We can do it

INVESTMENT IN HUMANS, TECHNOLOGICAL DIFFUSION, AND ECONOMIC GROWTH By RICHARD R. NELSON, RAiND Corporation and EDMUND S. PHELPS, Yale University I. Introduction Most economic theorists have embraced the principle that certain kinds of

education the three R's, vocational training, and higher edu-cation-equip a man to perform certain jobs or functions, or enable a man to perform a given function more effectively. The principle seems a sound one. Underlying it, perhaps, is the theory that education en-hances one's ability to receive, decode, and understand information, and that information processing and interpretation is important for performing or learning to perform many jobs. In applying this principle we find it fruitful to rank jobs or functions according to the degree to which they require adaptation to change or require learning in the performance of the function. At the bottom of this scale are funictions which are highly routinized: e. g., running a power saw or diagnosing a malfunction in an automobile. In these func-tions, the discriminations to be made and the operations based on them remain relatively constant over time. In the other direction on this scale we have, for example, innovative functions which demand keeping abreast of improving technology. Even a highly routinized job may require considerable education to master the necessary discriminations and skills. But probably education is especially important to those functions requiring adaptation to change. Here it is necessary to learn to follow and to understand new technological developments. Thus far, economic growth theory has concentrated on the role of education as it relates to the completely routinized job. In its usual, rather general form, the theory postulates a production function which states how maximum current output depends upon the current services of tangible capital goods, the current number of men performing each of these jobs, the current educational attainments of each of these job-holders, and time. To simplify matters, some alnalysts have specified a production function in which output depends upon tangible capital and " effective labor"; the latter

is a weighted sum of the number of workers, the weight assigned to each worker being an increasing function of that worker's educational attainment. This specification assumes that highly educated men are perfect substitutes for less educated men (in the technical sense that the marginal rate of substittution between them is constant). Actually, it is possible that educated men are more sub- 69 70 AMERICAN ECONOMIC ASSOCIATION stitutable for certain capital goods than for other labor; they permit production with less complex machines. However, the exact specifica-tion of the production function does not concern us. The pertinent fea-ture of this kind of production function is this: The " marginal produc-tivity" of education, which is a function of the inputs and the current technology, can remain positive forever even if the technology is sta-tionary. In the models we shall later introduce, education has a positive payoff only if the technology is always improving. We shall consider now the importance of education for a particular function requiring great adaptation to change. We then propose two models which these considerations suggest. II. The Hypothesis We suggest that, in a technologically progressive or dynamic econ-omy, production management is a function requiring adaptation to change and that the more educated a manager is, the quicker will he be to introduce new techniques of production. To put the hypothesis simply, educated people make good innovators, so that education speeds the process of technological diffusion. Evidence for this hypothesis can be found in the experience of United States agriculture.' It is clear that the farmer with a relatively high level of education has tended to adopt productive innovations earlier than the farmer with relatively little education. We submit that this is because the greater education of the more educated farmer has in-creased his ability to

understand and evaluate the information on new products and processes disseminated by the Department of Agriculture, the farm journals, the radio, seed and equipment companies, and so on. 2 The better educated farmer is quicker to adopt profitable new processes and products since, for him, the expected payoff from innovation is likely to be greater and the risk likely to be smaller; for he is better able to discriminate between promising and unpromising ideas, and hence less likely to make mistakes. The less educated farmer, for whom the information in technical journals means less, is prudent to delay the introduction of a new technique until he has concrete evidence of its profitability, like the fact that his more educated friends have adopted the technique with success. This phenomenon, that education speeds technological diffusion, may take diferent forms outside of agriculture. In large, industrial corpora- 1 See E. M. Rogers, Diffusion of Innovations (Free Press, 1962), especially Chap. 6. 2 To be sure, some of the correlation described between education and diffusion may be spurious. Some farmers are undoubtedly both progressive and educated because they come from progressive and prosperous farming families that could afford to give them an education. But there is no question that educated farmers do read technical, innovation-describing literature more than do less educated farmers-and presumably because they find it profit-able to do so. CAPITAL THEORY 71 tions, in which there is a fine division of labor, the function of keeping abreast of technological improvements (though perhaps not the ultimate responsibility for innovation) may be assigned to scientists. In this case, their education is obviously important; but so too is the education and sophistication of top management which must make the final deci-sions.' So much for our broad hypothesis and the evidence supporting it. We shall

consider now two specific models of the process of technological diffusion and the role of education. III. Two Models of Technological Diffrusion We shall adopt a postulate about the factor-saving character of tech-nical progress which permits us to speak meaningfully about the " level" or " index" of technology. Specifically, we suppose that technical prog-ress is Harrod-neutral everywhere (i. e., for all capital-labor ratios), so that progress can be described as purely labor-augmenting. This means that if output, Q, is a function of capital, K, labor, L, and time, t, the production function may be written (1) $Q(t) = F[K(t), A(Q)L(Q)]$ In (1), the variable A (t) is our index of technology in practice. If we interpret (1) as a vintage production function in which K(t) is the quan-tity of currently purchased capital, L(t) the labor working with it, and Q(t) the output producible from it, then A (t) measures the best-practice level of technology, the average technology level " embodied" in the representative assortment of capital goods currently being purchased. Alternatively, we could suppose that all technical progress is wholly " disembodied" and that (1) is the " aggregate" production function for the firm, industry or economy and A (t) is the average index of technol-ogy common to all vintages of capital, old and new. In addition to this concept, we introduce the notion of the theoretical level of technology, T(t). This is defined as the best-practice level of technology that would prevail if technological diffusion were completely instantaneous. It is a measure of the stock of knowledge or body of techniques that is available to innovators. We shall suppose that the theoretical technology level advances exogenously at a constant ex-ponential rate X: (2) $T(t) = TvM$ A > 0 3For an interesting essay on science policy, in which it is argued that Britain's growth has suffered from a shortage of scientists in management, that too small a

fraction of scientists are engaged in using (rather than adding to) the existing stock of knowledge, see C. F. Carter and B. R. Williams, " Government Scientific Policy and the Growth of the British Economy,"' The Manchester School, Sept., 1964. 72 AMERICAN ECONOMIC ASSOCIATION First model. Our first model is as simple a one as we can invent. It states that the time lag between the creation of a new technique and its adop-tion is a decreasing function of some index of average educational attain-ment, h, of those in a position to innovate. (We may think of h as denot-ing the degree of human capital intensity.) Letting w denote the lag, we can represent this notion as follows: (3) A(t) = T(t - w(hI)), w'(h) < 0. The level of technology in practice equals the theoretical level of tech-nology w years ago, w a decreasing function of h. Substitution of (2) in (3) yields (4) A(t)= Toe)jt-w(h)] If h is constant, two results follow from (4). First, the index of tech-nology in practice grows at the same rate, X, as the index of theoretical technology. Second, the " level" or path of the technology in practice is an increasing function of h, since an increase of It shortens the lag be-tween T(t) and A (t). An important feature of this model is that, ceteris paribus, the return to education is greater the faster the theoretical level of technology has been advancing. As equation (5) shows, the effect upon A (t) of a mar-ginal increase of h is an increasing function of X, given A (t), and is positive only if X > 0. aA (t) (5)~~~~~~ A -1 --ww (h) TOXtt (5) = Xw'(it)ToeM[tw(= W--w '(h)A(t). The same property is displayed by the " marginal productivity of educa-tional attainment." Using (1) and (4) we have (6) Q(t) = F[K(t), ToeXlt,(h)]L(t)] Hence, (7) OQ(t)_XTQ eX[t)]L(t) [-w'(h)]F2 = - Xw'(h) X Wage Bill. Thus the marginal productivity of education is an increasing function of X, given the current wage bill, and is positive only if X> 0. This fea-ture is not

found in the conventional treatment of education described at the beginning of this paper. This first model is not altogether satisfactory. It is unreasonable to suppose that the lag of the best-practice level behind the theoretical CAPITAL THEORY 73 level of technology is independent of the profitability of the new tech-niques not yet introduced. Further, it is somewhat unrealistic to sup-pose that an increase of educational attainments instantaneously re-duces the lag. In these respects, our second model is somewhat more realistic. Second model. Our second model states that the rate at which the latest, theoretical technology is realized in improved technological practice de-pends upon educational attainment and upon the gap between the theoretical level of technology and the level of technology in practice. Specifically, (8) A(t) = c(h)[T(t) - A(t)] or equivalently A (t) - T(t) - AQ()- (8't) = (h) 4t , ()= O, V4(z) > 0. A (t) kl A Q1) j According to this hypothesis, the rate of increase of the technlology in practice (not the level) is an increasing function of education attain-ment and proportional to the " gap," (T(t) - A (t))/A (t). Some results parallel to those in the first model can be obtained if we again postulate exponential growth of T(t), as in (2), and constancy of h. First in the long run, if h is positive, the rate of increase of the level of teclhnology in practice, A(t)/A(t), settles down to the value X, inde-pendently of the index of education attainment. The reason is this: if, say, the level of h is sufficiently large that A (t)/A (t) > X initially, then the gap narrowed; but the narrowing of the gap reduces A (t)/A (t); the gap continues to narrow until, in the limit, A (t)/A (t) has fallen to the value X at which point the system is in equilibrium with a constant gap. Another result is that the asymptotic or equilibrium gap is a decreas-ing function of educational attainment. Thus increased educational attainment increases

the path of the technology in practice in the long run. Both these results are shown by Figure 1 and by (9), which is the solution to our differential equation (8), given (2): / 4) 4, (9) A(t) = tAO - To) e-t?+ TOeXt. As both (9) and Figure 1 imply, the equilibrium path of the technology in practice is given by (10) A*(t) = T 44k)? h , X 74 AMERICAN ECONOMIC ASSOCIATION A(t) T lt) 1h) T(t) A(t ? A(t) FIGURE 1 the equilibrium gap is given by T(t) - A*(t) x A*(t) =(I) In a technologically stangnant economy (X = 0), the gap approaches zero for every h> O. In a technologically progressive economy (X> 0), there is a positive equilibrium gap for every Ih and X. The equilibrium gap is increasing in X and decreasing in h. In the first model it was seen that the marginal productivity of educa-tional attainment is an increasing function of X and positive only if X > 0. That is also true of the second model in the long run (once the effect of an increase of h has had time to influence the level of A (t) as well as its rate of change). Equation (12) shows that the elasticity of the long-run equilibrium level of technology in practice, A *(t), with respect to h is increasing in X: (12) aA*(I) h FAr ( )[r 1 ah4 A*(t) L (Ii) J Lb(h) + Xi This indicates that the payoff to increased educational attainment is greater the more technologically progressive is the economy. These are only partial models and excessively simple ones. No ma-chinery has been given for determining educational attainment. 4 The 4 This is done in a paper by Phelps which develops a Golden Rule of Education. It is shown that GoldenR ule growthr equiresm ore educationt he more technologicallyp rogressiveis the economy. CAPITAL THEORY 75 theoretical level of technology has been treated as exogenous. Finally, it might be useful to build a model which combines elements of both the first and second model: the rate of technical progress in practice may depend both upon the length

of time during which a new technique has been in existence and upon its profitability. But we hope that these two models may be a useful starting point. IV. Concluding Remarks The general subject at this session is the relationship between capital structure and technological progress. Recalling that the process of education can be viewed as an act of investment in people that educated people are bearers of human capital, we see that this paper has relevance to that subject. For, according to the models presented here, the rate of return to education is greater the more technologically progressive is the economy. This suggests that the progressiveness of the technology has implications for the optimal capital structure in the broad sense. In particular, it may be that society should build more human capital rela-tive to tangible capital the more dynamic is the technology. Another point of relevance for social investment policy may be men-tioned. If innovations produce externalities, because they show the way to imitators, then education-by its stimulation of innovation-also yields externalities. Hence, the way of viewing the role of education in economic growth set forth here seems to indicate another possible source of a divergence between the private and social rate of return to educa-tion. Finally, the connection between education and growth which we have discussed has a significant implication lor the proper analysis of eco-nomic growth. Our view suggests that the usual, straightforward inser-tion of some index of educational attainment in the production function may constitute a gross misspecification of the relation between education and the dynamics of production.