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*Research, Development and Human Capital Accumulation**

We develop an endogenous growth model that integrates research and development (R&D) with human capital accumulation. Given decreasing returns to scale, together with a threshold constraint on human capital, in R&D, steady-state growth is determined solely by preferences and human capital technology: it is independent of research activity which, itself, is driven by human capital accumulation. In accordance with recent empirical evidence, the model implies that long-run growth is both independent of scale effects and invariant to a wide range of policies.

1. Introduction

Two of the strongest candidates for explaining long-term growth are research and development (R&D) and human capital accumulation. On the one hand, R&D is essential to the processes of invention and innovation from which an economy acquires new and better quality products and technologies. On the other hand, human capital accumulation is the means by which skills are improved for the benefit of any type of productive activity, including R&D. Empirical evidence on each of these potential growth mechanisms has been presented by a number of authors, including Coe and Helpman (1993), Griliches and Lichtenberg (1984) and Lichtenberg (1992) for the case of R&D, and Barro (1991), Barro and Sala-i-Martin (1995) and Mankiw, Romer and Weil (1992) for the case of human capital accumulation. At the theoretical level, Romer (1990) provided the first fully-articulated

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growth model based on R&D, with subsequent contributions by Aghion and Howitt (1992) and Grossman and Helpman (1991), while Lucas (1988) is credited with the seminal analysis of growth based on human capital accumulation, to be followed by Becker, Murphy and Tamura (1990) and Stokey (1991).

For the most part, the roles of human capital accumulation and R&D in generating growth have been studied separately from each other, with few attempts having been made to integrate them within a single, unifying framework.[1] Two recent exceptions are the analyses by Eicher (1996) and Redding (1996) who emphasize the potential interaction (strategic complementarity) between investments in education and investments in research. In this paper, we present a different model in which the pair of activities take place simultaneously, subject to a realistic description of their underlying technologies. Our analysis yields results which accord well with the stylized facts, including certain observations that other models have found difficult to explain.[2]

The framework that we use describes an artificial economy in which identical, infinitely-lived agents invest time in learning (education and training), and supply their skilled labor to firms engaged in manufacturing and research. The result of an agent's learning is the accumulation of human capital, while the product of a firm's research activity is a design, or blueprint, for a new intermediate good employed in manufacturing. Essentially, the framework is a combination and extension of the human capital accumulation models of Lucas (1988) and Uzawa (1965), and the R&D product variety models of Grossman and Helpman (1989) and Romer (1990). The principle consideration in developing this framework is the plausible characterization of both human capital and R&D technologies on the basis of credible theoretical arguments and persuasive empirical evidence. Specifically, we assume

[1]We distinguish between the acquisition of skills through private investments in education and the acquisition of skills through serendipitous learning-by-doing in productive activity. For models which combine the latter with endogenous technological change, see Stokey (1988) and Young (1993).

[2]Since writing this paper, we have become aware of the contribution by Arnold (1998), who develops a similar model to ours with similar results. The main difference is that, in our case, the analysis contains a somewhat richer and fuller account of individual optimizing behavior. For example, our description of product development is based on an explicit specification of the R&D technology faced by each potential designer, rather than on an aggregate R&D technology. One implication of this, together with other features of our model, is that we are able to solve precisely for the number of designers, rather than having to assume that this number is sufficiently large. Another implication is that the probability of successful innovation is assured to remain bounded in our model. To some extent, therefore, the microfoundations of our model are rather more transparent and secure, though the two analyses are clearly complementary to each other.