rates of return and admitted SAT score, which suggest that a high proportion of the engineering success is due to student characteristics.

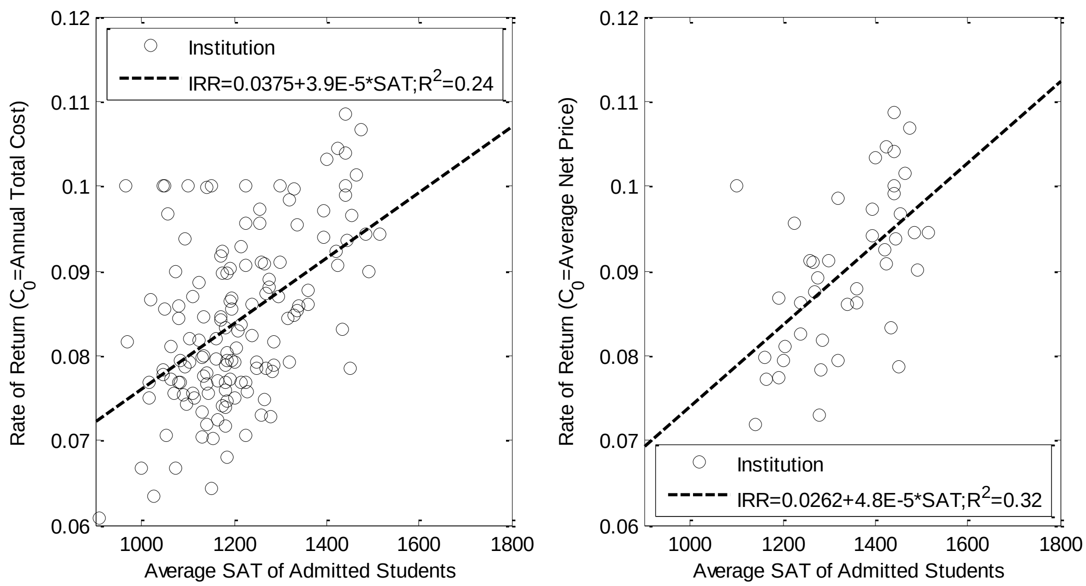

Figure 6: Correlation between average SAT score of admitted students and institutions' rates of return

There are significant societal implications for related to these findings that are influenced by government policies and free market forces. The reduced rates of return for higher education imply reduced living standards, reduced labor mobility, and increasing social tensions; fewer citizens will pursue advanced degrees if rates of return for education continue to decline. The public is showing signs of increasing frustration with the education system, and specifically the lack of growth in educational productivity (measured in terms of units of instruction or student knowledge per dollar). To the layperson, it seems that tuition costs are continuing to escalate [21] with no improvement in in critical thinking, complex reasoning, or writing skills [22]. Concurrently, many developed and developing nations face significant debt burdens and future entitlements that suggest a coming age of austerity [23].

Related government policies include availability of student loans, student testing, funding of research, immigration, taxes, and many others. Changes in these policies can improve rates of return by increasing career salaries or by reducing education costs; potential changes in policy are not being suggested by the authors at this time. However, free market forces are forever at play as demonstrated by the growth of new educational models such as the Kahn Academy [24], education merit badges [25, 26], and other forms of on-line education. To remain viable, engineering educators must control costs while increasing their students' ability to compete and contribute.

Conclusions

This study was intended to lay the groundwork for further analysis. The primary conclusion is that rates of return for engineering education (now on the order of 6 to 10%) have declined significantly from Psacharopoulos' study in 1972 (then on the order of 19%). This decline is due to the reduction in engineering salaries relative to the increasing costs of engineering education. A continued downward trend in the rate of return for engineering education is not sustainable in the long term. Indeed, if engineering has the highest or one of the highest rates of return compared to other degrees and profession, then there is almost certainly a "bubble" in higher education as characterized by the point at which the internal rate of return falls below the inflation rate. Especially troubling is that these results model the "private" rates of return as observed by the student. By comparison, the "public" rates of return would include the true cost of education including subsidies, grants, infrastructure, etc. and so would be necessarily much lower.

There are additional results not provided here due to length limitations. Further research will investigate the relative value of engineering majors, the preliminary results of which suggest that variations in salary profiles are excellent predictors of growth/decline of engineering enrollments. While this study focused on bachelor degreed engineers, future research will also investigate the relative value of associates to doctoral degrees, with important implications on risk aversion and entrepreneurship. Ultimately, the research hopes to find correlations between measures of student engagement and returns on education to provide improved guidance to students and administrators.

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