ENGINEERING UNDERGRADUATE ENROLLMENT AND THE ENGINEERING LABOR MARKET: A LAGGED-SUPPLY ANALYSIS

by

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(ABSTRACT)

The relationship between economic and demographic factors and the flow of new students into undergraduate engineering programs was investigated. An empirical analysis was undertaken based on a lagged-supply model developed earlier by Richard Freeman. The analysis involved the replication of the Freeman model over the 1948-1972 period, the extension of the model through 1986, and the forecasting of first-year engineering enrollments up to the year 2000.

The model developed in this thesis was able to a accurately mirror the engineering enrollment trends from 1948 to 1986. The economic variables--especially R&D expenditures and starting engineering salaries relative to median income of college graduates--were found to be important factors in the flow of freshmen into engineering. None of the variables relating to demographic trends were found to be significantly related to first-year engineering enrollment.

The importance of the federal government's role in the engineering labor market through research and development funding is discussed, along with forecasts of possible trends in first-year engineering enrollment.

ACKNOWLEDGEMENTS

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Chapter I

INTRODUCTION

> Competitiveness is the degree to which a nation, under free and fair market conditions, produces goods and services that meet the test of international markets while simultaneously maintaining and expanding the real incomes of its citizens. Productivity growth, technological innovation and human skill and motivation are critical structural determinants of competitiveness.
>
> -National Science Foundation, 1987

> ...that demographic "bubble" will burst in 1990, and the number of traditional college-age people will continue to decline at least through 1994...Let us not set ourselves up for a surprise enrollment crash in 1990. Colleges must...confront the undeniable demographic facts. They must prepare for a real decline, both in the number of traditional students and in overall enrollment.
>
> -John Kraus, 1987

> It is entirely possible that the supply of people trained in science and engineering will not decline at all, despite the drop in the college age population...OTA concludes that career choices and market forces have a greater impact on the supply of engineers than do demographic trends.
>
> -Office of Technology Assessment, 1985

Taken together, the three quotes that begin this thesis chart the landscape of the discussion of the supply of scientists and engineers to the U.S. work force. The National Science Foundation (1987) considers scientists and engineers at all degree levels to be the fuel that will drive the competitive U.S. economic engine. Scientists and engineers are essential to increasing the nation's competitive edge through productivity growth and technological innovation. In fact, an important responsibility of NSF is to foster the flow of scientists and engineers through the "pipeline" by financing educational programs at pre-college, college, and graduate levels.

However, John Kraus writes of a dark cloud on the academic horizon, of fewer individuals in the traditional 18-24 year-old college-going cohorts. He makes the demographic "determinist" argument that declines in the number of college-age people will inexorably lead to declines in undergraduate enrollments. From the OTA perspective, in contrast, science and engineering enrollments and degrees are not directly linked to demographic trends; demographics is not destiny. Other factors--particularly labor-market conditions--are more important in attracting individuals to careers in the sciences.

Thus, scientists and engineers are key elements in the U.S. work force, particularly in the current climate of international competitiveness. There is, though, rather strong disagreement about the influence that demographic trends--the decline in the size of the college-age cohort--will have on college and university enrollments. An important issue is then, given the uncertainty of the demographic effects, how can the nation insure that there will be enough of these highly-trained workers for the likely continued strong demand? To answer that question, one needs to determine the variables that affect the flow of students into science and engineering fields. How do entering college students form expectations about careers, and in turn choose a field of study? In particular, what are the factors that influence a student's expectation-formation process?

The intent of this thesis is to explore the linkage between both labor-market and demographic variables and first-year undergraduate enrollment in engineering. The field of engineering was chosen for a number of reasons. Of all scientific and technical fields at the undergraduate level, engineering provides the clearest path between education and employment. The B.S. in engineering is the terminal degree for entry into the labor force, unlike fields such as physics, chemistry, and mathematics where graduate degrees are almost always required for full participation in the labor force. Moreover, most engineers work in the development and production side of the economy, and are thus likely to be directly influenced by economic conditions.

Finally, due to the sustained efforts of organizations such as the American Society for Engineering Education and the National Science Foundation, better time-series data are available on the engineering profession than for nearly any other field. First-year students were selected for analysis because unlike individuals already in engineering schools or the labor force, newly-entering freshmen are most free to choose careers on the basis of current and expected market conditions and are thus most able to adjust to changes in those economic conditions.

Specifically, this analysis involves the replication and 20-year extension of an econometric model developed by Richard Freeman in 1971 and updated in 1976. The 20-year extension (through 1986) takes the analysis through the dramatic changes that have taken place in the engineering marketplace. As displayed in Figure 1, the engineering labor market--as reflected in enrollments in engineering programs--has been in a cyclical pattern since 1967, with enrollments and graduates decreasing in the early 1970s, and then rapidly increasing to unprecedented heights in the early 1980s. First-year enrollments peaked in 1982, and total full-time enrollments topped-out one year later and have declined through 1986.

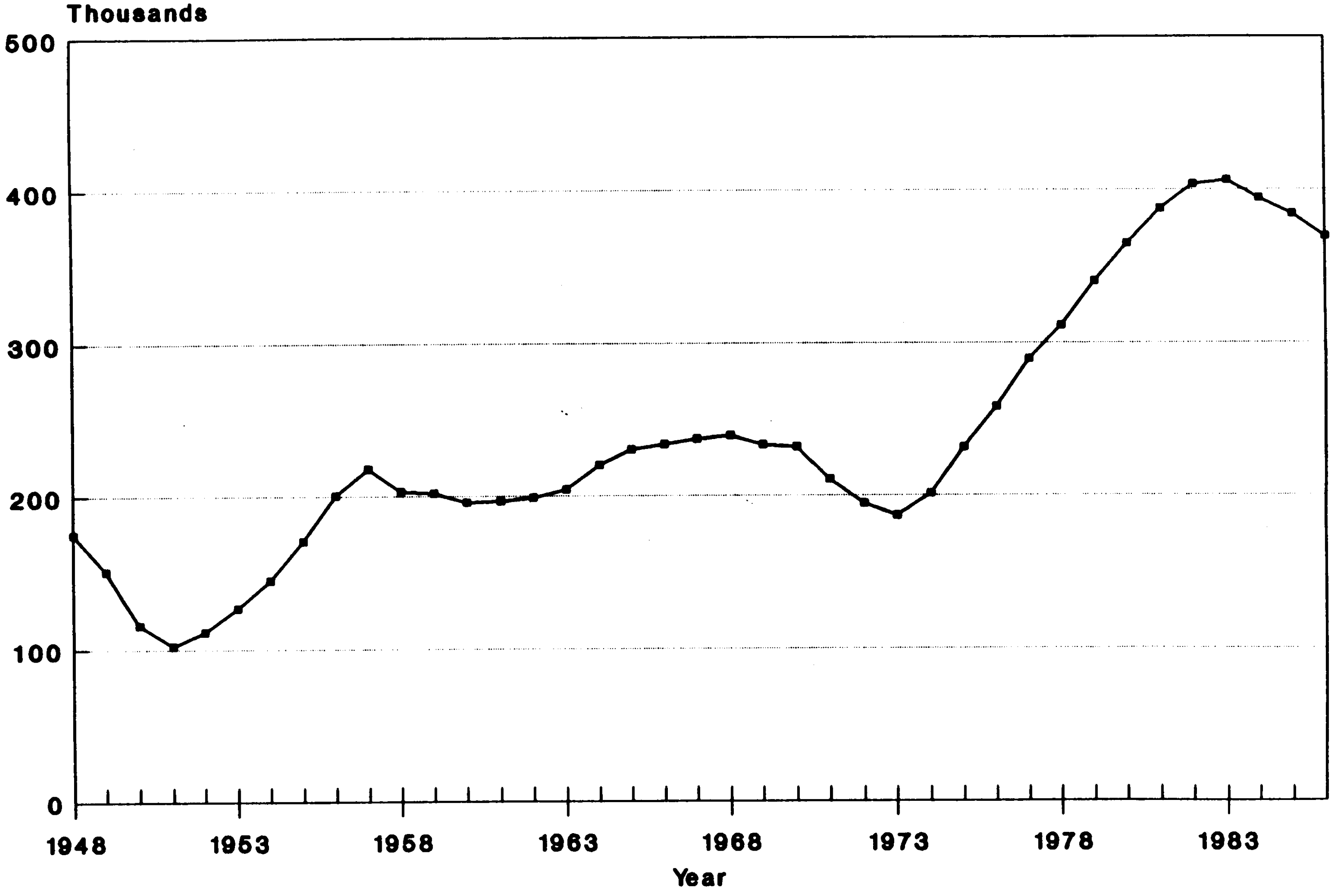

Figure 1. Full-time engineering enrollment, 1948-1986
Source: Engineering Manpower Commission

The set of equations developed by Freeman describes a theoretical model of expectations formation on the part of potential engineering students and employers. Although not a full supply/demand system, the model does provide a basis for exploring the variables influencing the students' decision-making process through the use of a lagged-supply structure.

The key issue for both students and employers is the "production lag" for engineers. Since the engineering bachelor's is a four- to five-year degree, employers intent on hiring newly-graduated engineers must contend with a supply that lags years behind the current economic conditions. Students too face the same forecasting problem--how do they develop expectations of market conditions four to five years out? What economic clues might they use in making the enrollment decision?

Freeman's model provides a useful framework for exploring the supply-side variables. Properly specified, the model should allow forecasting under various macro-economic assumptions. Moreover, there is a clear policy question in all of this: what kind of policies would an administration pursue to increase the supply of engineers? What are the levers available at the federal level to affect the system?

Hypotheses and Analysis Plan

The central hypothesis of this thesis is that the lagged-supply concept is critical to the modelling and forecasting of freshman enrollments in engineering. In other words, the model structure posited by Richard Freeman in the early 1970s explicitly incorporating the 4- to 5-year production lag between enrollment and graduation is still relevant to the engineering labor market of the 1980s.

Within that central thesis are several working hypotheses:

a. National economic factors such as R&D expenditures, salaries, etc, are closely related to freshman enrollments in engineering.

b. Demographic variables, while significantly related to freshman enrollments, are not solely the determinants of freshman enrollments.

c. The field choice of entering college freshman is highly sensitive to market factors, particularly the relative position of engineering salaries versus alternative occupations.

The analysis will proceed in three stages. First, the original (1971) and updated (1976) Freeman models will be replicated over the same periods as originally studied. Second, other possible exogenous variables, including alternative measures of population size, industrial activity, and federal expenditures will be tested for explanatory power in the model. Finally, a series of forecasts will be made for first-year engineering enrollment over the period 1987 to 2000. In the forecasting process, the explanatory measures will be set to vary at different rates, thus providing a picture of the sensitivity of the forecast to changes in the nations' economy.

Chapter II

THEORETICAL BACKGROUND AND REVIEW OF THE LITERATURE

Labor Market Dynamics

One of the central themes in research on the labor market for highly-trained manpower is the importance of the lag between the decision to pursue training, and degree completion and entry into the labor market. According to Cain, et al.[1], the long training period required for science and engineering occupations forces individuals making career decisions--and business and governmental agencies seeking to influence those decisions in technical areas--to forecast market conditions years into the future. The volatility in the market for engineers stems largely from two factors: the time lag between market signals and market responses in supply and demand and the variability of the government-generated demand for specialists.

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[1] Glen G. Cain, Richard B. Freeman, and W. Lee Hansen, Labor Market Analysis of Engineers and Technical Workers. (Baltimore, Maryland: The Johns Hopkins University Press, 1974), pp. 7.

Because of the lengthy training period involved, supply represents a response to past market conditions while demand is more heavily dependent on current conditions. Career decisions made today will alter supply conditions four to five years into the future. Moreover, the extent of the volatility in this labor market depends on the ease of adjustments on the demand and supply sides.

Of course, not all high school seniors planning an engineering career will react in the same way to changes in market conditions. In theory, there exists a relationship between the potential wages or salary available to workers and the choices they make about their occupations.[2] The choice of a particular occupation is a function of 1) the benefits and costs to the individual who chooses the work and 2) the personal characteristics of the individual which attracted him to the occupation. For the purposes of this analysis, non-pecuniary factors such as the distribution of tastes and preferences are assumed to be relatively constant or to vary in ways that are unrelated to variation in remuneration.

The fact that undergraduate engineering students have

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[2] Ibid., pp. 34-35.

been--and continue to be--a remarkably homogenous group may help to control for changes in taste and preference factors that a more heterogenous population may have experienced over time. Two statistics document the homogeneity of engineering cohorts: 1) over the 1948-1986 period 93 percent of engineering students were male; and 2) 12 percent of the 1986 engineering B.S. degrees were earned by members of minority groups (6 percent Asian, 3 percent black, 3 percent Hispanic). Thus, engineering students are overwhelmingly male and white.

While not all potential engineering students will change plans according to changes in economic variables, there are likely to be people on the margin with no strong commitment to any single occupation among the alternative occupations available. These individuals will usually change their career plans as incentives change and will move into the areas that provide the greatest utility maximization in terms of income.

Adjustment to Disequilibrium

In the short-run analysis, market disequilibrium exists when, at prevailing salaries, the number of workers demanded does not equal the number of workers supplied. Rising unemployment and falling wages relative to other occupations provide evidence of a surplus; excessive vacancies and relatively rising wages are evidence of a shortage.[3]

In their now-classic article Dynamic Shortages and Price Rises, Arrow and Capron[4] presented an analysis of the mechanism by which the science and engineering market reacts to changes in demand. At any moment in the equilibrium shift, the market experiences a shortage, termed by Arrow and Capron as a "dynamic shortage." There are a series of time lags built into the system--a lag in the production of engineers, a lag in salary response to a shortage because the firm takes time to recognize and react to the existence of a shortage at the current salary level, and a time lag for individuals to react to the market change. Since none of these market changes are instantaneous, dynamic shortages during periods of demand change are an inherent part of the process, and not an indication of trouble in the system. This labor market for B.S. engineers, then, is characterized by a low elasticity of supply, especially over the short-run,

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[3] Ibid. p.61.

[4] Kenneth J. Arrow and William M. Capron, "Dynamic Shortage and Price Rises: the Engineer-Scientist Case." Quarterly Journal of Economics (May 1959): 301.

because of the inherent time lag in the reaction of suppliers (potential engineering students) to changes in demand.

Like Arrow and Capron, Hansen[5] noted that rapid increases in demand, coupled with a relatively unchanged supply, will result in employers being unable to hire, at existing wage levels, all the engineers they wish. He argued that the important factor in the equilibrium process for scientists and engineers is change in salaries relative to those in alternate occupations, rather than change in science and engineering salaries alone. Hansen contends that much of the concern expressed in the 1960s over shortages of scientists and engineers and possible negative effects on the national economy were misplaced.

In the long run, supply responses to an increase in demand will come from 18-year-olds who choose to enter engineering, and from reduced drop-out rates as the economic incentives for completion of an engineering degree rise. In the short term, there are a number of alternative sources:[6]

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[5] W. Lee Hansen, "The Economics of Scientific and Engineering Manpower." The Journal of Human Resources 2 (Spring 1967): 193.

[6] Cain, et. al., Labor Market Analysis of Engineers and Technical Workers. pp. 64-65.

1) recent engineering graduates who might otherwise have entered a non-engineering field of study;

2) individuals eligible for retirement may be encouraged to continue working;

3) foreign citizens who could immigrate to the United States;

4) scientists moving into engineering from other fields, or technicians being upgraded to make the shift into engineering work.

However, there is considerable question about the "quality" of these alternate sources, and for the most part industry is interested in "newly minted" graduates from engineering schools for the bulk of their hiring.[7] While recognizing the existence of these alternate labor sources, this thesis is based on an analysis of the long-term flow of college freshman into the engineering pipeline.

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[7] National Research Council, Office of Scientific and Engineering Personnel, Labor-Market Conditions for Engineers: Is There a Shortage? Washington, D.C.: National Academy Press, 1984, p. 23.

Two Approaches to Modelling Labor Markets for Highly-Educated Individuals

A. Rational Expectations

The concept of rational expectations holds that individuals use all the information available to them to come to decisions in a market place, and that they will neither consistently over or underestimate the market. In the long run, expectation (or forecast) errors will be non-systematic. According to Muth[8] the economy does not waste information under rational expectations. Expectations depend on the structure of the entire system, thus errors made by economic agents are random and are not consistently affected by some unused variable. Expectations are formed consistent with general optimizing behavior by incorporating all available information about the market in question.[9]

Taking a rational expectations approach, R. Peter Pashigian[10] developed a supply/demand model for lawyers.

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[8] John F. Muth, "Rational Expectations and the Theory of Price Movements," Econoмectrica 29 (July 1961): 315.

[9] Walter Nicholson, Microeconomic Theory (Chicago: Dryden Press, 1985), p.390.

[10] B. Peter Pashigian, "The Market for Lawyers: The Determinants of the Demand for and Supply of Lawyers." The Journal of Law and Economics 20 (April 1977): 53-85.

Like engineers, lawyers are a highly-trained work force, with an extended training period, so Pashigian's analysis may be applicable to the engineering labor market. Nevertheless, while the number of new lawyers has experienced periods of growth and decline during Pashigian's analysis period, the fluctuations were not nearly as active as those for engineers.

Pashigian developed a series of reduced-form equations for the total number of lawyers, the number of new admissions to the bar, and the number of first-year law students. Assuming under rational expectations that first-year law students neither systematically over or underestimate their future earnings, Pashigian equated anticipated earnings with current stock of lawyers, number of students in the pipeline, and a series of demand-related variables. The model for the number of first-year law students is as follows:

$$F_{t-3} = wD_t /[(1 - d)\ c_t\ b_2) \\ + [(d - w)\ L_{t-1}]/[(1-d)c_t] + g_t''$$

where the first expression represents a series of exogenous variables and the second the expected number of practicing lawyers (L = the number of lawyers). Relevant to this analysis, D equals an additive relationship between independent variables,

$$D_t = (a_0 - b_0) + a_{t-3}\ Z_t + (a_1 - b_1)(1 + r)^3\ H_t\ U_t$$

where Z is a vector of demand variables (for example, GNP, personal and business legal transactions, and regulatory activity) and the expression $(1 + r)^3\ H_t\ U_t$ represents the long-run equilibrium earnings of a lawyer.

The results of a regression procedure of the total number of lawyers onto Z, the vector of demand variables, indicated that real GNP was the most important factor in the demand for lawyers. GNP was presumed to be an indicator of total economic activity, so that a rise in GNP leads to increases in the demand for lawyers from a variety of sources. In addition, earnings outside the legal profession were negatively related to both number of lawyers and the number of new admits to the bar, so that the number of lawyers appeared to decline with increases in the foregone earnings of becoming a lawyer. Other variables found to have a positive relationship with the demand for lawyers were the number of court cases and the divorce rate.

From the regression coefficients, Pashigian found that the market for lawyers exhibited a very slow speed of adjustment toward equilibrium. This was considered consistent with the pipeline lags, particularly with the addition of slots to new first-year law classes. Pashigian concluded that cobweb oscillations do not describe the market for lawyers because of the slowness of the supply response and the extended length of the periods of equilibrium and disequilibrium.

In essence, then, the Pashigian analysis equates the number of first-year law students, the number of new admits to the bar, and the total number of lawyers with a set of exogenous demand variables and a complex measure involving salary. The most powerful demand variables were found to be real GNP and salaries in other occupations. However, other than salaries in competing occupations, the Pashigian analysis appears to views the labor market for lawyers in a vacuum. While Pashigian's implicit assumption of an unlimited pool of potential law students is not entirely unreasonable, the addition of a variable relating to trends in baccalaureate recipients may serve to improve the model.

B. Lagged-Supply

In his book The Market for College-Trained Manpower, Richard Freeman[11] developed a econometric model of the process of enrolling in and completion of an engineering B.S. program. He employed a cobweb-type lagged-supply model in this analysis, with the hypothesis that there is incomplete adjustment between supply and demand in each market cycle. The interaction of the 4- to 5-year lag built into the career choice and training process with this incomplete adjustment hypothesis, coming out of the early work by Arrow and Capron, is a critical element of Freeman's model.

Freeman's model focuses on changes in the number and starting salaries of BS engineers. His initial analysis covers the period from 1947 to 1967, a time of rapid change in the U.S. employment picture in general and growth in the number of engineers employed throughout the economy. An updated version of the model, reported by Freeman in 1976,[12] is described near the end of this section.

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[11] Richard B. Freeman, The Market for College-Trained Manpower: A Study in the Economics of Career Choice, (Cambridge, Massachusetts: Harvard University Press, 1971), pp. 58-75.

[12] __________, "A Cobweb Model of the Supply and Starting Salary of New Engineers," Industrial and Labor Relations Review 29 (January 1976): 236-248.

Three equations form the Freeman model:[13] the first describes the supply of freshman engineers; the second starting engineering salaries; and the third representing the full lagged-supply relationship.

(1) Supply of freshman engineers:

$$ENR_t = a_0 \; FRSH_t + a_1 \; ESAL_t - a_2 \; ASAL_t + a_3 \; VET_t - a_4 \; (ENR/FRSH)_{t-1}$$

(2) Salary determination by employers:

$$ESAL_t = - c_0 \; GRAD_t + c_1 \; RD_t + c_2 \; DUR_t$$

(3) The full lagged-supply model:

$$ENR_t = a_0 \; FRSH_t - a_1c_0 \; GRAD_t + a_1c_1 \; RD_t + a_1c_2 \; DUR_t - a_2 \; ASAL_t + a_3 \; VET_t - a_4 \; (ENR/FRSH)_t$$

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[13] The full Freeman analysis contains a fourth equation for estimating the supply of engineering graduates. That equation sets engineering graduates equal to number of engineering freshman four years earlier and lagged engineering and alternative salaries. Because this thesis centers on the supply of freshman engineers, the engineering graduate equation was not included in the analysis. In addition, the availability of an accurate time-series on the number of engineering graduates made prediction of that variable for the full lagged-supply equation unnecessary. An explanation of the method used for estimating the number of engineering graduates for forecasting purposes is detailed in Chapter IV of this thesis.

Where: ENR = first-year full-time engineering enrollment
FRSH = total male full-time freshman
ESAL = starting salaries for BS engineers
ASAL = annual earnings of professional workers
VET = number of veterans enrolled as freshmen
ENR/FRSH = proportion of freshman class enrolled in engineering
RD = total R&D expenditures
DUR = durable goods output
GRAD = engineering BS graduates in previous academic year

According to equation (1), the number of first-year engineering enrollments is positively related to changes in number of male freshman, starting engineering salaries, and the number of veterans enrolled as freshman, and negatively related to other professional salaries and the fraction of last year's freshman class enrolled in engineering. This supply equation makes a number of assumptions about occupational choice. First, starting salary rather than lifetime earnings is used as the incentive variable. Second, the number of male freshman is used as the population variable, presumably because during the 1950s and 1960s almost all engineers were male. Third, Freeman includes variables relating to World War II veterans, assuming that during the post-war period, fluctuations in the number of veterans in college had a disproportionate effect on engineering. This hypothesis was not supported by the regression results.

The demand side of the system uses salary as the dependent variable. Changes in engineering salaries are negatively related to the number of graduating B.S. engineers and positively related to R&D expenditures and output in durable goods industries. Firms will set this year's salary based on presumed market conditions and a perception of the number of engineers available. Firms will assume that this year's supply will equal supply over recent years.

In the face of an exogenous increase in demand, firms will plan next year's salary level on the basis of this new demand and last year's supply. Salaries will be increased beyond the equilibrium level, providing a strong signal to students to enter engineering, increasing the potential for an oversupply a few years later because of the training period involved. Note that Freeman uses this period's R&D and durable goods figures, rather than a lagged function. Thus, demand drives salaries, which enters the supply equations as an independent variable, affecting the number of freshman who choose to major in engineering.

The salary equation (2) is substituted into the enrollment equation (1) to yield a single equation summarizing the lagged-supply mechanism. Here, Freeman hypothesizes a relationship between engineering graduates and freshman engineering enrollment. According to this model, there is a negative relationship between the size of the graduating class and freshman enrollment in the next year. In other words, a large graduating class saturates the existing job market, meeting or exceeding demand, and thus reducing opportunities for the succeeding generations of engineers. Entering students react, then, not so much to salary fluctuations but to changes in job vacancies, or opportunities, a non-price equilibrating mechanism.[14]

In his initial regression analysis of the above model over the 1948-1967 period, Freeman found that the model did an excellent job at explaining the trends in engineering enrollment. The R^2 measures for each of the equations were at the 0.9 level, and all variable coefficients exhibiting the expected signs. Regression results indicated that in equation (1) engineering salary and total number of freshmen were the chief explanatory variables for freshman enrollment,

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[14] Although the recursive nature of the Freeman model--that overreaction of firms to increases in demand results in an oversupply of engineering graduates in subsequent cycles--appears to require such an oversupply/undersupply cycle, this is not necessarily the case. If demand continued to grow in each year absorbing the increased output of engineers, (for example, in reaction to a fully-funded SDI program) then there need not be an oversupply situation leading to a cyclical dip in engineering enrollments.

and that R&D expenditures and durable goods output and the number of graduating engineers were all significantly related to starting salaries in equation (2). In the full lagged-supply model (equation 3) total freshman enrollment, the number of engineering graduates, and R&D expenditures were found to be the factors most directly related to first-year engineering enrollment. Although statistically significant, durable goods output and the share variable (ENR/FRSH) were less powerful factors in the model. The veterans variable was not included in the final regression calculations presumably because that variable was found not to be significant in the earlier equations.

Freeman extended his model through 1972 in his article <u>A Cobweb Model of the Supply and Starting Salary of New Engineers</u>. Beyond the addition of 10-years of data, Freeman modified the freshman engineer supply equation (1) and in turn the full lagged-supply model. The veteran and share (ENR/FRSH) variables were eliminated from the supply equation, probably because the veterans hypothesis was no longer relevant in the 1960s and 1970s and moreover, neither variable was critical to the explanatory power of the model. In addition the FRSH (total number of freshman) variable in the supply equation in the original model was replaced with terms for lagged first-year engineering enrollment. The set of equations in the updated model is, then:

(1) Supply of freshman engineers:

$$ENR_t = a_1\ ESAL_t - a_2\ ASAL_t + a_3\ ENR_{t-1}$$

(2) Salary determination by employers:

$$ESAL_t = - c_0\ GRAD_t + c_1\ RD_t + c_2\ DUR_t$$

(3) The full lagged-supply model:

$$ENR_t = a_1(-c_0\ GRAD_t + c1\ RD_t + c2\ DUR_t) - a_2\ ASAL_t + a_3\ ENR_{t-1}$$

In his analysis, Freeman presented a set of reduced-form equations based on an underlying supply/demand relation. The set of equations described a theoretical model of expectations formation on the part of potential engineering students and employers. Freeman hypothesized that expectations are developed by students based on relative opportunities as evidenced by changes in R&D and durable goods output and salaries in other occupations. Employers base their decisions on the numbers of graduating engineers and the same R&D and durable goods output market indicators.

Summary

Two themes emerge in the research literature relating to labor-markets for highly-educated manpower. First, there is considerable discussion about whether at certain moments in our history the nation was experiencing a shortage or surplus, and if so, what the effects on the national economy were. Overall, one would conclude that statements of shortages, or impending shortages, and the negative effect such shortages will have on the economy have been discounted in the literature. As Arrow and Capron conclude, such shortages are normal outgrowths of the movement toward equilibrium, and are brought on by the slow reaction of the principal actors in the market--employers and engineers.

Second, there does seem to be general agreement that the production lag for engineers is an important concept. Freeman explicitly includes the production lag in his lagged-supply model. It is interesting to note that the Pashigian analysis for first-year law students comes to much the same conclusion. The number of first-year law students is positively related to the earnings of lawyers but negatively affected by alternate professional salaries and the size of the existing stock of lawyers. In fact, coming from quite different theoretical directions, the entering student equations of Pashigian and Freeman are very similar. Both models equate entering students with measures of exogenous demand, earnings relative to other professions, and the size of the existing labor pool.

The results of applying the Freeman model to a data set covering the 1948-1986 period will be described in Chapter IV of this thesis, following a review of time-series trends relating to the market for newly-graduated B.S. engineers in Chapter III.

Chapter III

HISTORICAL OVERVIEW OF VARIABLES RELATED TO ENGINEERING ENROLLMENTS

Over the 1948-1986 period, the labor market for B.S. engineers has been characterized by marked fluctuations, not just in numbers of engineering students and graduates, but in the attractiveness of engineering employment relative to other occupations. For purposes of this descriptive analysis, the years following the second world war can be subdivided into four periods, growth in the 1950s, the turbulent 1960s, the 1970s "depression," and the rapid growth and peak in the 1980s.

Figure 2 displays the trend in first-year engineering enrollments over the study period. Beginning in 1948, the number of freshman engineers dropped quickly to a low of approximately 30,000 and then began a rapid rise through the 1950s to the 80,000 level. Another dip in number followed through the early 1960s, and then the numbers rose again to the 80,000 level in the mid 1960s. As reflected in the number of students, the engineering market suffered a serious

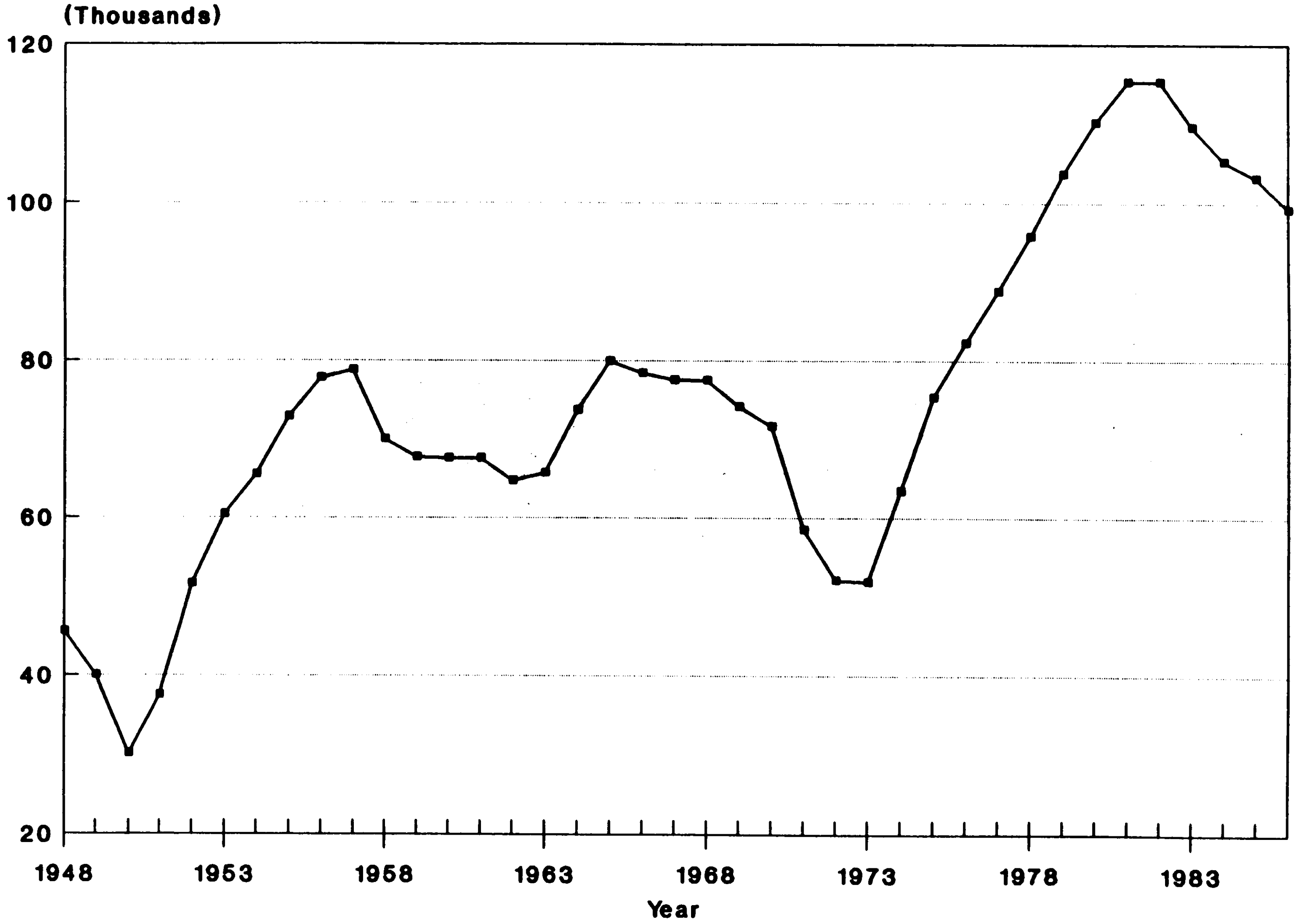

Figure 2. First-year engineering enrollment, 1948-1986
Source: Engineering Manpower Commission

downturn in the early 1970s, and in a dramatic turnaround, grew at an unprecedented rate until the early 1980s. Not surprisingly, the early 1970s was the time when much of the discussion of shortage and surplus of engineers took place, and was the time when Freeman updated his lagged-supply model. First-year enrollments peaked in 1982 and have declined since then. Early indications are that enrollments have continued to drop in 1987.

Figures 3 and 4 illustrate that underneath the first-year enrollment trend are a number of factors that do not consistently move in parallel with enrollment trends. During the seesaw movement of first-year enrollments in the 1950s, 1960s, and 1970s, the number of male 18-year-olds grew rapidly as a result of the post-war baby boom. The growth trend topped out in 1980 as the "pig in the python" of post-war children moved out of the 18-year-old cohort. Since 1980, and through the mid-1990s, the number of 18-year-olds is expected to drop back to levels of the 1960s and then rise again as the children of the baby boomers (the baby boom echo) turn 18. This sizable dip in the 18-year-old cohort is the cause for much of the distress over college enrollments

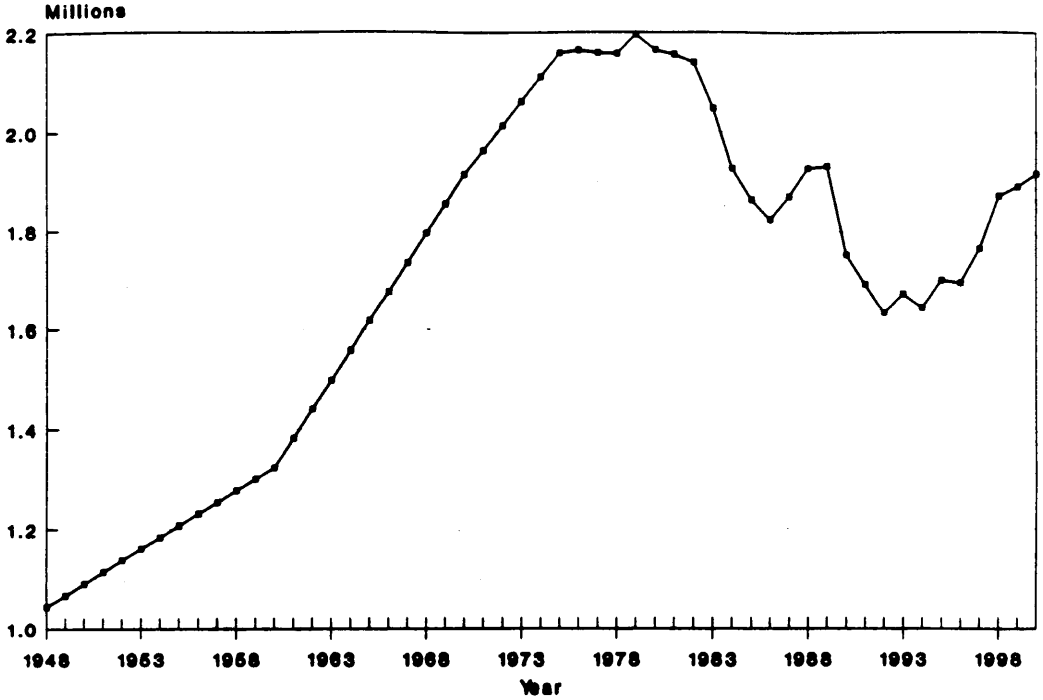

Figure 3. Male 18-year-olds in the U.S. population with projections from 1983 to 2000
Source: Bureau of the Census

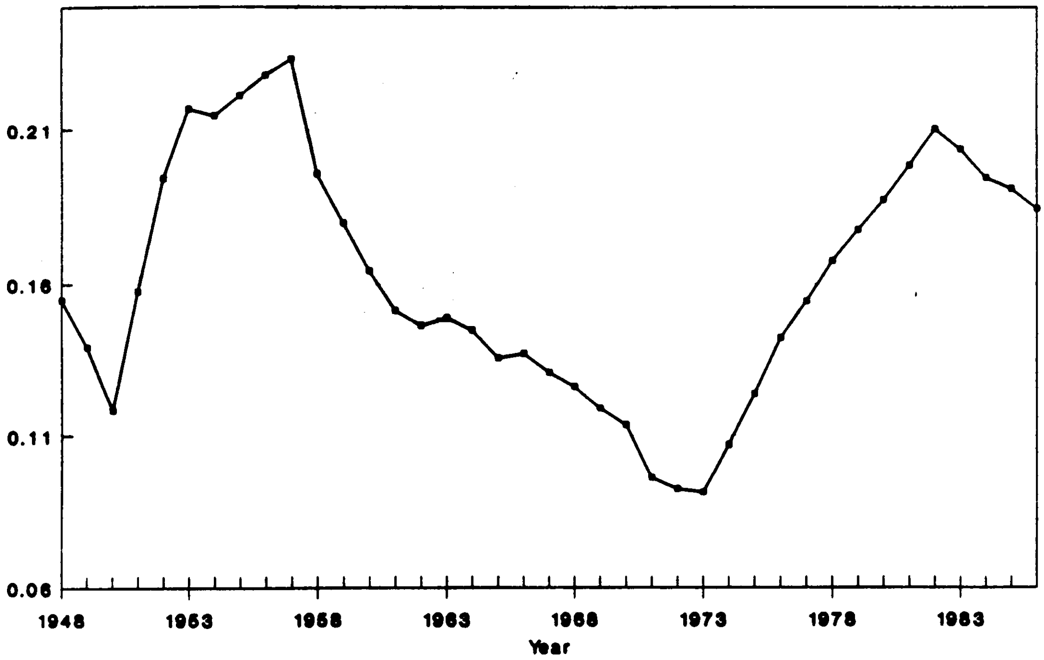

Figure 4. Proportion of college freshmen in engineering
Sources: Engineering Manpower Commission and Department of Education

expressed in the Kraus[15] article cited in Chapter I.

Despite the drop in number of 18-year-olds, and the correlated drop in the number of high school graduates, first-year college enrollments have remained fairly steady in the 1980s.[16] More importantly, Figure 4 demonstrates that the proportion of freshman enrolled in engineering has varied at least as much as the overall demographic and enrollment trends. The proportion of college freshmen in engineering turned up sharply in the 1950s, but then declined steadily in the 1960s and early 1970s. As long as the number of college enrollment grew, as it did in the 1960s, that decline in share of college enrollments did not translate into fewer engineering students. However, the coupling of the proportional decline with the levelling off of the total number of freshman college students did result in the early 1970s "depression" in engineering enrollment. The curve reverses in 1973, at the beginning of the recent growth in number of first-year engineering students.

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[15] John Kraus, "Colleges Must Prepare for the Enrollment Crash of 1990," The Chronicle of Higher Education, January 6, 1988, p. B2.

[16] U.S. Department of Education, Center for Education Statistics, Digest of Education Statistics, 1987 (Washington, D.C.: U.S. Government Printing Office, 1987), p. 130.

The critical point here is that engineering enrollments have often moved in directions quite different from the demographic trends, falling in periods of population growth, and recently rising as the male 18-year-old cohort shrinks. Obviously other factors are at work in the engineering market. One of the most important of these is shown in Figure 5, which illustrates the position of engineering salaries relative to salaries of other college graduates[17].

As documented in Figure 5, beginning in the early 1950s, starting salaries for engineers grew at a faster rate than for all college graduates. According to Hansen[18], the period from 1946 to 1952 was one of decline in the relative earnings position of engineers. Beginning in 1953, however, starting engineers experienced an improvement in their earnings position relative to starting salaries for all workers. That relative position improved somewhat in the 1960s, but began to decline markedly from 1970 to 1973.[19] The gap between

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[17] Data in Figure 5 are shown in constant dollar terms and are indexed by dividing each data point by the 1948 salary level. The comparative salary series from the Bureau of the Census represents median salary of males age 25-34 with 4 or more years of college.

[18] W. Lee Hansen, "The "Shortage" of Engineers," The Review of Economics and Statistics 43 (August 1961): 255.

[19] Freeman, "A Cobweb Model of the Supply and Starting Salary of New Engineers," p. 240.

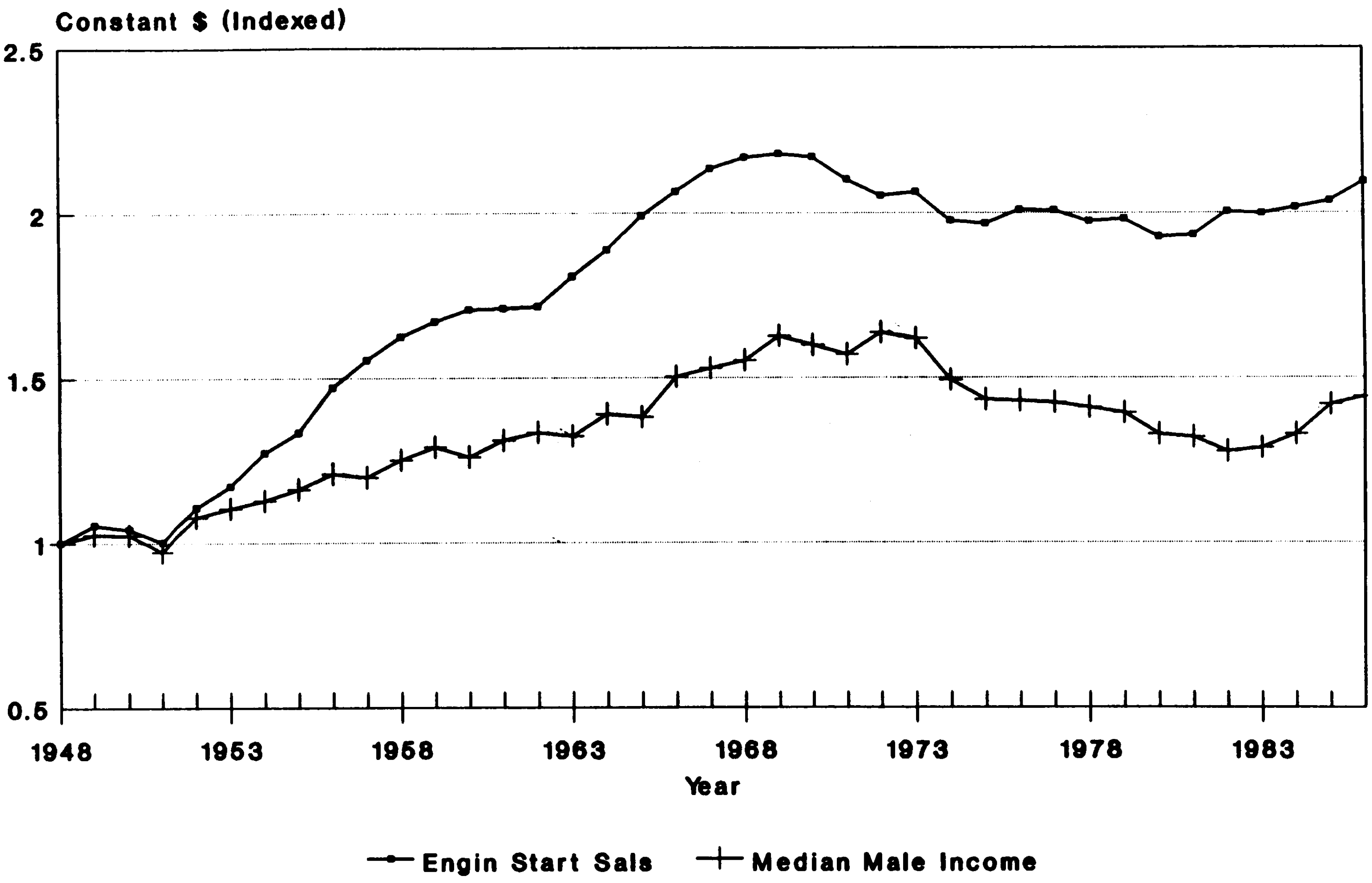

Figure 5. Comparison of beginning salaries for engineers and college graduates age 25-34
Sources: Bureau of the Census and the Engineering Manpower Commission

engineering salaries and those of other workers, which had narrowed in the early 1970s grew wider in the mid-1970s. Engineering salaries rose at a faster pace than for all male college graduates, and increased their relative position into the 1980s, when salaries of other workers began to catch up. These changes in relative salary position are remarkably consistent with the trends in first-year engineering enrollments seen in Figure 2.

In addition to changes in relative salaries, other factors have been considered influential on the engineering labor market. Figures 6 and 7 illustrate two of these variables: national expenditures for research and development, and durable goods output. Of the two, variation in R&D expenditures appears to have had the most direct impact on engineering employment and in turn, first-year enrollments. As shown in Figure 6, by far most of R&D funding is expended in the applied area, where engineers are most likely to be employed, rather than in basic research. In constant dollar terms, R&D expenditures began a rapid climb in the 1950s and 1960s. After these two decades of growth, federal R&D spending, which accounts for about one-half of all R&D was cut back in the mid-1960s and decreased in the early 1970s. Following the 1970s decline, R&D spending began again to grow rapidly, fueled--at least on the

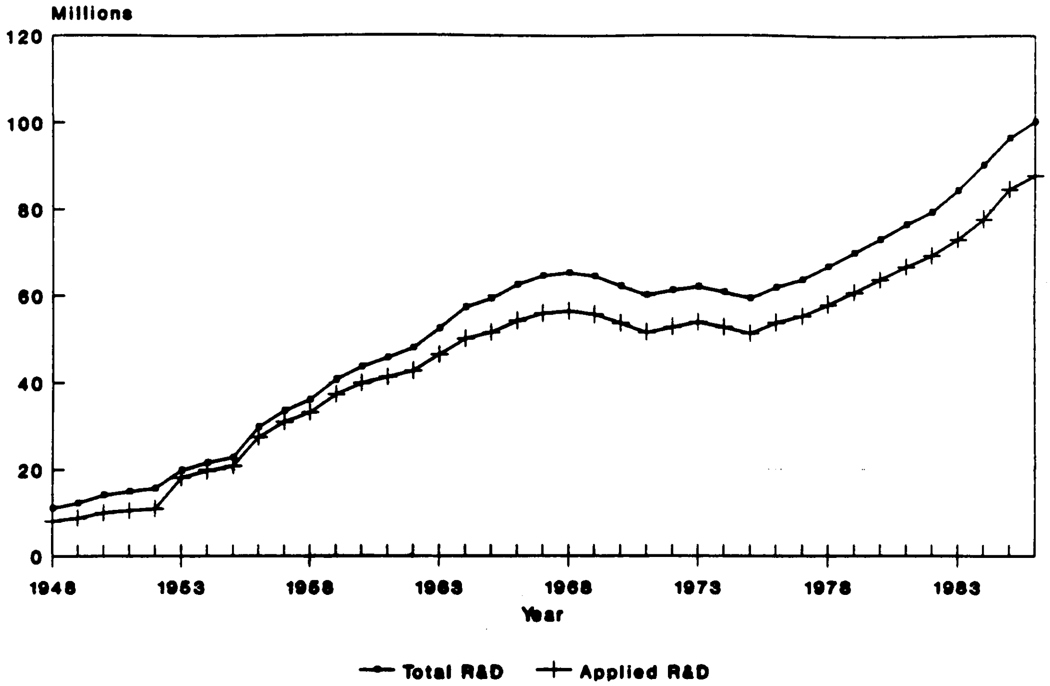

Figure 6. National expenditures for R&D in constant 1982 dollars
Source: National Science Foundation

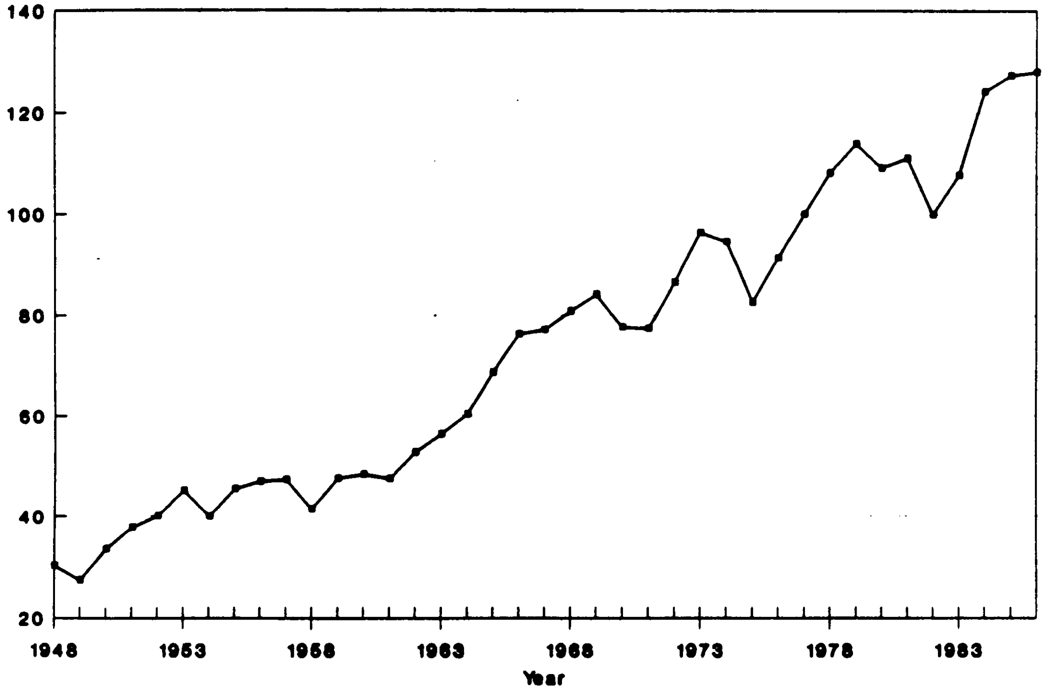

Figure 7. Durable goods output (Index: 1977 = 100)
Source: Department of Commerce, Bureau of Economic Analysis

federal side--almost entirely by an increase in defense R&D expenditures.[20] Interestingly, these increases in defense and applied areas are exactly the sectors where engineers are most likely to find work.

The picture for durable goods output is considerably more mixed. The durable goods index has exhibited greater year-to-year variation than R&D expenditures, but the overall trend--as shown in Figure 7--has been upward. It does appear, though, that periods of rapid growth in durable goods output--eg. the 1950s and early 1960s, and 1975 to 1979--coincide with growth periods for the number of first-year engineering students.

Review of time-series data related to engineering enrollment, then, tends to support the hypothesis that non-demographic factors, in particular relative salaries and research and development expenditures, are more closely related to first-year enrollments than are demographic trends. In the decade of growth immediately following World War II, demographic and economic factors moved together. However, those trends parted company in the early 1960s, as

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[20] National Science Board, Science & Engineering Indicators-1987 (Washington, D.C.: U.S. Government Printing Office, 1988), p. 77.

the demographic growth continued and engineering salaries levelled off relative to other occupations. Engineering salaries fared somewhat better by the middle part of the 1960s. The severe enrollment drop in the 1970s and the subsequent growth in the 1980s corresponded very closely with trends in research and development expenditures and relative salaries, and not with changes in the number of 18-year-olds, high school graduates, or college freshmen. The chapter that follows describes the results of evaluating the Freeman model, and the relationship of demographic versus non-demographic variables to first-year engineering enrollments, over the data series just described.

Chapter IV

METHOD AND RESULTS

The empirical analysis of the Freeman lagged-supply models described in Chapter II proceeded in four stages: 1) replication of the original set of equations published in 1971 and covering the years 1948-1967; 2) replication of the 1976 model for the years 1948-1972; 3) extension of the model through 1984 and comparing the predicted data with actual figures; and 4) employing a set of coefficients based on the full 1948-1986 data set to forecast first-year engineering enrollments to the year 2000. A table of means, standard deviations, and ranges of the variables used in this analysis is presented in Appendix A. Detailed descriptions of each data series--including notes on sources--can be found in Appendix B.

In developing the analysis described here, three assumptions were made concerning the engineering labor market that warrant discussion. First, the supply of individuals entering engineering has been restricted to those completing formal bachelors-degree training. The recursive structure of the Freeman model would not be as appropriate if entry from other sources which did not require the 4 to 5-year training period were a major factor in the engineering labor market.

Second, while it is recognized that subfields within engineering--for example electrical and petroleum engineering--are differentially affected by economic trends, for the purposes of this analysis engineering is considered as a single field. The development of separate equations for engineering subfields would be a useful undertaking, but was judged to be beyond the scope of this thesis.

Third, an implicit assumption is made about the qualitative aspects of new entrants to the engineering labor market. It is assumed that the quality of B.S. engineers has been relatively constant, or has varied randomly over the study period relative to other factors such as job requirements. Of particular relevance here is the assumption that there has not been a consistent change over time in the requirements for the number of engineers to satisfy a particular level of demand. The assumption that the "comparative worth" of engineers in relation to job requirements is constant, or at least changes fairly gradually, allows us to estimate a model with consistent coefficients of the exogenous variables. If this were not the case, i.e., that a discrete technological breakthrough markedly altered the number of engineers necessary to perform engineering functions in the economy, then the regression coefficients would have to be re-estimated after each of these structural changes.[21]

One improvement made over the Freeman analysis is the use of a data series on alternative salaries more closely comparable to first-year engineering salaries. Freeman used a salary data series representing incomes of all professionals in his analysis. However, salaries for all professionals may not relate directly to salaries for individuals just beginning their careers. This potential age-related problem has been controlled for in this analysis through the use of salaries of male college graduates in the youngest cohort available from the Bureau of the Census, age 25-34. We would expect, then, that the coefficients for the alternative salary variable to be somewhat different in the

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[21] One important factor in the rationale for this assumption is the nearly insurmountable definitional and measurement problems a researcher would face in dealing with changes in the quality of an individual or group of individuals over time. As have the prior analyses, this thesis will hold to the assumption of constant relation between job requirements and quality of new B.S. engineers.

replications developed here from those in the Freeman analysis.

A. Replication of 1948-1967 Model

Displayed in Table 1 are the results of replicating the first version of the Freeman model over the 1948-1967 period.[22] Freeman's use of log difference variables, presumably to reduce effects of serial correlation in the regression model, was followed in this stage of the analysis. In equation 1, the supply of freshman engineers was found to be positively related to engineering starting salaries and the number of college freshman and negatively related to the alternate salary measure. Equation 2 shows some small positive relation between R&D expenditures and engineering salaries, but the sign of the durable goods variable was the opposite of what was expected. The final lagged-supply model (equation 3) did yield a higher R^2, and t-statistics on both the coefficients for the number of college freshmen and the number of engineering graduates were significant.

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[22] In Tables 1, 2, and 3, the Freeman results are shown first, followed by the coefficients calculated in this analysis.

TABLE 1

Replication of Freeman Lagged-Supply Model for the Years 1948-1967[a]

1. Supply of Freshman Engineers
(Dependent variable = ENR--first-year engineering enrollment)

Intercept	FRSH	ESAL	ASAL	R^2	D-W
Freeman (1971) coefficients					
-0.11	0.76*	2.70*	-0.47	0.75	1.64
	(0.20)	(0.52)	(0.32)		
Replication					
0.02	0.84	0.58	-0.18	0.26	1.33
	(0.49)	(1.10)	(0.97)		

---

[a] All variables are in log-difference form with standard errors in parentheses below coefficients.
D-W = Durbin-Watson statistic.
An asterisk indicates a t-statistic significant at the 0.05 level.

TABLE 1 (cont)

2. <u>Salary Determination</u>
(Dependent variable = ESAL--starting salaries for B.S. engineers)

	Intercept	RD	DUR	GRAD	GRAD-1	GRAD-2	R^2	D-W
Freeman (1971) coefficients								
a.	0.001	0.32* (0.08)	0.10* (0.03)	-0.10* (0.02)			0.81	3.27
b.	-0.003	0.36* (0.05)	0.10* (0.02)	-0.002 (0.03)	-0.15* (0.03)	0.08* (0.02)	0.95	2.53
Replication								
a.	-0.03	0.21 (0.12)	-0.17* (0.09)	-0.04 (0.05)			0.28	1.86
b.	-0.04	0.09 (0.11)	-0.06 (0.09)	0.22 (0.12)	-0.31* (0.15)	0.10 (0.10)	0.58	1.95

TABLE 1 (cont)

3. <u>Full lagged-supply model</u>
(Dependent variable = ESAL--starting salaries for B.S. engineers)

	Intercept	FRSH	GRAD	RD	DUR	R^2	D-W
Freeman (1971) coefficients							
	-0.7	0.57*	-0.50*	0.60*	0.14	0.86	1.57
		(0.19)	(0.09)	(0.22)	(0.11)		
Replication							
	0.02	0.72*	-0.59*	0.32	-0.01	0.70	2.03
		(0.30)	(0.14)	(0.31)	(0.23)		

Where:
ENR = first-year full-time engineering enrollment
FRSH = total male full-time freshman
ESAL = starting salaries for BS engineers
ASAL = annual earnings of professional workers
RD = total R&D expenditures
DUR = durable goods output
GRAD = engineering BS graduates in previous academic year

The results of this stage of the replication were somewhat disappointing. In all three equations, the R^2's were consistently lower than those reported by Freeman, and with the exception of equation 3, few of the coefficients in the three equations were significant. Probably the best that can be said for these results is that except for the durable goods variable, the signs of the coefficients were all in the expected directions, and that the log difference technique did correct for autocorrelation problems, as shown by the acceptable Durbin-Watson statistics.

One likely reason for the discrepancies in the results of this first set of equations lies in differences in the data series used. While a considerable effort was made to reconstruct the data series used by Freeman in his first models, it became clear that much of the data for the immediate post-war period was not of the same quality as later figures. In fact, the early data was amassed before the higher-quality federal data-collection agencies such as the National Science Foundation and the National Center for Education Statistics began their work in the mid-1950s.

B. Replication of 1948-1972 Model

The findings of the second stage of the analysis, replication of Freeman's 1976 model, were considerably more encouraging. As shown in Table 2, there was nearly complete agreement between the Freeman work and the present analysis. In equation 1.b., the addition of the lagged enrollment terms provide a simple lag structure to the model, and represent a sort of "moving average" of freshman engineering enrollment. Thus, last year's engineering enrollment has a positive sign, but freshman enrollment two years in the past--already in their junior years--is negatively related to first-year enrollment. Except for the lack of a significant t-level in the recent college graduates salary term, equation 1.b. is nearly identical to the comparable Freeman results.

The close parallel between the 1976 Freeman model and the current analysis was also reflected in the remaining two equations in the system. Of particular importance is the extremely strong relationship between engineering starting salaries and R&D expenditures shown in the second equation. The R^2 approaches unity, and the calculated t-statistic of 13.33 is significant well beyond the 0.01 level. In fact, further analysis of the second equation revealed that R&D

TABLE 2

Replication of Freeman Lagged-Supply Model for the Years 1948-1972[a]

1. Supply of Freshman Engineers
(Dependent variable = ENR--first-year engineering enrollment)

	Intercept	ESAL	ASAL	ENR-1	ENR-2	R^2	SEE	D-W
Freeman (1976) coefficients								
a.	15.25	4.15*	-3.36*			0.76	0.12	1.09
		(0.72)	(0.73)					
b.	8.53	0.86*	-0.95*	1.14*	-0.64*	0.91	0.06	2.11
		(0.41)	(0.43)	(0.12)	(0.15)			
Replication								
a.	14.06	2.07*	-2.38*			0.64	0.16	0.71
		(0.53)	(0.89)					
b.	8.03	1.05*	-1.27	1.15*	-0.69*	0.86	0.10	1.98
		(0.49)	(0.63)	(0.18)	(0.19)			

---

[a] All variables are in log form with standard errors in parentheses below coefficients.
D-W = Durbin-Watson statistic.
An asterisk indicates a t-statistic significant at the 0.05 level.

TABLE 2 (cont)

2. <u>Salary Determination</u>
(Dependent variable = ESAL--starting salaries for B.S. engineers)

	Intercept	RD	DUR	GRAD-1	R^2	SEE	D-W
Freeman (1976) coefficients							
	3.54	0.41* (0.03)	0.06 (0.05)	-0.06 (0.03)	0.99	0.03	1.23
Replication							
	7.39	0.40* (0.03)	0.11* (0.05)	-0.04 (0.03)	0.98	0.04	1.11

TABLE 2 (cont)

3. <u>Full lagged-supply model</u>
(Dependent variable = ESAL--starting salaries for B.S. engineers)

	Intercept	GRAD-1	RD	DUR	ASAL	ENR-1	ENR-2	R^2	SEE	D-W
Freeman (1976) coefficients										
a.	13.50	-0.45* (0.08)	0.31* (0.11)	0.21 (0.15)	-0.91* (0.41)	0.60* (0.12)		0.95	0.06	1.70
b.	12.70	-0.35* (0.11)	0.32* (0.11)	0.19 (0.15)	-0.90* (0.40)	0.83* (0.21)	-0.26 (0.19)	0.95	0.06	1.98
Replication										
a.	22.10	-0.49* (0.20)	0.35* (0.15)	0.48 (0.25)	-1.51* (0.62)	0.39 (0.29)		0.87	0.10	1.66
b.	19.90	-0.39* (0.19)	0.42* (0.15)	0.26 (0.27)	-1.14 (0.68)	0.73* (0.30)	-0.46* (0.19)	0.90	0.09	1.66

Where: ENR = first-year full-time engineering enrollment
FRSH = total male full-time freshman
ESAL = starting salaries for BS engineers
ASAL = annual earnings of professional workers
RD = total R&D expenditures
DUR = durable goods output
GRAD = engineering BS graduates in previous academic year

expenditures alone was an excellent predictor of engineering starting salaries, generating an R^2 of 0.94.

Equation 3.b.--the full lagged-supply model--appears to confirm many of the theoretical assertions made in Chapter II, that first-year engineering enrollments rise with growth in R&D expenditures and durable goods output, and fall with increases in the size of engineering graduating classes and alternative salaries. As in the Freeman analysis, the durable goods output is less powerful a factor than the other exogenous variables and as expected, the coefficient of the alternative salary variable is somewhat different from Freeman's, although still with the appropriate negative sign.

C. Extension of the Model through 1984 and Comparison of Predicted Enrollments with Actual Data

The third phase in the analysis was to extend the regression over the 1948-1984 period and arrive at a final equation for use as a forecasting tool. The years 1985 and 1986 were left out of this step to allow for a two-period test of the predictive power of the model.

As shown in Table 3, the equation 1 coefficients were found to be remarkably similar to those in the 1948-1972

TABLE 3

Extension of the Freeman Lagged-Supply Model for the Years 1948-1984[a]

1. <u>Supply of Freshman Engineers</u>
(Dependent variable = ENR--first-year engineering enrollment)

	Intercept	ESAL	ASAL	ENR-1	ENR-2	R^2	SEE	D-W
Freeman coefficients for 1948-1972								
a.	15.25	4.15*	-3.36*			0.76	0.12	1.09
		(0.72)	(0.73)					
b.	8.53	0.86*	-0.95*	1.14*	-0.64*	0.91	0.06	2.11
		(0.41)	(0.43)	(0.12)	(0.15)			
Extension through 1984								
a.	17.63	2.59*	-3.40*			0.78	0.15	0.79
		(0.28)	(0.48)					
b.	7.63	1.04*	-1.34*	1.19*	-0.63*	0.92	0.09	1.85
		(0.35)	(0.45)	(0.14)	(0.13)			

---

[a] All variables are in log form with standard errors in parentheses below coefficients.
D-W = Durbin-Watson statistic.
An asterisk indicates a t-statistic significant at the 0.05 level.

TABLE 3 (cont)

2. Salary Determination
(Dependent variable = ESAL--starting salaries for B.S. engineers)

	Intercept	RD	DUR	GRAD-1	R^2	SEE	D-W
Freeman coefficients for 1948-1972							
	3.54	0.41* (0.03)	0.06 (0.05)	-0.06 (0.03)	0.99	0.03	1.23
Extension through 1984							
	8.73	0.45* (0.03)	-0.01 (0.05)	-0.14* (0.04)	0.96	0.05	0.36

TABLE 3 (cont)

3. Full lagged-supply model
(Dependent variable = ENR--first-year engineering enrollment)

	Intercept	GRAD-1	RD	DUR	ASAL	ENR-1	ENR-2	R^2	SEE	D-W
Freeman coefficients for 1948-1972										
a.	13.50	-0.45* (0.08)	0.31* (0.11)	0.21 (0.15)	-0.91* (0.41)	0.60* (0.12)		0.95	0.06	1.70
b.	12.70	-0.35* (0.11)	0.32* (0.11)	0.19 (0.15)	-0.90* (0.40)	0.83* (0.21)	-0.26 (0.19)	0.95	0.06	1.98
Extension through 1984										
a.	20.70	-0.43* (0.09)	0.35* (0.11)	0.40* (0.09)	-1.49* (0.29)	0.47* (0.10)		0.94 (Durbin h = 1.44)	0.08	1.59
b.	17.50	-0.27* (0.09)	0.35* (0.11)	0.26* (0.09)	-1.23* (0.27)	0.89* (0.16)	-0.43* (0.13)	0.95	0.07	1.75

Where: ENR = first-year full-time engineering enrollment
FRSH = total male full-time freshman
ESAL = starting salaries for BS engineers
ASAL = annual earnings of professional workers
RD = total R&D expenditures
DUR = durable goods output
GRAD = engineering BS graduates in previous academic year

regression. The major difference found was that the extension of years added 12 data points to the analysis and resulted in more of the coefficients having significant t-statistics. Some differences were found in equation 2--the salary equation--but again, the most important factor in that equation is research and development expenditures.

Equation 3.b. describes the final form of the lagged-supply model for first-year engineers. The equation yields a very high R^2 and the Durbin-Watson statistic of 1.75 indicates that serial correlation is not present. All coefficients are significant at least at the 0.05 level, and all signs are in the hypothesized directions. Because of the potential for serial correlation stemming from the presence of lagged dependent variables on the right-hand side of the equation, a Durbin-h test was performed on the ENR-1 variable in equation 3.a. The Durbin-h of 1.44 indicates that the null hypothesis of no serial correlation cannot be rejected. The results of that statistical test support the assumption that autocorrelation is not present in the model.

One of critical issues that formed the basis for this analysis was the importance of demographic variables in the modelling of first-year engineering enrollments. Table 4 documents the effect of adding a variable for total freshman

TABLE 4

Full Lagged-Supply Model: Alternative Exogenous Variables[a]

(Dependent variable = ENR--first-year engineering enrollment)

	Intercept	GRAD-1	RD	DUR	ASAL	ENR-1	ENR-2	FRSH	R^2	SEE	D-W
a.	20.70	-0.43*	0.35*	0.40*	-1.49*	0.47*			0.94	0.08	1.59
		(0.09)	(0.11)	(0.09)	(0.29)	(0.10)			(Durbin h = 1.44)		
b.	17.50	-0.27*	0.35*	0.26*	-1.23*	0.89*	-0.43*		0.95	0.07	1.75
		(0.09)	(0.11)	(0.09)	(0.27)	(0.16)	(0.13)				
c.	34.32	-0.64*	0.71*	0.43*	-2.59*			0.17	0.90	0.10	1.23
		(0.09)	(0.11)	(0.12)	(0.36)			(0.26)			
c.	20.59	-0.43*	0.33*	0.38*	-1.59*	0.47*		0.10	0.94	0.08	1.54
		(0.09)	(0.12)	(0.10)	(0.36)	(0.1)		(0.21)	(Durbin h = 1.61)		
e.	17.60	-0.27*	0.36*	0.26*	-1.20*	0.90*	-0.44*	-0.03	0.95	0.07	1.76
		(0.09)	(0.13)	(0.10)	(0.35)	(0.17)	(0.15)	(0.24)			

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[a] All variables are in log form with standard errors in parentheses below coefficients.
D-W = Durbin-Watson statistic.
An asterisk indicates a t-statistic significant at the 0.05 level.

Where:
ENR = first-year full-time engineering enrollment
FRSH = total male full-time freshman
ASAL = annual earnings of professional workers
RD = total R&D expenditures
DUR = durable goods output
GRAD = engineering BS graduates in previous academic year

college enrollment to the lagged-supply equation. The weakness of the relationship between engineering enrollments and cohort-size variables such as the number of 18-year-olds, as demonstrated in Chapter III, led to the choice of college freshman as a more direct demographic-related variable. However, as shown in Table 4, the inclusion of the college freshman variable in equations 4.b., 4.c., and 4.d. adds little to the model. In each of the three equations, the college freshman coefficient is small and not statistically significant. It is interesting to note that as lagged first-year engineering enrollments are added to the equation, the college enrollment coefficient decreases in value, lending support to the hypothesis that the lagged variables provide a cohort-size factor to the model.

As a result of the above findings, equation 4.b. was chosen as the model that would be used in the forecasting phase of this thesis. Preceding the forecasting, however, the predictive power of the model was tested by using the coefficients resulting from the 1948-1984 regression to forecast backward (backcast) from 1984 to 1948, and forward to 1986. The results of that procedure are displayed in Figure 8 and Table 5.

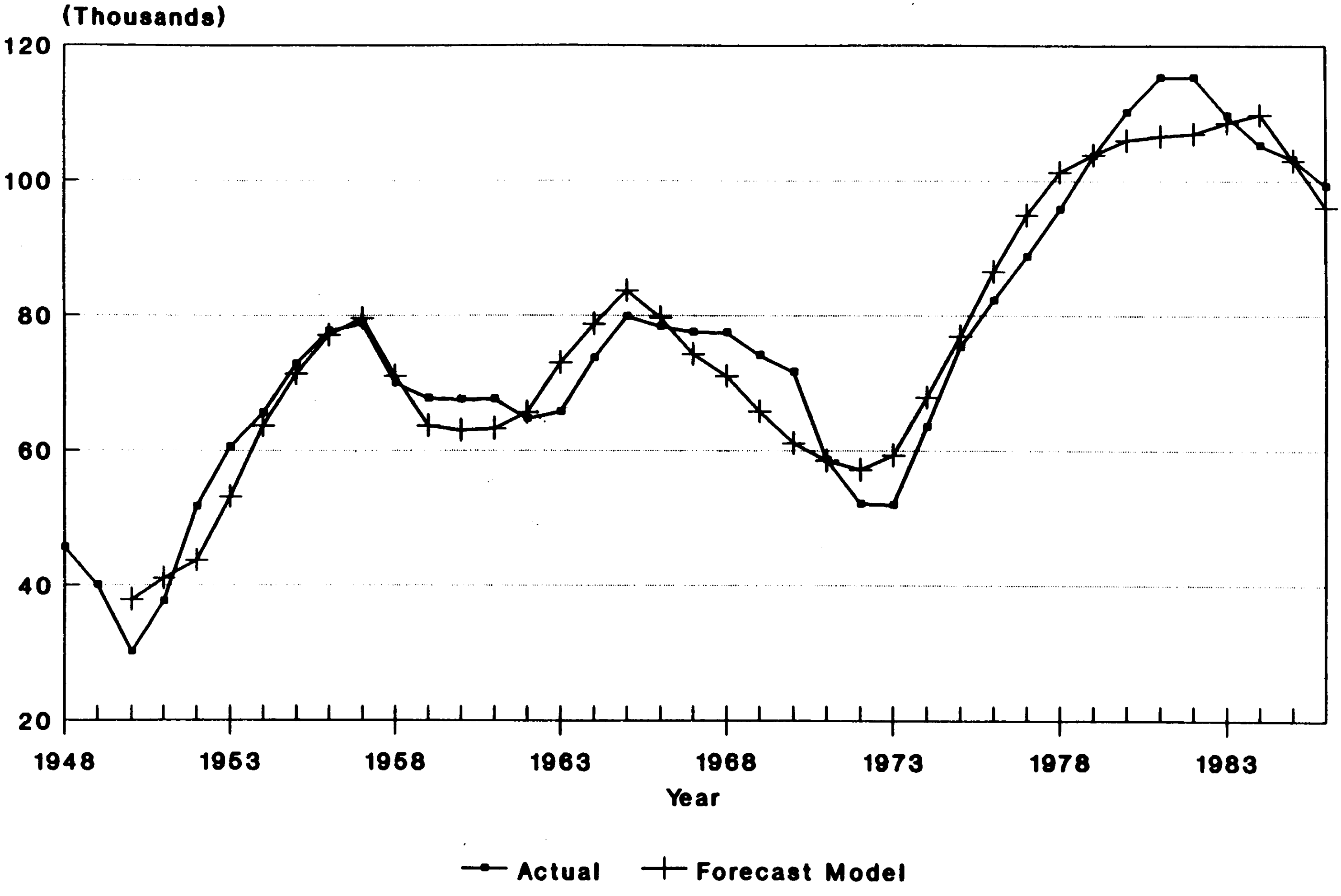

Figure 8. First-year engineering enrollment: actual and forecast

TABLE 5

First-Year Engineering Enrollment: Actual versus Forecast

Year	Actual	Forecast	Year	Actual	Forecast
1948	45,600		1968	77,484	71,004
1949	40,000		1969	74,113	65,833
1950	30,100	37,863	1970	71,661	61,096
1951	37,560	41,004	1971	58,566	58,496
1952	51,631	43,711	1972	52,100	57,100
1953	60,478	53,141	1973	51,925	59,251
1954	65,505	63,613	1974	63,444	67,839
1955	72,825	71,361	1975	75,343	76,941
1956	77,738	77,081	1976	82,250	86,594
1957	78,757	79,566	1977	88,780	94,925
1958	70,029	71,017	1978	95,805	101,283
1959	67,704	63,630	1979	103,724	103,831
1960	67,556	62,945	1980	110,149	106,017
1961	67,575	63,252	1981	115,280	106,653
1962	64,707	65,664	1982	115,303	106,976
1963	65,740	73,043	1983	109,638	108,574
1964	73,682	78,774	1984	105,249	109,764
1965	79,872	83,717	1985	103,225	103,059
1966	78,400	79,708	1986	99,238	96,067
1967	77,551	74,302			

As Figure 8 shows, the model proved to be an effective predictor of first-year engineering enrollments from 1950 to 1984. An indication of the lack of bias in the model is the fact that the area of discrepancy on either side of the actual curve is about equal. That is, the model neither consistently overestimates nor underestimates the actual enrollment data. In fact, over the entire prediction period, the actual data exceeds the predicted by 15,994 individuals, or just 0.6 percent of the total first-year enrollment in engineering from 1950 to 1986. Looking forward from 1984, Table 5 shows that the model predicted almost precisely the 1985 figure, and was on the low side for 1986.

As discussed in Chapter I, one intent of this analysis was to explore whether variables beyond those in the Freeman model would be effective predictors of first-year engineering enrollment. Earlier in this chapter, a more restricted age-related salary variable than the one used by Freeman was adopted in the model. As a final step in the construction of the forecast model, a series of regressions was run, substituting alternative data series for the alternative salary, R&D, and durable goods variables. The substitute variables were as follows:

Variable	Substitute
Alternative salaries	Median wages in manufacturing
Total R&D	Applied R&D Defense expenditures for capital goods
Durable goods	Gross private domestic investment
College freshmen	Male 18-year-olds

None of the substitute variables were found to be better predictors of first-year engineering enrollment than the initial variables. Not surprisingly--because they are measuring nearly the same factors--applied R&D and gross private domestic investment were nearly exact replacements for total R&D and durable goods output. Unexpectedly, the defense expenditures variable was found not to be useful in the model, either as a substitute for R&D or as an additional variable. It may be that the length of the period under study dampens the effect of the defense expenditures variable, which may in fact be an important factor in the engineering labor market in recent years.

D. Forecasting First-Year Engineering Enrollment, 1987-2000

Two steps were taken in preparation for the forecasting of first-year engineering enrollment to the year 2000. First, the coefficients in the lagged-supply model were calculated for the entire 1948-1986 period. The resulting forecasting equation (with all coefficients in log form) is as follows:

$$\begin{aligned} ENR = 17.16 - 0.26\ GRAD\text{-}1 + 0.35\ RD + 0.26\ DUR \\ - 1.21\ ASAL + 0.90\ ENR\text{-}1 - 0.43\ ENR\text{-}2 \end{aligned}$$

Second, assumptions were made about the trends that the exogenous variables (R&D, durable goods, and alternative salaries) might follow in the future. These assumptions were based on the average annual percent change over the study period as recorded in Table 6. Essentially, the forecast parameters were chosen to bracket the expected range of movement in the three variables. Three levels were chosen, a low growth rate (negative for alternative salaries), a baseline--or "best guess"--and high growth rate.[23]

A simplifying assumption was made about the fourth exogenous variable, the number of engineering B.S. graduates. In order to concentrate on the three variables discussed

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[23] Because of the recent unusually high growth rate of research and development expenditures, a further step was taken with the R&D variable. The three growth rates were reviewed with colleagues at the National Science Foundation who are involved in the monitoring of R&D expenditures. Their reaction was that the 4 percent high rate may be somewhat generous, that a 3 percent upper bound might be more realistic, but that the 4 percent rate would surely bracket the upper bound of R&D expenditure growth.

TABLE 6

Actual and Forecast Percent Change in Exogenous Variables, 1948-1986[a]

Variable	Average Annual Percent Change 1948-1986	Average Annual Percent Change 1967-1986	Forecast Parameters Percent Change over Inflation Low	Forecast Parameters Percent Change over Inflation Baseline	Forecast Parameters Percent Change over Inflation High
Total R&D Expenditures	5.46	2.28	0.0	2.0	4.0
Durable Goods Output	3.38	2.30	0.0	2.0	4.0
Alternative Salaries	0.89	-0.26	-1.5	1.0	2.5

[a] Percent change based on variables in constant dollar terms.

above, the graduation rate for engineers was assumed to be a constant percentage of first-year enrollments, and that rate was calculated over the 1948-86 period to average 61 percent.[24]

Figures 9, 10, and 11, along with Table 7, display the results of this forecasting exercise. Each of the figures shows the effect of changes in one of the three exogenous variables. The baseline estimate is identical for the three graphs, that is, R&D up 2% per year, durable goods output up 2%, and alternative salaries growing 1 percent above inflation. As expected, the three levels of explanatory measures resulted in relatively wide variation in the path that first-year engineering enrollments might follow. Note that the trends in enrollments caused by the three variables are essentially additive. In other words, a rise in both R&D expenditures and durable goods output will result in greater first-year enrollments than would result from a change in just one the variables.

As in the regression analysis of the lagged-supply model, the importance of the R&D and alternative salary

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[24] Although inspection of trend data revealed that the graduation rate for freshman engineers is not constant, a full analysis and modelling of graduation rates was beyond the scope of this analysis.

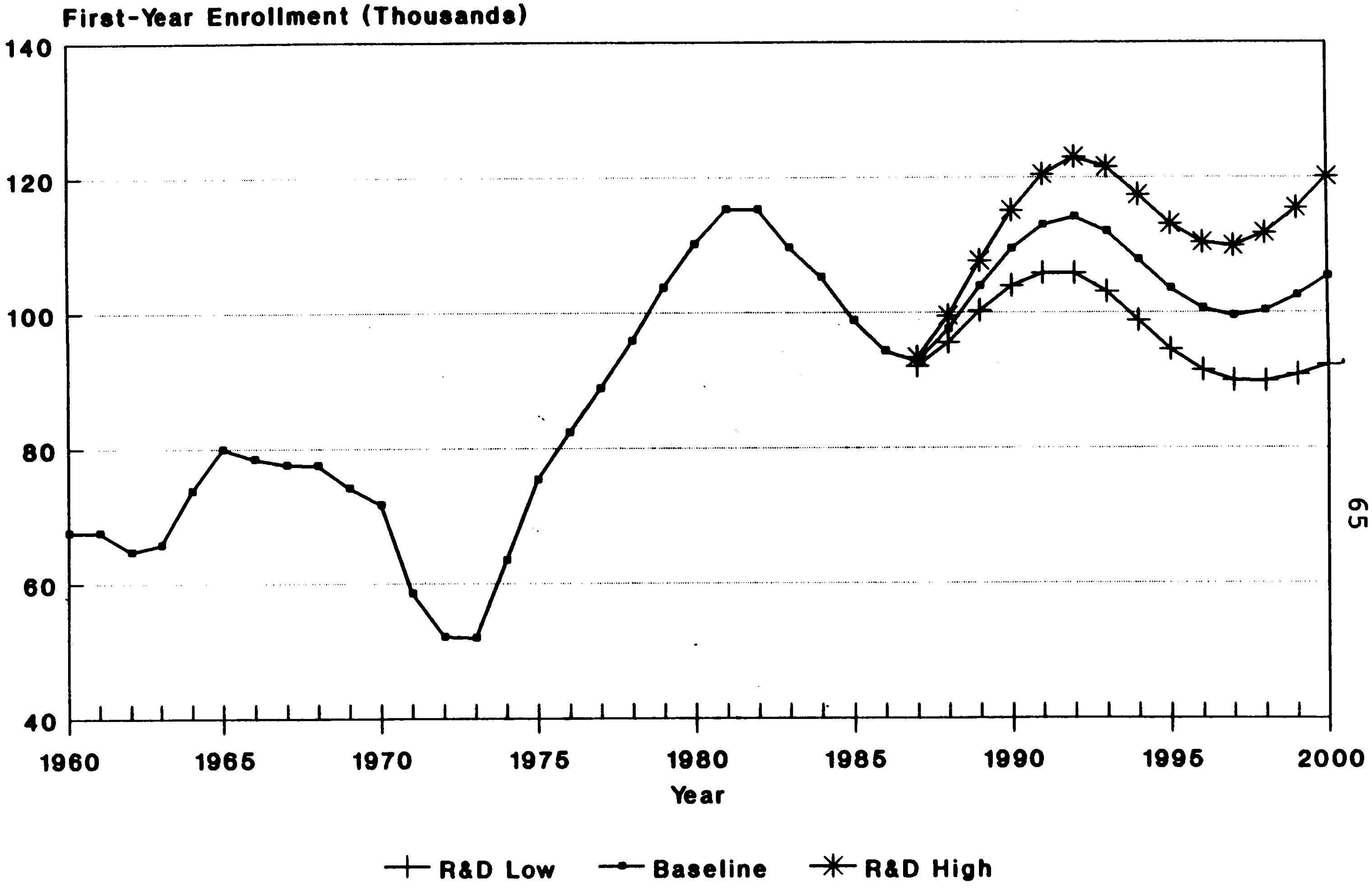

Figure 9. Forecasting the number of freshmen engineers while varying the growth rate in total R&D funding. See Table 6 for growth rate assumptions.

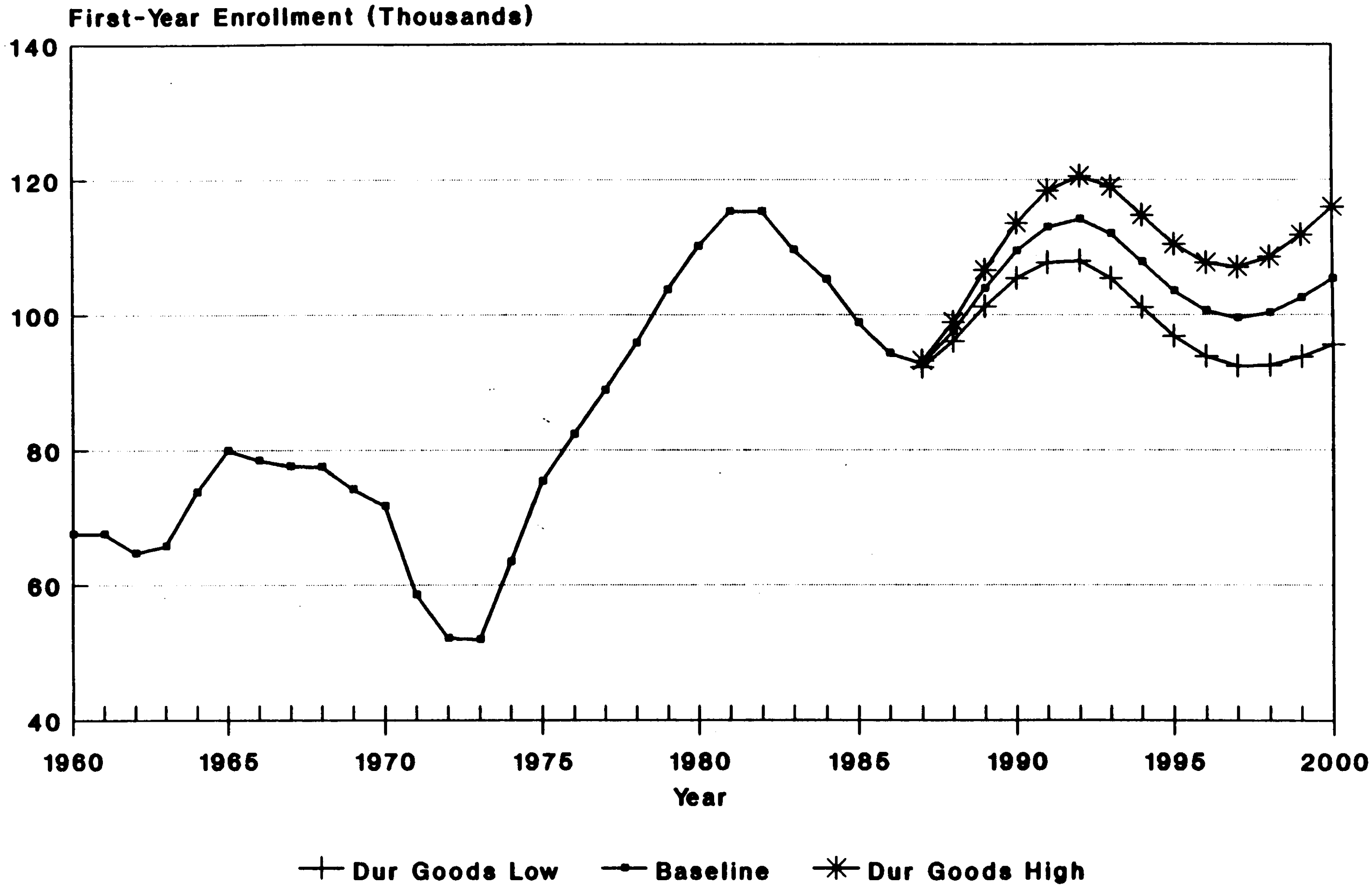

Figure 10. Forecasting the number of freshmen engineers while varying the growth rate in durable goods output. See Table 6 for growth rate assumptions.

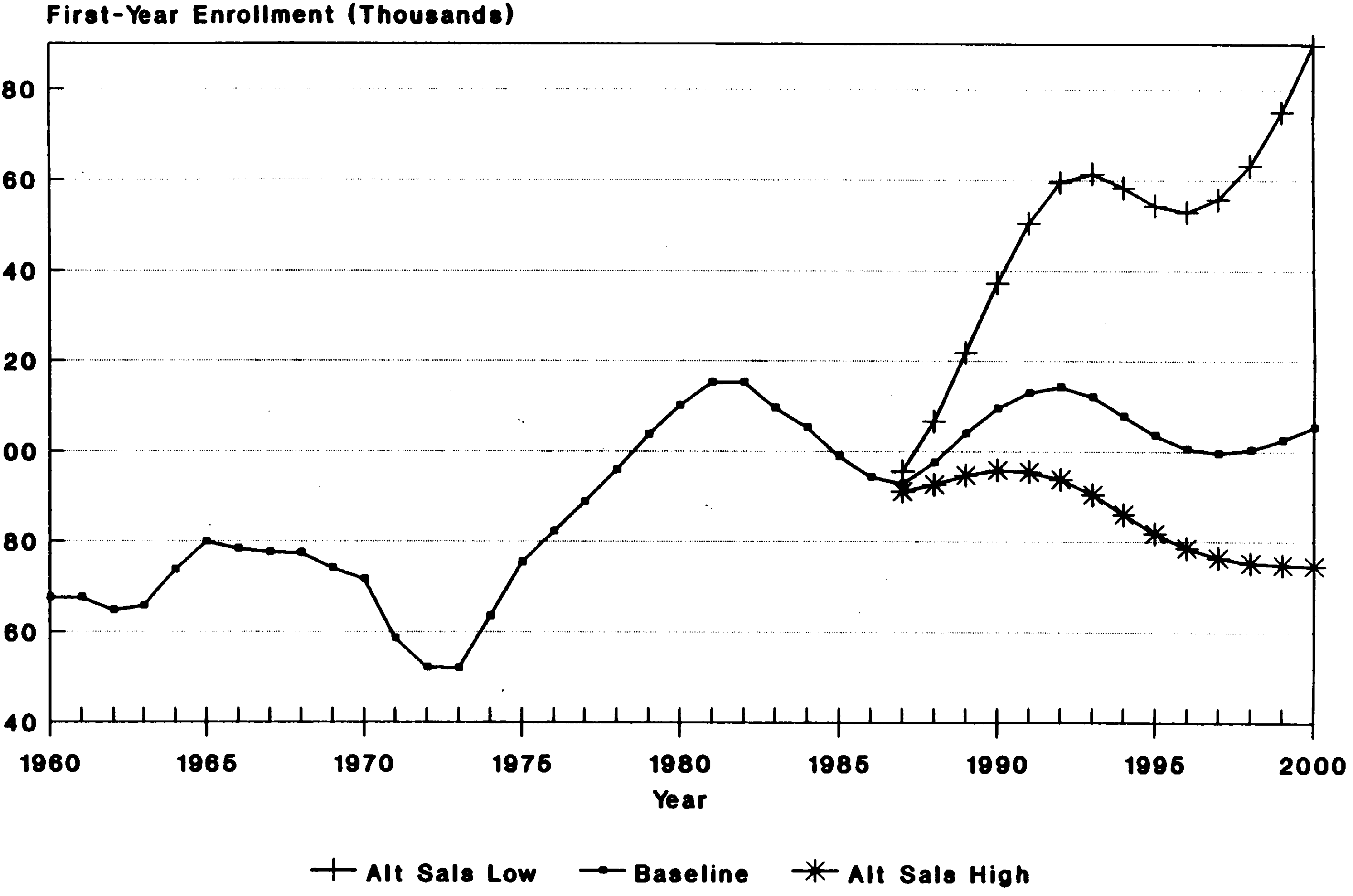

Figure 11. Forecasting the number of freshmen engineers while varying the growth rate alternative salaries. See Table 6 for growth rate assumptions.

TABLE 7

Actual and Projected First-Year Engineering Enrollment Under Varying Assumptions About Growth of Endogenous Variables

	Growth Rates of Explanatory Variables						
Year	Baseline R&D+2% DUR+2% ASAL+1%	Low R&D R&D+0%	High R&D R&D+4%	Low DUR DUR+0%	High DUR DUR+4%	Low ASAL ASAL-1.5%	High ASAL ASAL+2.5%
Actual							
1960	67,556	67,556	67,556	67,556	67,556	67,556	67,556
1961	67,575	67,575	67,575	67,575	67,575	67,575	67,575
1962	64,707	64,707	64,707	64,707	64,707	64,707	64,707
1963	65,740	65,740	65,740	65,740	65,740	65,740	65,740
1964	73,682	73,682	73,682	73,682	73,682	73,682	73,682
1965	79,872	79,872	79,872	79,872	79,872	79,872	79,872
1966	78,400	78,400	78,400	78,400	78,400	78,400	78,400
1967	77,551	77,551	77,551	77,551	77,551	77,551	77,551
1968	77,484	77,484	77,484	77,484	77,484	77,484	77,484
1969	74,113	74,113	74,113	74,113	74,113	74,113	74,113
1970	71,661	71,661	71,661	71,661	71,661	71,661	71,661
1971	58,566	58,566	58,566	58,566	58,566	58,566	58,566
1972	52,100	52,100	52,100	52,100	52,100	52,100	52,100
1973	51,925	51,925	51,925	51,925	51,925	51,925	51,925
1974	63,444	63,444	63,444	63,444	63,444	63,444	63,444
1975	75,343	75,343	75,343	75,343	75,343	75,343	75,343
1976	82,250	82,250	82,250	82,250	82,250	82,250	82,250
1977	88,780	88,780	88,780	88,780	88,780	88,780	88,780
1978	95,805	95,805	95,805	95,805	95,805	95,805	95,805
1979	103,724	103,724	103,724	103,724	103,724	103,724	103,724
1980	110,149	110,149	110,149	110,149	110,149	110,149	110,149
1981	115,280	115,280	115,280	115,280	115,280	115,280	115,280
1982	115,303	115,303	115,303	115,303	115,303	115,303	115,303
1983	109,638	109,638	109,638	109,638	109,638	109,638	109,638
1984	105,249	105,249	105,249	105,249	105,249	105,249	105,249
1985	103,225	103,225	103,225	103,225	103,225	103,225	103,225
1986	99,238	99,238	99,238	99,238	99,238	99,238	99,238

TABLE 7 (cont)

	Growth Rates of Explanatory Variables						
Year	Baseline R&D+2% DUR+2% ASAL+1%	Low R&D R&D+0%	High R&D R&D+4%	Low DUR DUR+0%	High DUR DUR+4%	Low ASAL ASAL-1.5%	High ASAL ASAL+2.5%
				Forecast			
1987	92,712	92,068	93,349	92,239	93,179	95,610	91,050
1988	97,532	95,583	99,482	96,099	98,958	106,610	92,558
1989	103,922	100,255	107,649	101,220	106,643	121,761	94,677
1990	109,452	103,984	115,093	105,414	113,561	137,199	95,831
1991	112,987	105,867	120,433	107,720	118,402	150,542	95,438
1992	114,164	105,823	122,982	107,985	120,567	159,520	93,773
1993	112,067	103,155	121,553	105,459	118,949	161,490	90,397
1994	107,825	98,832	117,437	101,153	114,794	158,297	86,027
1995	103,515	94,549	113,133	96,861	110,485	154,344	81,840
1996	100,600	91,475	110,432	93,824	107,720	152,992	78,615
1997	99,517	89,905	109,941	92,373	107,060	155,742	76,470
1998	100,284	89,793	111,760	92,477	108,578	163,233	75,298
1999	102,516	90,791	115,483	93,779	111,874	175,130	74,817
2000	105,366	92,207	120,091	95,546	115,976	189,730	74,552

variables is made clear in the forecast graphs. The width of the high and low forecast brackets is substantial for R&D expenditures, but extremely wide for alternative salaries. The forecast figures in Table 7 for the year 2000 demonstrate this range of estimates. For R&D expenditures, the estimates range from a low of 92,000 first-year students to a high of 120,000, or a range of 28,000 students, or 28 percent of current enrollment. Varying alternative salaries results in a wider range, from about 191,000 at the lower bracket of salaries (recall that ASAL is negatively related to enrollments) to 74,000 for the highest salary growth rate, a range greater than the 1986 number of first-year engineering students.

One consistent factor in the various forecasts is the continuation of the recursive nature of the lagged-supply model. Even in Figure 11, where alternative salaries have a dramatic impact on the forecast, first-year engineering enrollments are shown to recover from their current downturn, rise into the 1990s and then dip once again between 1995 and 2000. The relationship between these forecasts and the actual flow of freshman into engineering is discussed in Chapter V.

Chapter V

SUMMARY AND DISCUSSION

In 1974, Cain, et al, wrote a prescient description of the engineering labor market:[25]

> Rates of return have on average exceeded the rates for the average degree holder, they have fluctuated much more than for all degree holders, thereby reflecting the interplay of the much larger supply and demand shifts within this occupation.

The kind of shifts described above continue today: trends in engineering enrollment in the 1980s have been nearly a perfect reflection of the cyclical nature of the engineering labor market. The current decade began with rapid growth in engineering enrollments and degrees, and a booming job market for all types of engineers. Engineering B.S. graduates were pursued by employers, with starting salaries increasing dramatically. By the middle of the decade, however, the upswing in enrollments and in turn, degrees, turned into a decline, which has continued through 1987.

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[25] Cain, et al., Labor Market Analysis of Engineers and Technical Workers, p. 41.

The intent of this thesis was to explore the relationship between economic condition and the supply side of that labor market--the flow of new students into undergraduate engineering programs. The model developed here provides a set of factors that appear to underlie the recent market fluctuations. According to the Freeman lagged-supply model, sharp increases in demand for engineers in the 1970s, fueled by impressive growth in research and development expenditures, drove starting salaries upward relative to other career options, sending a strong signal to entering college freshman to pursue engineering bachelors degrees. That bulge of engineering students came through the pipeline beginning in 1978 and increased in number through 1986. However, as that surge of new engineers entered the labor market, demand levelled off and engineering salaries lost ground relative to other occupations. Perceiving this change in demand as expressed in salaries, the number of college freshman choosing engineering levelled off in 1983 and declined thereafter.

Four hypotheses were set out at the beginning of the thesis:

1. The lagged-supply structure is effective in modelling and forecasting the number of first-year engineering students.

2. National economic factors such as R&D expenditures, salaries, etc, are closely related to freshman enrollments in engineering.

3. Demographic variables, while significantly related to freshman enrollments, are not the sole determinants of first-year enrollments.

4. The field choice of entering college freshman is highly sensitive to market factors, particularly the relative position of engineering salaries versus alternative occupations.

The first hypothesis, that the lagged-supply model is an effective tool in describing trends in freshman engineering enrollment--is certainly supported by the empirical results. The model developed in this thesis was able to a very large degree to mirror the enrollment trends from 1948 to 1986. Its usefulness as a forecasting tool is also apparent. The structure of the model leads to forecasts of both growth and decline in engineering enrollments, a more realistic picture than straight-line extrapolation models would generate. As Professor Harvey Brooks of Harvard has said "forecasts tend to be surprise free, but the future tends to be surprise rich." As a forecasting tool, the lagged-supply model appears to provide insight beyond the surprise-free extrapolations. The key to use of the model is in making accurate estimations of changes in the exogenous variables. This is another strength of the model--the forecasting equation requires the estimation of only four exogenous variables, all of which are now being maintained nationally in well-established data series.

For the remaining hypotheses--the importance of demographic versus market factors--the answer appears clear. None of the demographic variables relating to cohort size were found to be significantly related to first-year engineering enrollment. The market variables--especially R&D expenditures and relative salaries--were established as critical factors in the flow of freshmen into engineering. The effect of large negative coefficient on the college graduates salary variable was seen in the forecasting exercise.

The evidence from this analysis--the very high R^2, the degree of statistical significance of the exogenous variables, and the close fit of the predicted enrollments to actual data over a long 39-year period--support the conclusion that the lagged-supply model describes the mechanism underlying the recursive nature of engineering enrollments. One criticism of the Freeman model is the short time horizon theorized for students and employers. In the lagged-supply model, both parties react rapidly to current-period stimuli.

Research on the time horizon issue has recently been published by Mark Berger in Industrial and Labor Relations Review.[26] Berger studied earnings factors involved in the choice of college major, theorizing that individuals look more toward the long-term salary gains than the short-term variables in the Freeman lagged-supply analysis. This life-cycle hypothesis--that the present value of future earnings stream is critical to choice of major rather than beginning earnings--is consistent with the Pashigian rational-expectations approach. Berger found that individuals will tend to choose majors where the present value of predicted future earnings stream increases relative to that of other fields, rather than relying exclusively on starting salary. Thus there is some evidence that reliance on short-term variables such as starting salaries may be a flaw in the lagged-supply model.

Nevertheless, the results of the present analysis do provide a basis for discussing the impact that national policy decisions could have on flows through the engineering pipeline. It is apparent--both from public-policy statements and from growth in federal and corporate research budgets--

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[26] Mark C. Berger, "Predicted Future Earnings and Choice of College Major," Industrial and Labor Relations Review 41 (April 1988): 425.

that U.S. government and industry have concluded that a strong research and development enterprise is critical to our international economic competitiveness. Accordingly, we should expect to see healthy R&D budgets for the near future. Growth in federal R&D support, however, is unlikely to be as strong as in recent years because of the planned levelling-off of Department of Defense R&D expenditures, already reflected in the 1989 federal budget.

Given the importance of research and development funding in the lagged-supply model, the federal government could have a major influence on the supply of engineers. Full funding of large high-technology projects such as the space station or the Strategic Defense Initiative would, according to the analysis presented in this thesis, lead to growth in engineering salaries relative to other professions and in turn, an upturn in first-year engineering enrollment. Thus federal R&D funding decisions provide an important signal to the engineering labor market, which has traditionally been highly reactive to such messages.

Even without any conscious governmental effort to increase engineering enrollments, the forecasts developed here uniformly project a rise in first-year engineering enrollments in the near future. This projected upturn is driven by the four-year lag structure of the model, for as the current drop in enrollments has its effect on engineering degrees in the next few years, the employment situation could improve markedly, with fewer engineering graduates and continued moderate demand. In reaction to this market improvement, the model forecasts growth in the number of first-year engineers in the 1990s.

It is important to recognize that growth in the number of first-year engineers does not require health in the overall labor market for college graduates. On the contrary, the negative coefficient for alternative salaries developed in this analysis means that an economic recession, with a negative impact on employment in general, could raise engineering enrollments so long as R&D expenditures continue to grow. Again, it is the position of engineering salaries relative to those in other comparable occupations that appears to be the critical stimulus to entering students. The importance of relative salaries makes a great amount of intuitive sense, and at the same time it is one central findings of this analysis.

To conclude, we know that over the long-run, the return to the study of engineering at the undergraduate level has proven to be better than returns to most baccalaureate degrees. Nevertheless, the fluctuations in the engineering job market contrast with this return advantage and continue to trouble potential engineering students, employers, and government agencies. It is hoped that this thesis has shed some light on the factors involved in the fluctuation in the supply to that market, and in addition, in the way those factors will affect future flows of students into engineering.

Appendix A

DESCRIPTIVE STATISTICS OF THE DATA SET VARIABLES

Variable	Scale	Mean	Standard Deviation	Range Low	Range High
ARD (tot applied res and dev expend)	millions	46.13	20.92	8.0	87.8
ASAL (salaries of college graduates)	dollars	7647.32	1031.64	5567.4	9378.3
DEF (defense expend on capital goods)	millions	48282.17	17436.71	8585.8	79513.5
DUR (durable goods output)	index	73.6	29.62	27.5	128.0
ENR (freshman engineers)		75033.0	21342.48	30100	85203
ESAL (starting engin salaries)	dollars	7358.03	1542.98	4160.9	9061.9
FRSH (male college freshmen)		478491.13	126835.2	238490	630970
GNP (Gross National Product)	billions	2271.04	766.74	1108.7	3713.3
GPDI (gross private domestic invest)	billions	381.02	139.62	168.8	659.7
GRAD (male engin B.S. recipients)		43367.59	14667.44	22236	78178
MANI (manufacturing wages)	dollars	5611.33	800.27	3828.24	606.98
POP (male 18-year-olds)		1665743.59	399541.1	1044000	2196000
RD (total research and dev expend)	millions	52.91	23.75	11.1	100.2
TOTENR (total engin enrollment)		237858.92	84795.12	102210	406144
TOTSAL (total engin salaries)	dollars	12694.12	2025.18	8487.4	15341.8
UNEM (national unemployment rate)		5.62	1.65	2.9	9.5

[a] Salaries and wages are deflated by CPI (1967 = 100); output measures (GNP, GPDI, RD, ARD, DEF) are deflated by GNP implicit price deflator (1972 = 100).

Appendix B

DATA SOURCES USED IN EMPIRICAL ANALYSIS

Introduction

While well-developed data sources relating to engineering enrollments and degrees exist for recent years, much of the data series for years prior to 1967 are fragmentary and conflicting. As a result, a number of the time series used in the Chapter IV analyses had to be constructed from more than one source. The approach taken was to select data from the major national data sources when conflicts arose between time-series, even when an alternative data series seemed more complete. Thus, data from the two main engineering associations involved in data collection--the American Society for Engineering Education (ASEE) and the Engineering Manpower Commission (EMC)--were used as the benchmark series for enrollment, degrees, and salaries. Other data series were used for early years, and occasionally, imputation was necessary to fit the time series together. Those estimation procedures are noted below where appropriate.

Other national data producers were used as benchmark sources for total enrollments (National Center for Education Statistics-NCES) and R&D expenditures (National Science Foundation-NSF). Again, when a conflict arose, the trends and magnitudes represented by these benchmark series were used in favor of other sources.

Data Series

A. Total first-time undergraduate enrollment at 4-year colleges and universities

1948-1949: Estimated from Folk, Hugh, The Shortage of Scientists and Engineers. The Folk time series encompasses all first-time students, and thus the figures were greater than the NCES data which include 4-year colleges and universities only. The Folk data were brought into line with the NCES figures by regressing common years of the Folk time-series onto the NCES data.

1950-1986: National Center for Education Statistics, Opening Fall Enrollment, annual series.

B. Male first-time undergraduate enrollment

1948-1949: Estimated from Folk data using the method described above.

1950-1986: National Center for Education Statistics, Opening Fall Enrollment, annual series.

C. Full-time first-year enrollment in B.S. engineering programs

1948: The percent change from 1947 to 1948 shown in the Folk data series was applied to the 1949 ASEE data to yield an estimate for 1948. A second estimation procedure, regression of the Folk data against the ASEE and EMC data ($R^2 > .95$) and then using the resulting coefficients to calculate the 1948 data point produce a nearly identical figure.

1949-1951: American Society for Engineering Education, Factors Influencing Engineering Enrollment, p. 8. While the Folk data series extends from 1945 to 1967, the 1945 to 1951 data were out of line with the ASEE figures. The Folk data from 1952 on fit nicely between the ASEE data of 1951 and the benchmark EMC data series beginning in 1967. Thus only the years from 1952 to 1966 were used from the Folk report.

1952-1966: Folk, Hugh, The Shortage of Scientists and Engineers, p.86.

1967-1986: Engineering Manpower Commission, Engineering and Technology Enrollments, various years.

D. Total full-time enrollment in B.S. engineering programs.

1948: Estimated as in C above.

1949-1963: American Society for Engineering Education, Factors Influencing Engineering Enrollment, 1965, p. 8.

1964-1966: National Center for Education Statistics, Engineering Degrees and Enrollments. This series diverged slightly from the ASEE and EMC data in absolute value, but not in trend. Accordingly, the annual percent changes were used to estimate annual figures for 1964, 1965, and 1966 to fill the gap between 1963 ASEE data and 1967 EMC data series.

1967-1986: Engineering Manpower Commission, Engineering and Technology Enrollments, various years.

E. Total Engineering B.S. degrees

1940-1948: Adkins, Douglas L., The Great American Degree Machine: An Economic Analysis of the Human Resource Output of Higher Education, pp. 214-218.

1949-1986: Engineering Manpower Commission, Engineering and Technology Degrees, various years.

F. Starting B.S. engineering salaries

Endicott, Frank S., Trends in Employment of College and University Graduates in Business and Industry, various years.

G. Median Professional B.S. Salaries

1948-1986: National Society of Professional Engineers, Professional Engineers Income and Salary Survey, various years.

H. National Unemployment rate

Economic Report of the President: January 1987, p. 288.

I. Median Income of Males age 25-34 with 4 or more years of college

U.S. Bureau of the Census, Series P. 60, reported annually in Money Income of Households, Families, and Persons in the United States. Table title is "Education and total money income in 19--, persons 25 years old and over by age, race, and sex."

J. GNP (current and 1982 dollars)

Economic Report of the President: January 1987, p. 244-246.

K. Gross Private Domestic Investment (1982 dollars)

Economic Report of the President: January 1987, p. 288.

L. Total and Applied R&D Expenditures

1940-1959: Folk, Hugh, The Shortage of Scientists and Engineers, pp. 33-34.

1960-1986: National Science Foundation, National Patterns of Science and Technology Resources, 1984 (NSF 84-311) and unpublished updates.

M. National Defense Outlays for Capital Investment

Executive Office of the President, Office of Management and Budget, Budget of the United States Government, FY 1988, Historical Tables, pp. 9.3(1) - 9.3(4).

O. Consumer Price Index (1967 = 100)

Economic Report of the President: January 1987, p. 307.

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