present lack of such methods weakens support for the reforms and threatens to aggravate fiscal disparities that may already be large. The longer-run research, however, should place greater emphasis on broader performance incentives and reforms integrated with general systems of school finance. Enthusiasm for the specific reforms popular today—career ladder plans and the like—may prove transient, but the general problem of improving educational performance will remain, and it is on this problem that the research should concentrate.

Notes
1 The contributions of Berne and Siegel were developed in a long series of papers (see Barro, 1987, for cities) and then consolidated into a book, Berne and Siegel (1984).
2 For a useful review of approximately 40 such models and their findings, see Tsang and Levin (1983).
3 Two of the most important such studies, both dealing with costs of educating the handicapped, are Kakalik, Furry, Thomas, and Carney (1981) and Moore, Strang, Schwartz, and Braddock (1988).
4 Such models have been developed and applied to several states by Jay Chambers and Thomas Parrish (see, for example, Chambers & Parrish, 1984).

References


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The Education Production Function: Its Evolving Role in Policy Analysis

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Production research in education has been dominated by attempts to estimate the structural parameters of what has been called the education production function. These estimation attempts are viewed in this article as only one way the production function concept can be drawn upon to inform debates over education policy. After exploring what it means to posit the existence of the education production function, the article critically reviews past estimation efforts and gives examples of how the production function can be used as a source of insights to guide policy-relevant inquiries into education productivity.

This is an assessment of what economics has to offer the student of education production. The economist's notion of a production function is used to organize the discussion. It is viewed, to borrow Imre Lakatos's (1970) terms, as the theoretical hard core of a major research program. Two research traditions are identified within this research program. Both are viewed as outgrowths of the belief that it is fruitful to posit the existence of an education production function. The first is the better established and involves the many attempts during the last 20 years to obtain parameter estimates of the education production function. It is viewed as a sensible but troubled line of research, one that has been emptied of its economics content and is showing signs of unraveling. The second tradition is less concerned with estimating the education production function per se than in using the production function as a gateway to broader economic theories and reasoning that can be used to guide inquiry. By foreshadowing interest in estimation, or at least in estimation as it has been conventionally conceived, this approach is able to finesse a number of the thorny problems plaguing the first tradition. It is viewed as a promising but largely unexplored line of research, one that is rich in implications for policy. Given the central role played by the production function in both research traditions, the paper begins with a discussion of what it means to posit the existence of an education production function.

Conceiving the Education Production Function

Strictly defined, a production function, education or otherwise, describes the maximum level of output possible from alternative combinations of inputs. It summarizes technical relationships between and among inputs and outputs. The production function tells us what is currently possible. It provides a standard against which practice can be evaluated on productivity grounds.
Administrative Implications

What is not obvious from the textbook definition is how fundamental and central the production function is to the study and practice of administration. If the production function exists, there is something systematic about the transformation of inputs into outcomes. If the production function exists and is known, the administrator, or policy analyst, can calculate the level of productions that is technically possible under given circumstances. With this knowledge, administrators can make accurate assessments of efficiency and have the requisite knowledge to effect improvement.

If, in contrast, there is no such thing as an education production function, the administrative role in improving productivity is severely curtailed. If there is no production function, there is nothing systematic about the activity under study and it becomes unclear what an administrator can contribute. There is no benchmark against which to assess performance. Changes in the selection and deployment of resources will have no predictable effect. Under such circumstances, one set of decisions is as acceptable as any other.

Although the production function has immense administrative implications, there is a recurring question about whether the education production function is, in fact, real.

**Questioning the Reality of the Education Production Function**

The claim regarding the administrative usefulness of the education production function imposes two requirements. The production function must be real and it must be known. It follows that those seeking to deny the reality of the production function face a difficult task. Withdrawn from them are empirical means of definitively refuting the existence of the production function. The failure of empirical analyses to reveal or demonstrate the existence of regularities and systematic qualities of the transformation of inputs into education outcomes can be dismissed on the grounds that they are simply demonstrating a continued ignorance of a very real production function.

Although it is not possible to dismiss the existence of the education production function on empirical grounds, it is possible to attack it conceptually. For example, an important question can be asked about how many education production functions there are. In one sense, this is a trivial specification question. If the education production function is real, it may take the form of several relatively simple production functions or a single more complex function that accounts for whatever contingencies may be characteristic of education activities. For example, one might suppose that the transformation of inputs into education outcomes differs substantially according to race or sex or age or some other student characteristic. Such differences could be represented by positing the existence of a series of distinct production functions, each representing a particular combination of the relevant student characteristics (Hanushek, 1972, 1976).

This balkanization of the production function can be pushed to extreme lengths. A separate production function might exist for differences in the subject being taught, for differences across particular topics taught within subjects, for differences in the length of time of year, week, and day during which instruction takes place, and so forth. Alternatively, a single, albeit highly complex, production function can be posited that accounts for all contingencies and complexities associated with the production of education outcomes. In either case, the reality of the production function is not the issue.

In another sense, specification problems raise more substantive issues that come closer to the reality question. Suppose there is a separate production function for every imaginable combination of factors. What this means in concrete terms is that regularities in the relationship between inputs and outcomes appear only when the conditions become so circumscribed that only unique events are captured. But if only unique events are captured by the production function, it is hardly obvious that there is anything regular or systematic about the larger education process.

In this light, one might be tempted to conclude that specification difficulties can be used to question the meaningfulness or reality of the production function concept. But this temptation is worth resisting because specification difficulties are quite consistent with the idea that at some level there is something systematic and regular about education production, and this is the heart of the production function concept. Specification problems have more to do with how useful for administrative purposes the production function will be and when its characteristics are known. The more numerous (i.e., more complex) the production functions, the more difficult it will be to obtain knowledge of their characteristics and the more limited will be the generalizability of the knowledge.

A more serious problem arises if the production function is in fact real but for some reason unknowable. Suppose that in addition to being numerous, production functions are also ever changing. The administrator might become knowledgeable of the production function governing a particular combination of circumstances only to find that these have changed unpredictably from one instant to the next. Granted, the administrative advantages of knowing the finite set of ever-changing production functions conceived here are nil, but notice that, strictly speaking, the production function's reality has not been successfully attacked. There is still something systematic about education production. In order to see the regularities, however, one needs access to unknown (or, at minimum, difficult to acquire) knowledge, namely, what precise circumstances will obtain from one instant to the next.

Questions can also be asked about the degree to which actors concerned with education production pay attention to the education production function. If the production function is real but ignored, it ceases to apply to the phenomena it purports to describe. Notice, once again, that this does not question the reality of the production function. Indeed, the fact that a real production function is being ignored is all the more reason to learn more about its characteristics. Once the production function is known, administrative steps could conceivably be taken to encourage decision makers to pay attention to it. But this presumes that administrators have an interest in improving productivity. In publicly administered settings, this presumption is open to question (Boyd & Hartman, 1988; Bramwell, 1986).

Going further, suppose that it is more than a matter of ignoring an underlying real production function and that the actors involved in education make successful efforts to destroy the production function. In other words, suppose the actors, perhaps deliberately, make education unsystematic. Under these circumstances, the status of the production function changes over time.

This logic leads to questions about re-creation. If something has been destroyed, re-creation may be possible; re-creation in a preferred form may even be possible. Reasoning along these lines also prompts questions about the origins of the destroyed production function. Production functions are not static entities awaiting discovery. Instead, they develop and may change dramatically over time. This may happen haphazardly as a by-product of technological change and trial and error, or it may be pursued systematically through research and development. In this latter sense, it may be more correct to think of the education production function as something created or invented rather than simply discovered.

The possibility that the education production function can be destroyed is balanced by the possibility that it can be re-created, perhaps in a superior form. The larger point is that the education production function's reality may be a decision variable. In this light, the question about reality is reduced to a question about whether it is possible to create an education production function. As long as it is possible to establish an education production function, there is a role for administration to play in improving educational productivity.

Finally, the recognition that education actors play a role in the creation, destruction, and re-creation of the education production function raises questions about the resulting production function's evenness. In some
places, the production function may have developed in one fashion; in others, it may have developed quite differently. This is a variant of the specification problem discussed earlier. The differential evolution of the production function is simply another contingency that needs to be addressed in the specification of what likely is a highly complex function. The policy analyst can reasonably despair over how difficult it will be to become knowledgeable of the education production function, but this has little to do with whether or not the education production function is real.

To summarize, the presumed existence of the education production function lies at the heart of administrative efforts to improve educational productivity. Second, it is not possible to dismiss the existence of the education production function on empirical grounds. Third, it is difficult, if not impossible, to dismiss its existence on conceptual grounds. For these reasons, the education production function is well suited to serve as the conceptual base of a policy-oriented research program. It is correctly viewed, to use Lakatos's (1970) term, as the hard-core theoretical commitment of a research program that itself need not be the direct subject of inquiry. This, however, is no guarantee of success, and the ultimate value of the education production function concept will be measured by the fruitfulness of the research traditions it inspires. Two distinct research traditions have grown out of the production function concept; each is examined below.

The Estimation Approach

Economic research dealing with production in education has been dominated over the past 20 years or so by efforts to obtain accurate parameter estimates of the education production function. Although these studies do not all make explicit reference to the underlying production function and are not all carried out by economists, they share a goal of estimating relationships between readily manipulatable school and teacher characteristics and desired education outcomes on the basis of survey data and natural experiment research designs. Hanushek (1986, p. 1159) identified 147 separately estimated education production functions that have appeared in the published literature. (For examples of major studies making use of the production function concept, see Bowles, 1970; Brown & Saks, 1975, 1986; Hanushek, 1972; Katzman, 1971; Murnane, 1975; Rossmillier, 1986; and Summers & Wolfe, 1977.)

This drive to estimation is understandable in light of the immense administrative value discussed earlier of knowing the education production function. But these estimation efforts have also been highly problematic. Production function analysts have known for years that they face serious problems in their efforts to specify the education production function for estimation purposes. Beginning with Bowles's (1970) pathbreaking paper and continuing with the insights offered by Hanushek (1979, 1986), Katzman (1971), and Levin (1976), there have been available clear explanations of what production function estimation requires and the difficulties these requirements create. The dominant response has been to proceed with estimation without independent knowledge of how adequate the specification is. This strategy has merit, but requires sensitivity to the high-risk nature of the enterprise as well as to the importance of consistency in results.

If analysts pursuing this strategy had conducted a large number of separate studies using different data, methodological designs, statistical techniques, measures, and so forth and had found consistent results depicting relationships between manipulatable input variables and desired outcome variables, it could be argued plausibly that genuine progress had been made toward knowing the education production function. The more varied the underlying studies and the more consistent the results, the greater the confidence there would be in using the estimates as the basis of policy.

Compare this hypothetical scenario with the actual results of attempts to estimate the education production function. Existing findings have two telling characteristics. One is their inconsistency. This became clear in one of the earliest surveys of production function research. Harvey Averch and his colleagues observed:

Almost every study finds one or two or three school characteristics significantly related to student outcomes. But these studies generally examine a large number of school resources. Along with the two or three resources that are found to be significant, many are found to be insignificant.

And, when we compare the results of various studies, we find that the same resources do not appear among the lists of significant variables studies have compared (1972, p. 45).

More recently, Eric Hanushek (1986) reviewed this research and also found a noteworthy degree of inconsistency. He found, for example, that among 106 studies estimating the relationship between teacher education and educational outcomes, 6 reported a statistically significant positive relationship, 26 a statistically insignificant positive relationship, 5 a statistically significant negative relationship. 32 a statistically insignificant negative relationship, and 37 reported statistically insignificant results that could not be categorized. Inconsistent results were also characteristic of the other input variables. Hanushek examined: teacher/pupil ratios; teacher experience, teacher salary, and expenditures per pupil.

Hanushek's results illustrate the second characteristic of existing production function estimates: What consistency there is suggests that no systematic relationship exists between the variables of interest. Returning to the results for teacher training, 95 of the 106 relationships estimated were statistically insignificant; only 11 studies reported statistically significant relationships, and these were split quite evenly over the direction of the relationship. Hanushek found similar evidence of insignificant relationships for the other variables he considered. In summarizing his findings, he commented:

The results are startlingly consistent in finding no strong evidence that teacher-student ratios, teacher education, or teacher experience have an expected positive effect on student achievement. There appears to be no strong or systematic relationship between school expenditures and student performance (1986, p. 1162; emphasis in original).

What can be concluded from statistically insignificant results? In a sense, they constitute useful findings. We gain confidence in such self-evident statements that simply spending more on education has no dependable positive effect on student achievement. And we can gain confidence in perhaps less self-evident statements that simply increasing teacher-pupil ratios and teacher experience levels and teacher training levels has no dependable positive effects on student achievement. Is a list of the things that do not make a difference all that production function research has to offer? The production function concept is based on the idea that there is something systematic about the transformation of resources into learning outcomes. Findings demonstrating insignificant relationships simply prompt new questions and further efforts to discover elements of the systematic transformation of inputs into outcomes.

There is also the inconsistency to consider. In the case of the relationship between teacher training and pupil achievement, 11 studies found significant relationships (6 positive and 5 negative). Is it wise to ignore these studies or, in effect, to treat them as if positive results somehow cancel negative ones so that in the net there is no relationship? The inconsistency in itself may be quite instructive. Recall that the analysts lack independent knowledge of how well they have specified the production function they seek to estimate. Inconsistency across studies is the tell-tale sign of the failure to have an adequate specification. If the specification is inadequate, even negative findings, such as the large number of statistically insignificant relationships reported by Hanushek, cannot serve as a valid basis of policy.

Regardless of whether the focus is on the inconsistency or the insignificance of the relationships, this line of research is incomplete. Two strategies have emerged. One continues the deductive approach characteristic of the early estimation attempts; the other shifts to an approach more oriented toward an inductive outcome and has come to be known as effective schools research.
The Deductive Strategy

The inconsistently insignificant results described above have prompted analysts to consider more closely the specification of their production function model. Substantial improvements have been made, and modern production function estimation attempts come closer to the requirements laid down earlier by Bowles and others. Over time, analysts have adopted value-added formulations requiring longitudinal data, they have been more attentive to distinctions between stocks and flows of resources, and they have been more sensitive to the level of analysis as well as to the numerous contingencies that seem to characterize education production.

As welcome as this progress is, analysts continue to lack independent knowledge of how adequate their specification is, and as a consequence the research strategy remains high risk. Again, confidence that insight has been gained into the characteristics of the education production function comes only if the results are consistent across a large number of preferably quite diverse studies. One cannot hope that a single study can be conclusive in this regard.

Although modern production function research is in its infancy, the limited evidence available suggests a pattern that is disconcertingly familiar. Consider, for example, two production function studies that were conducted at an unprecedented level of disaggregation (Brown & Saks, 1976; Rossmiller, 1986). Both studies reached into classrooms and attempted to depict within-classroom differences in the use and effects of schooling resources. Each of these efforts includes elements of disappointment. Rossmiller, commenting on his estimates of relationships between teacher-related variables and students' achievement, is the more outspoken:

In summary, the results of the stepwise regression analyses described above are a bit disheartening. One would hope that the regression coefficients would be consistent and stable, or at least that they would change in an orderly fashion. Unfortunately, the few variables which consistently entered the final regression equations tended to be quite unstable, showing positive standardized regression coefficients in some years and negative coefficients in other years. (1986, p. 15)

Brown and Saks were also disappointed in their inability to show that their measures of how a teacher utilized time within classrooms made any difference in learning outcomes: "In no case do we find that a variable measuring how time is used ... is significantly related to achievement" (1986, p. 497).

The pattern of inconsistent and insignificant results may be repeating itself. Additional insight can be found in closely related research traditions such as the process-product and teacher effects studies conducted by educational psychologists and sociologists. There are those convinced that substantial progress has been made by this research toward identifying the ingredients of good teaching.

Brophy and Good (1986) have provided a comprehensive and generally optimistic review. For example, variables such as pace and coverage have emerged as promising constructs for understanding (and ultimately influencing) the production of learning within classrooms (Barr & Dreeben, 1983; Gamoran, 1988). The optimism such findings generate invites close scrutiny. A single study showing that coverage and pace are either unrelated or negatively related to learning outcomes could quickly resurrect the charge that findings regarding pace and coverage are inconsistent and therefore inconclusive.

Moreover, there is the recurring pattern of modest or insignificant relationships. Even Brophy, one of the chief proponents of the optimistic view, concedes that teacher-effects research does not yield such high correlations between process measures and outcome measures. Instead of being at or above .90, even the correlations that do reach statistical significance tend to range between about .20 and .40, indicating only weak to moderate relationships between teacher behaviors and student outcomes. (1988, p. 13)

And there is no shortage of others who dwell on the inconclusive nature of the entire process-product, teacher effects line of research. Wise and his colleagues put it this way:

Assertions that discrete sets of behaviors consistently lead to increased student performance have been countered by inconsistent and often contradictory findings that undermine faith in the outcomes of simple process-product research. (Wise, Darling-Hammond, McLaughlin, & Bernstein, 1984, p. 10)

A recurring pattern of inconsistent and insignificant results can be expected to prompt still further refinements in the specification of the underlying production function model. One possible and perhaps promising future direction concerns the treatment of outcome variables. Increasing amounts of attention are being given to higher order mental processes (Alexander & James, 1987; Resnick, 1987) as well as to non-traditional means of assessing human capabilities (Suggins, 1987). Perhaps the next generation of production function estimation studies will take advantage of these advances and more directly account for higher order and other kinds of human capabilities. Perhaps we can expect increased use of performance assessments, portfolio analyses, oral examinations, and the like as outcome measures in production function estimation research.

What is the prognosis for such improvement? If success has been elusive when the task was to discern relatively simple relationships between inputs and simple lower order types of outcomes, what justifies thinking that adding measures of higher order skills will make success any more probable? It just may be the case that failure to take account of higher order outcomes is the precise cause of the inconsistent and insignificant results that have dogged production function estimation over the years. Though this is possible, there is little to suggest that it is likely. Poor outcome specification is just one of the many possible inadequacies of the production function specification. It is risky to single it out as the most important source of difficulty. This is not the say that improving the outcome side is ill advised. Rather, it is a strategy with merit, but the risks are high.

A production function is an economic concept, one that can illuminate important aspects of productive activities. Yet the conceptual richness of the concept has been held at bay by the drive to obtain parameter estimates. Rather than explore the richness of economic production theory, analysts have been forced to make simplifying assumptions so that estimation could be carried out. The underlying model has become a caricature of itself and, with a few exceptions (Brown & Saks, 1987; Levin, 1970), the estimation studies have had no particular economics content. Granted, the deductive strategy has become increasingly more sophisticated econometrically, but econometrics is not economics. These studies could just as easily have been conducted by statistically sophisticated sociologists, psychologists, or experts on teaching and educational administration.

The Inductive Approach

The absence of economic reasoning is also characteristic of the more inductive effective schools research strategy that developed out of frustration with the inconsistent and insignificant results of the early efforts to estimate education production functions. This research builds on empirical findings showing that teachers and schools differ in their effectiveness (Armor et al., 1976; Murnane, 1975; Murnane & Phillips, 1981) coupled with the recurring failure to identify with confidence the precise ingredients of success. It abandons the highly deductive approach of conventional production function estimation in favor of a more inductive approach based on intensive case studies of unusually effective or ineffective schooling settings (for an overview, see Education Research Service, 1983).

The absence of economic reasoning is less surprising in this context because economists have not been active in this type of research. It is nonetheless striking in light of the conceptual link between effectiveness research and the education production function. The absence is also regrettable because the economics of effectiveness has important implications for policy analysis. For example, school effectiveness research runs the risk of encouraging inefficient production
practices. It is a backwards-looking approach that is based on past (or, at best, present) exemplary practices. It fails to account for change taking place in the surrounding context. This can be seen in the area of technological development. Researchers have found a slowness to adopt technological innovations in classrooms (Cuban, 1986). This slowness may be for good or bad reasons, but so long as it exists it will be difficult to find naturally occurring instances of excellence wherein innovative uses of technology are present.

In contrast, sites of excellence tend to be places making exemplary use of traditional, labor-intensive instructional technologies. It is hardly surprising that principals and teachers loom large in effective schools studies. But such a heavy emphasis on professionally trained human resources is very expensive and insensitive to underlying shifts in the sources and level of financial support for schools (Brimelow, 1986; Kirst, 1988). It is also insensitive to surrounding labor market conditions and the prospects for recruiting and retaining administrators and teachers who are capable of functioning at the targeted level of excellence (Carnegie Forum on Education and the Economy, 1986; Darling-Hammond, 1984; Feistritzer, 1983; Murnane, Singer, & Willett, 1988).

The neglect of economic issues within effective schools research is symptomatic of the continuing drive to estimation that characterizes the deductive strategy. The goal has been to understand the origins of effectiveness. This is quite analogous to what those using the deductive strategy are trying to accomplish. Production function specification problems again become relevant. It is only if the same ingredients of success are found in highly diverse sites that confidence can be gained in the findings as a basis for policy.

Just as is the case for those pursuing the deductive strategy, there is dispute about how much progress has been made. There are those convinced that effective schools research has identified the means of improving schools; the litany of effective school characteristics has received widespread publicity (Kyle, 1985; Rosenholtz, 1985). There are also skeptics, or at least those who urge caution (Cuban, 1983; Purkey & Smith, 1983; Rowan, Bossert, & Dwyer, 1983). Success at transforming ineffective schools into effective ones is the ultimate test of this research from a policy-making perspective. The failure to do so is analogous to the difficulties that those pursuing the deductive strategy have had at achieving consistently significant results in their estimation attempts.

Interestingly, and perhaps not surprisingly, given the common conceptual roots, the deductive and inductive research strategies seem to be moving closer to one another. As production function estimation attempts become more disaggregated and move more deeply into the classroom, they begin to take on the characteristics of intensive case studies. As effective schools studies seek to demonstrate policy implications, they are drawn away from emphasizing the peculiarities that contribute to effectiveness at one school or the kinds of attributes that can be more reasonably replicated in other settings.

To summarize, the drive to estimate the education production function, whether using a deductive or an inductive research strategy, will likely remain a high-risk endeavor forever searching for consistently significant replicable relationships. This does not deny the importance of the payoff if and when the production function (or some aspect of the Beckerian model) is produced. But it does suggest that the search is likely to be long, frustrating, and costly.

The Gateway Approach

This leads to the second research tradition. The idea here is to use the production function as a gateway to the application of production and other branches of economic theory to education phenomena. The goal is not to estimate parameters of the underlying production function, at least not in the sense described earlier. It is instead to apply economic reasoning to the manifold instances of resource allocation that have bearing on educational activities. The balance of this paper presents three examples of how economic theories can be drawn upon more directly to guide policy-oriented research.

The Production of Education Services

A fruitful distinction can be drawn between the supply of inputs like teachers’ time and space and the supply of education services like units of biology or remedial reading instruction. The process through which discrete inputs are transformed into services is itself a production process that can become the object of study.

Economic phenomena like economies of scale and scale differentials can play an important role in the ability of a schooling organization to translate inputs into services (Barro, 1987; Monk, 1987b, 1987c). Future research could develop in two directions. First, there could be research on the impact of scale and input prices on the mix of services produced. Future analyses will continue to address questions about the degree to which funding for special and compensatory education has detracted from funding for “regular” education. Additional questions are likely to arise about the degree to which the reform movement’s emphasis on academic offerings has prompted declines in vocational and occupational education. Background characteristics (like scale and input prices), which production theory suggests have important effects on the mix of services provided, could play an important role in this type of production research.

Second, there can be research on the means employed to provide a particular service. Many new inputs are arriving in classrooms. A good example is the microcomputer (Carnoy, Daley, & Loop, 1987; Cuban, 1986; Levin & Meister, 1985). The arrival of these innovations and subsequent changes in their prices have important implications for the conduct of instruction. One can ask questions about the impact of computers on specific internal classroom processes, of which grouping is one of the most notable. If computer-assisted instruction raises the productivity of seatwork, one of the historic constraints on the use of grouping will be reduced, perhaps substantially, in classrooms. Economic models of production predict that as the relative price of computer-assisted instruction goes down and the productivity of seatwork goes up, increases in the incidence of grouped forms of instruction ought to follow. Moreover, such models also predict increases in the number of groups and a concomitant reduction in average group size (Brown, 1988; Monk, in press).

Distributing the Returns of Teacher Excellence

There is a productivity dimension to the allocation of excellent teachers that has important, and not much considered, research and policy implications. When administrators have responsibility for a faculty with large, unambiguous variation in quality, a common tendency is to focus on the equity dimension of the resource allocation problem (Bridges, 1986; Monk, 1987a). The idea is to distribute the excellent and the not-so-excellent teachers fairly among students.

By drawing on production theory and placing emphasis on implications for efficiency, the problem takes on a different character. For example, it is possible to use the economist’s notion of jointness in the supply of resources to conceptualize teacher excellence. If a resource is supplied jointly, the fact that one individual benefits from the resource does not detract from the ability of a second (or third or fourth . . . ) individual to benefit simultaneously and to the same degree.

Suppose that excellent teachers are those who are able somehow to protect students already present in their classes from adverse effects occasioned by the arrival of additional students. Such teachers, in effect, are able to achieve the returns associated with one-on-one tutoring despite the number of students assigned to them. More realistically, teachers will vary in their ability to act as jointly supplied resources holding their current students harmless from adverse effects occasioned by additional students.

What follows from even a reluctant willingness to conceive of teacher excellence along these lines? An important first step
would be to determine if and to what degree teachers vary in this way. The resulting research would be quite different from extant efforts to study the effects of class size. The new studies would involve examining the effects of increasing the class size of teachers already known to be excellent using conventional criteria. The primary goal would be not to determine how the excellent teacher achieved this result, but rather to see if in fact excellence, as it is currently identified, carries elements of jointness. To be more precise, the question becomes, At what point does the addition of students begin to detract from the learning (however measured) of those already present, and what is the nature of the decline?

Assuming that a class of identifiable teachers exists whose teaching possesses elements of jointness in supply, the administrative implications are striking. It becomes possible to imagine unambiguous improvements in efficiency. As long as the students already present in the excellent teachers' classrooms are not harmed by the arrival of new students, total learning will have increased at no additional cost. Moreover, the arrival of new students in an excellent teacher's class may even occasion savings if the district is able to release the less excellent teachers who lose students.

The efficiency gain is less clear when the pupils already present begin to learn less as new pupils arrive. Total learning may still increase (at the outset, the gain for the new arrivals will still be larger than the loss of those already present), but it is no longer a Pareto improvement in the sense that some are made better off while no harm comes to others. It is, therefore, very important to know the point at which the decline occurs and how precipitous it is for the students already present.

There is also the burden on the teacher to consider. Although the addition of students may not adversely affect those already present, this may occur only because the excellent teacher is making extraordinary efforts to hold students harmless from the crush of the additional burden. In other words, the cost may be shifted to the teacher who is made less well off because of the additional students. The savings occasioned by the release of less excellent teachers could, in principle, be used to compensate the excellent teachers for the additional burden. This might take the form of additional salary or the form of additional resources over which the teacher would be responsible. One of the advantages that this type of individual "merit pay" would offer is a clear and obvious explanation for differences in compensation packages. Teachers receiving more would be carrying greater loads as measured by the number of pupils brought to an outcome standard.

Schooling in such a world would differ greatly from prevailing practice. Class sizes would vary, perhaps dramatically. Parents and students would face the option of being one of a larger number of students in an excellent teacher's class or one of a smaller number in a less excellent teacher's class, where excellence is conceptualized in terms of the element of jointness in what the teacher provides.

Returns to Subject Matter Knowledge Embodied in Teachers

There is a trend toward placing greater emphasis on the subject matter preparation of teachers, especially high school teachers in technical areas such as mathematics and science (Carnegie Forum, 1986; Holmes Group, 1986). The thinking seems to be that a high school teacher requires, at minimum, a full major in the subject to be taught, and that it is impossible to do justice to a subject area major if professional teacher education is included in the undergraduate program. This reasoning leads to calls for fifth-year and master's-level preservice teacher education programs that may or may not be linked in some reasonable way with a student's undergraduate program.

Input-output relationships. One of the first questions to ask pertains to the strength and nature of relationships between subject matter knowledge embodied in teachers and the learning gains of students. Is more teacher subject matter knowledge always to be preferred to less? Are some forms of knowledge to be preferred to others? Or, to bring a production theory concept to the foreground, at what point do diminishing marginal returns to subject matter knowledge begin to set in, and how precipitous is the diminution?

One response entails focusing on variation occurring in levels of formal subject matter preparation of teachers. This research need not await implementation of the experimental fifth-year teacher education programs coupled with required subject area majors described above. There is substantial naturally occurring variation in subject matter training of teachers, and this could be exploited to provide more immediate insights to its effects. Such studies could document the degree to which subject preparation varies among teachers and assess its effects on the conduct of instruction as well as on the learning outcomes of students. Particular attention could be paid to how less extensively prepared teachers compare with others in coping with their limited subject matter knowledge.

Isolating the effects of subject matter preparation using this approach will not be easily achieved because the sample will likely include life-cycle as well as vintage effects, not to mention variation in teachers' ability to profit from whatever training they received. Attention would also need to be paid to service and other forms of less formal education.

An alternative approach involves assessing teacher subject matter knowledge more directly, using independent performance and knowledge assessments techniques. Carlsen (1987) pursued this approach in his study of the effects of novice high school biology teachers' subject matter knowledge on classroom discourse. This approach faces its own difficulties, however, not the least of which are difficult questions about what counts as subject matter knowledge.

Findings from this type of research will force policy makers to confront thorny resource allocation problems. For example, suppose, as seems likely, that variation exists among students in the degree to which they benefit from a teacher's subject matter expertise. In particular, suppose that only a small number of students are able to draw upon the upper reaches of a teacher's knowledge base. Does it follow that this knowledge base needs to be available to all students despite the fact that upwards of 90 or 95 or 99 percent will never have occasion to draw upon it? Or does it follow that alternative means of supplying the expertise to the few who can draw upon it need to be explored? The economic approach draws attention to the latter course and encourages its exploration.

To push the issue to its logical extreme, suppose findings suggest that no students ever draw upon the upper reaches of teacher subject matter knowledge. Does it follow that advanced training for teachers is necessarily ill advised? Certainly not. The problem may lie not so much with embodying knowledge in teachers as with the kind of knowledge that has been and is being embodied. Different kinds of subject matter preparation are likely to have different effects in classrooms. Training designed along the lines of "fill the teacher with facts" is likely to be most vulnerable to the attenuation problem described earlier. Alternative approaches where there is less emphasis on facts and more on the nature of the knowledge base and how students acquire understanding could be less susceptible to attenuation (Gowin, 1981; Novak, 1977). Research demonstrating attenuation effects could stimulate efforts to reform rather than simply to increase the subject matter preparation of schoolteachers.

Substitution possibilities. A second important question concerns alternative means through which subject matter expertise can be introduced into classrooms. It presupposes, as seems reasonable, that subject knowledge is an essential ingredient of instruction, but questions whether the teacher is the best vehicle for providing this expertise. If the question is rephrased to ask whether it is possible to supply subject matter expertise in forms other than the proximate teacher, clearly the answer is yes. Techno-
ological developments involving computers, lasers, and telecommunication capabilities all facilitate access to raw data and information as well as to interpretations of data and information. As these technologies continue to develop, it is reasonable to suppose that such access will become increasingly cost effective (Becker, 1987; Carnoy, Daley, & Loop, 1987; Levin, Leinier, & Meister, 1986; Levin & Meister, 1985).

The availability of such technology makes possible experiments to estimate the substitutability of subject matter expertise embodied in alternative forms. A central question would be: To what degree can students make the substitution without sacrificing learning outcomes? By how much must the supply of non-teacher-based subject matter expertise be increased in response to a reduction of some fixed magnitude in what a teacher knows about a subject? These are questions about the technical side of educational production. They are questions about how possible it is to do something. They do not address differences in relative costs, the subject of the next section.

Research along these lines represents a sharp departure from more typical evaluations of technology where the focus is on the effects of adding a technological innovation to a classroom. The goal here is not to replace the teacher but rather to explore the prospects of substituting for the subject matter expertise of the teacher. It is not a matter of developing what Levin and Meister (1983) called "stand-alone" computer software, where learning can transpire in the absence of a teacher. It is instead a matter of reconceiving the role of the teacher; in this sense, it is compatible with career ladder and other ongoing efforts to reform teaching as a profession (Malen, Murphy, & Hart, 1988; Rosenholtz, 1987).

Relative costs. Finally, there are important questions to ask about cost. Costs arise in several guises. First, there is the cost of educating teachers and having them retain their expertise. Subject matter expertise is expensive to embody in a teaching force (Hawley, 1987). Moreover, it is subject to potentially high levels of depreciation and obsolescence, particularly if the individuals being trained are not especially adept learners (Weaver, 1983). However, this will certainly vary by field. Some fields are faster moving than others; moreover, external labor market conditions have bearing on how selective districts can be, and these vary systematically both over time and by field of study (Murnane, Singer, & Willett, 1988).

Third, there are costs that teachers face as they teach, and one of these is the foregone opportunity to pursue alternative lines of work; in the case of science and mathematics teachers, these foregone opportunities can be quite attractive (Levin, 1985; Rumberger, 1987). Moreover, unless teacher salaries change dramatically and begin to address these differential costs across subject matter specializations, further emphasis on subject matter specialization runs the risk of exacerbating an already serious problem regarding the retention of those who train to teach.

Summary

The education production function is a powerful conceptual tool, and it would be a mistake to dismiss its value on the basis of the disappointing attempts that have been made to estimate its characteristics. Although the ongoing efforts to estimate production functions have merit, they reflect the use of a high-risk research strategy and are remarkable for their minimal use of economic theory. Economics as a discipline has more to offer than what is revealed by existing efforts to estimate education production functions. Several examples have been offered of what is possible when production and related economic theories are drawn upon to guide inquiries. This is a promising type of research and illustrates an important part of what economics as a discipline has to offer the student of education productivity.

Note

Teachers teach outside their areas of certification on an emergency or permanent basis, particularly in fields, like mathematics and science, that are experiencing shortages. Thus, in addition to the cadre of teachers with the minimum level of subject-oriented training, there will be those with considerably less. (Stories are told of veteran teachers of a high school subject whose formal subject-oriented training is limited to a single undergraduate course taken, say, 25 years ago.) In the opposite direction, there are new recruits who boast complete majors in their intended specialization coupled with preservice teacher training. Moreover, there are alternative certification routes that facilitate entry into teaching for midcareer professionals who are presumably well versed in at least selected aspects of the subject areas they intend to teach. The net result is a "healthy" degree of naturally occurring variation in subject matter preparation of teachers.

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