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Engineering Shortages and Shortfalls: Myths and Realities

Demographic projections have given rise to concerns about this nation's ability to meet its future need for engineers

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Demographic projections have given rise to concerns about this nation's ability to meet its future need for engineers. A number of models have been developed to determine whether these concerns are warranted. In recent months the findings generated by one of these, the model created by the National Science Foundation's Division of Policy Research and Analysis (PRA), have been gaining prominence. This model projects a cumulative "shortfall" of 275,000 engineering graduates by the year 2011.

This dramatic conclusion has created a considerable amount of controversy. Many people have expressed skepticism about its validity, while others have embraced it unquestioningly as evidence of the need for action. In part, the wide range of reactions may stem from a lack of familiarity with the nature and structure of the PRA model, which has not been published in the open literature—and thus, has not been subject to the rigorous scrutiny of peer review.

The objective of this paper is to remedy this deficiency. PRA has developed two sets of projections: one for baccalaureates and one for doctorates. This paper will focus on baccalaureates since they are the most numerous component of the engineering community.

Model Structure

Market imbalances (i.e., shortages or surpluses of engineers) are generally defined as the difference between supply and demand. The concerns arising from the demographic projections can be summarized as a fear of such an imbalance—specifically, that there will be an inadequate supply of engineering graduates to meet future national needs. Thus, the modeling efforts have been aimed at projecting future engineering supply and demand.

The PRA model defines engineering supply as the number of bachelor's degrees produced in engineering fields. This supply is assumed to be equal to the product of two variables: a demographic variable, which provides an indicator of the size of the pool from which engineering graduates are drawn, and the fraction of that pool who acquire bachelor's degrees in engineering. This supply relationship is tautological rather than behavioral; it is true by definition and, in consequence, it cannot be refuted.

The model defines the pool from which engineering graduates are drawn as the number in the 22-year-old cohort. The trend in this number has been downward since the middle of the 1980s (Figure 1).

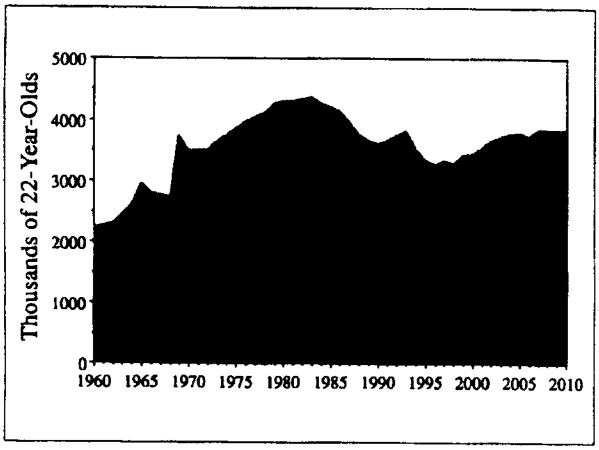

FIGURE 1 The decline in the U.S. college-age population continues until the late 1990s.

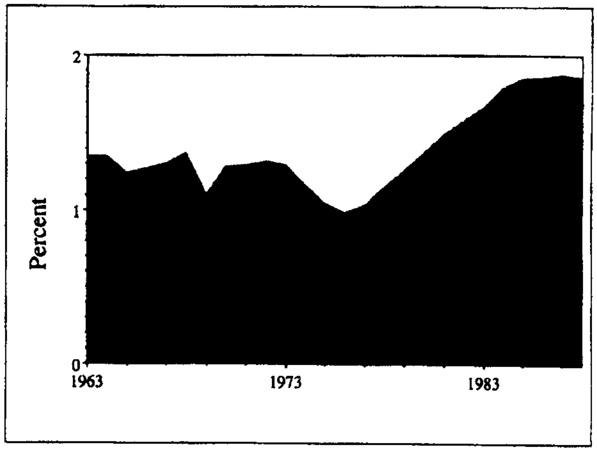

FIGURE 2 The U.S. engineering participation rate, the fraction of the college-age population earning engineering degrees, has increased since the mid-1970s.

The fraction of the pool acquiring degrees in engineering is defined as a "participation rate"—i.e., the number of bachelor's degrees awarded in engineering per hundred 22-year-olds. The trend in this fraction has been sharply upward since the middle of the 1970s (Figure 2).

Treatment of demand is more ambiguous. Demand is not explicitly defined; instead, the model considers a "proxy" for demand, defined as the annual production of bachelor's degrees in a given base year.

The reason given for finessing the direct treatment of demand is the conceptual difficulty in identifying the employment of those who have acquired engineering skills by completing bachelor's degrees in engineering fields. The difficulty arises from the mismatch between labor market data, which are occupationally oriented, and education data, which are organized by academic discipline. Many engineering graduates use their skills productively in occupations not officially counted as engineering occupations; and many in engineering occupations do not have engineering degrees. These mismatches make quantitative projection of demand highly uncertain.

PRA argues that use of engineering degree production in a base year as proxy produces a conservative estimate of demand because it limits future replacements and increases in demand to a fixed number of new graduates.

Model Projections

There are several versions of the PRA model—some published, some part of the underground literature, and some about to be published. The assumption made in the earliest model was that the participation rate would remain steady at about 1.67 percent, the level found for 1983. Given this assumption, future changes in degree production would result only from changes in the population pool from which these degree recipients are drawn. The data summarized in Figure 2 clearly show that this assumption is not valid. The participation rate averaged 1.42 percent for the 40-year period, 1959–1988. It varied from 0.98 to 1.88 percent, a range of over 90 percent, over this period. Between 1983 and 1988 the rate rose from 1.67 to 1.86 percent, an increase of almost 20 percent.

In the most recent version, the model relaxes its stringent assumption about participation rates. Instead, based on evidence from a University of California at Los Angeles survey of freshman career intentions, it assumes that the rate will fall from its 1988 value to approximately 1.6 in 1992, after which it will gradually rise again to about 1.7 in 1998. It is further assumed that, after 1998, the participation rate will stabilize and remain at the 1998 level.

The demand proxy varies with the version of the model examined. It is either the 1983 level of degree production or the annual average of 1984–1986 degree production. Both expressions of the demand proxy represented historic highs at the time these models were formulated (Figure 3).

The PRA model defines "shortfall" as the cumulative difference between proxy demand and supply. In other words, a shortfall is defined as the amount by which annual engineering degree production falls

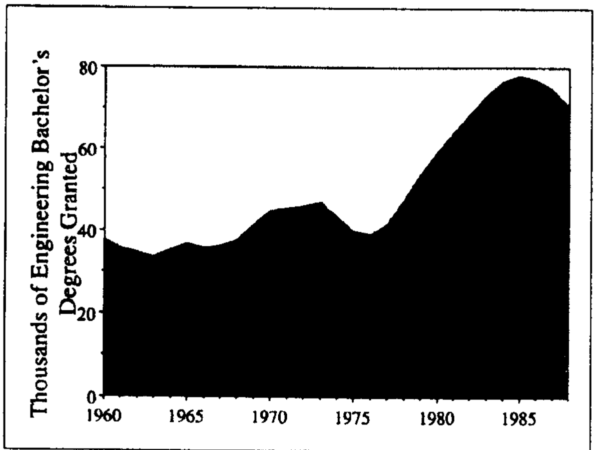

FIGURE 3 Annual production of engineering bachelor's degrees, the proxy for demand for engineers, peaked around 1984.

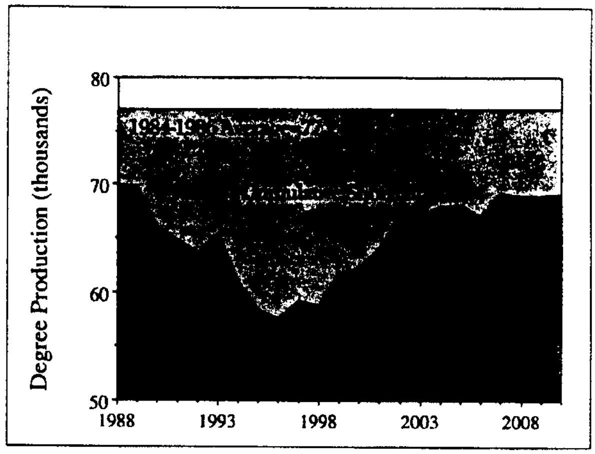

FIGURE 4 Cumulative shortfall of engineering bachelor's degrees, 1988–2010. Shortfall=1984–86 average annual number of engineering bachelor's degrees produced minus projected degree production.

below the average experienced in 1984–1986, cumulated over the years 1988–2011 (Figure 4). Based on this definition, the model projects a cumulative shortfall of 275,000 engineers.

Evaluation of Model

Responsible practitioners of the art of simulation modeling are aware of the limitations of an activity that, in earlier times, used the entrails of chickens as a tool of analysis. Consequently, they practice their art with humility and offer their results with a great deal of modesty. Such practitioners often undertake sensitivity analyses and provide a range of projections to underscore the uncertainty associated with their assessments. Unfortunately, the PRA model produces only one set of estimates, ignoring the important issue of uncertainty.

This failure to acknowledge uncertainty can be pernicious, in that it can seduce the unsuspecting user into believing that the results are more robust than they actually are, given the model's assumptions and definitions. As noted earlier, the model makes a number of arbitrary assumptions about the nature of supply and demand and about future values of these variables.

The model considers only degree production, excluding other sources of supply from its analysis. In engineering, mobility from closely related fields has traditionally been an important source of supply. Moreover, even when the analysis is restricted to degree production, the projections of participation rates for the years beyond 1992 have little factual basis. The degree production projections for 1988 to 1992, generated by participation rates based on freshmen intentions data, are probably reasonable. But the assumption that these rates will slowly rise and level off appears quite arbitrary. Figure 2 shows that these rates can exhibit a considerable range of variation.

Other things being equal, bachelor's degree production can be expected to vary equiproportionately with changes in participation rates, if we accept the tautological supply relationship postulated by the model. Given this expectation, sensitivity analysis would illuminate the range of uncertainty associated with the arbitrary selection of post-1992 participation rates.

The concept used for demand also needs closer scrutiny. As noted above, a proxy for demand is used: average degree production for 1984 to 1986. Implicit in that number is some growth rate in the work force with engineering skills. Arguing conceptual complexity, the PRA model did not examine this growth rate and chose instead to represent demand with one particular proxy. Other proxies can be examined to assess the sensitivity of the particular demand proxy used by the model. To illustrate, I examined the data published by the Bureau of Labor Statistics (BLS) and the National Science Foundation (NSF) to determine the growth rate of the work force with engineering skills in the 1980s, the period for which the model's proxy demand applies. I chose these two particular sources since they provide rough boundaries on the true estimates. The NSF estimates reflect the broadest available operational definition, combining information about degree field, occupation, and professional self-assessment. The 1988 NSF estimate was 2.615 million. The BLS estimates reflect a narrow occupational definition. The 1988 BLS estimate was 1.805 million. The average annual rate of growth exhibited by the NSF data for the period 1980–1988 was 10 percent; the rate exhibited by the BLS data for the same period was 3.5 percent. I believe the NSF estimates provide an upper bound on the estimated growth rate, while the BLS estimates represent a lower bound.

Given the growth rates of these proxies, a lower level of degree production than the 1984-1986 annual average rate might be expected to result in projected annual growth rates of less than the 3.5 to 10 percent range exhibited by these alternative proxies.

As a cross-check on the growth rate analysis described above, assuming that no degree recipient leaves the population on or before the age of 65 and all degree recipients leave at age 66, I cumulated bachelor's degree production in engineering fields for the period 1945–1988 as an estimate of the 1988 population with bachelor's degrees in engineering from U.S. institutions. The number was 1.9 million, about 37 percent below the proxy based on NSF data and about equal to the proxy based on BLS data. If all degree recipients who reach the age of 65 between 1988 and 1992 must be replaced by new graduates, the replacement rate will be approximately 1.4 percent. Given this replacement rate, the number of engineering degrees required to support alternative target growth rates for this period is summarized below:

Target Annual Growth Rate	Annual Number of Engineering Degrees Required
0 percent	23,000
2 percent	63,000
4 percent	105,000

The 1984–1986 degree-production target represents roughly 4 percent of this population. Thus, the target annual growth rate implied by the PRA model's estimate of proxy demand would be about 2.6 percent. Recognizing the constraints imposed by projected slower population growth and reduction in defense expenditures over the next decade, the Bureau of Labor Statistics projects employment in engineering occupations to grow at an average annual rate of 2.5 percent between 1988 and 2000, down from the 3.5 percent rate experienced between 1976 and 1988 and about equal to the growth rate implied by the crude cohort survival model described in the preceding paragraph (Silvestri and Lukasiewicz, 1989). The projected reduction in degree production generated by the PRA model for that period implies an average annual growth rate in the number of engineers with bachelor's degrees in engineering fields of about 2.2 percent for that period.

The model also suffers from a more generic shortcoming. Most of the simulation models used to assess these labor markets assume that markets do not equilibrate; that if an imbalance occurs between supply and demand, nothing will occur to correct it. In fact, history demonstrates that these labor markets do tend to equilibrate (Freeman, 1976; Ginzberg, 1986). Thus, projected imbalances derived from such models—both shortages and surpluses—are always overstatements of what actually will be experienced.

The model considers only degree production, excluding other sources of supply from its analysis.

The relevant policy issue should be whether the expected equilibration mechanisms triggered to correct these imbalances will be consistent with national needs and more global social objectives. For example, if an engineering shortage is expected, will employment of physicists, chemists, mathematicians, and others who are competent to do the work of engineers be a satisfactory means of addressing this shortage? Alternatively, will immigration from other countries be satisfactory? If not, then policymakers will need to consider other mechanisms that will equilibrate supply and demand with minimal unwanted side effects (National Research Council, 1988).

Policy Contributions

Given the shortcomings discussed above, the PRA model is not very useful for policy formulation. Boiled down to its essence, the model simply reinforces the common-sense notion that adverse demographic trends will make it more difficult in the future to produce a given number of engineering graduates. But the model does not provide meaningful information on whether we will need to recruit this number. Moreover, it does not provide a strong factual base for evaluating the types of measures that could or should be taken to alleviate potential problems. For example, the shortfall generated by the model does not constitute a meaningful statistical basis for deciding whether and by how much to increase student support. Instead, it produces a number, an estimated 275,000 shortfall, the magnitude of which in the minds of many implies a situation of crisis proportions.

How much growth do we want to see in our pool of engineering talent?

Failure to document fully the strengths, limitations, and degree of uncertainty associated with this number can ultimately undermine the credibility of simulation modeling—a method of analysis that can potentially shed light on important human resource policy issues—especially if the crisis predicted by this model does not occur.

A more fruitful strategy would be to deepen our understanding of demand. The critical questions to be addressed include: How should we define demand? Can we construct an operational definition of demand that will yield meaningful estimates? How much growth do we want to see in our pool of engineering talent? What constraints exist as barriers to such growth? How can we accommodate those barriers? The answers to these questions will better inform policy than the fanciful shortfalls generated by the PRA model.

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