Journal of Macroeconomics 40 (2014) 245–269

Contents lists available at ScienceDirect

Journal of Macroeconomics

journal homepage: www.elsevier.com/locate/jmacro

Embodied learning by investing and speed of convergence

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ARTICLE INFO

Article history:
Received 1 May 2013
Accepted 14 January 2014
Available online 7 February 2014

JEL classification:
D91
E21
O41

Keywords:
Transitional dynamics
Convergence
Learning by investing
Embodied technical progress
Decomposable dynamics

ABSTRACT

We study transitional dynamics and speed of convergence in economic growth. Based on a canonical framework the analysis revisits both "old" and "new" growth literature along three dimensions: (i) What if growth is not exogenous but endogenous and driven by learning by doing? (ii) What if technical progress is embodied rather than disembodied? And (iii) what if the vehicle of learning is gross investment as in the Arrowian tradition rather than net investment as in most recent contributions? From both a theoretical and a quantitative point of view we show that the speed of convergence (both asymptotically and in a finite distance from the steady state) depends strongly and negatively on the importance of learning in the growth engine and on gross investment being the vehicle of learning rather than net investment. And contrary to a presumption from "old growth theory", a rising degree of embodiment in the wake of the computer revolution is *not* likely to raise the speed of convergence when learning by investing is the driving force of productivity increases.

1. Introduction

Within the context of a dynamic general equilibrium model this paper studies how the composition of technical progress affects transitional dynamics – with an emphasis on the speed of convergence towards a balanced growth path.

There is a substantial literature attempting to empirically estimate the speed of convergence and theoretically assess what factors affect it. One of the first econometric studies of "conditional convergence" is Barro and Sala-i-Martin (1992). They found a speed of convergence of around 2% a year, implying that the time it takes to recover half the initial distance from steady state is 35 years. Later, a series of econometric studies raised a number of statistical issues, questioning the low estimates of the convergence speed. Caselli et al. (1996), for example, point out that the omitted variable- and endogeneity biases of prior studies – when corrected for – yield an estimate for the speed of convergence of about 10% a year. Other studies document significant variation across periods and groups of countries (for a survey, see Islam, 2003).

Simultaneously, a series of theoretical papers investigated the effects of a number of extensions of the standard neoclassical growth model (with exogenous technical change) on the speed of convergence. Mankiw et al. (1992) showed that including human capital in the accumulation process along with physical capital – by raising the output elasticity with respect to capital – brings the theoretical speed of convergence down to about to 2% per year, in line with their empirical estimate. Other extensions of the neoclassical growth model showed that convex capital installation costs (Ortigueira and

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http://dx.doi.org/10.1016/j.jmacro.2014.01.009
0164-0704/

Santos, 1997), an R&D sector (Eicher and Turnovsky, 1999), and less than full capacity utilization (Dalgaard, 2003,Chatterjee, 2005) also tend to reduce the theoretical speed of convergence.

The theoretical literature thus indicates that a shift from an exogenous to an endogenous growth perspective, depending on how growth is endogenized, predominantly tends to reduce the speed of convergence from the benchmark of 7–8% per year in the standard model with exogenous technical change to about 2–4% per year. The role in this context of the *composition* of technical change has received less attention. This is where this paper takes off. We consider the composition of technical change along three dimensions. The *first* relates to the *source* of technical change, where we contrast exogeneity with endogeneity in the form of learning by doing in the Arrow (1962) sense, that is, learning from investment experience. The *second* dimension relates to the *form* of technical change, i.e., the degree in which technical change is (capital-)embodied rather than disembodied, a distinction to which already Solow (1960) drew attention. We add a *third* dimension involving the *vehicle* of learning. What role does it play if we follow Arrow (1962) and assume that the vehicle of learning is *gross* investment rather than *net* investment as in most newer literature?

The motivation for introducing the exogeneity–endogeneity dimension is to prepare the ground for a study of the role of the two other dimensions. Endogenizing productivity increases as coming from learning by investing lowers the speed of convergence. This is so whether we speak of the asymptotic speed of convergence or the speed of convergence in a finite distance from the steady state. Intuitively, the presence of learning by investing adds a slowly moving complementary kind of capital (''investment experience'') to the dynamic system – thereby slowing down the adjustment process.

The motivation for focusing on the embodied–disembodied dimension is the following. Based on data for the US 1950–1990, the seminal Greenwood et al. (1997) paper estimates that embodied technical progress explains about 60% of the growth in output per man hour, the remaining 40% being accounted for by disembodied technical progress. So, empirically, embodied technical progress seems to play the dominant role. Furthermore, there are signs of an *increased* importance of embodiment of technical change in the wake of the computer revolution, as signified by a sharper fall in the quality-adjusted relative price of capital equipment (Greenwood and Jovanovic, 2001; Jovanovic and Rousseau, 2002; Sakellaris and Wilson, 2004).[2] In the ''old'' growth literature from the 1960s leading economists like Denison, Solow and Phelps were involved in an intense debate about the ''embodiment question'' , i.e., whether the embodiment–disembodiment distinction was important. Phelps (1962) claimed in an influential paper that the composition of technical progress along this dimension has no impact on the long-run growth rate but it affects transitional dynamics, more embodiment leading to faster convergence. Phelps considered exogenous technical progress. Boucekkine et al. (2003) showed, however, that endogenizing technical progress via learning by investing in an AK-style way destroys the first part of the claim. In our analysis below we take issue with the second part of Phelp's claim. We show that when learning by investing drives productivity growth, a rising degree of embodiment does *not* lead to faster convergence. The crux of the matter is that the role of embodiment depends on whether the productivity increases are treated as exogenous or endogenous.

Whether the vehicle of learning is net investment (as in Romer, 1986; Jovanovic and Rousseau, 2002; Boucekkine et al., 2003) or gross investment (as in the classical Arrow 1962 paper) is the third dimension on which we focus. The role of this distinction is little studied in the literature. It turns out that the distinction matters a lot for the dynamics both qualitatively, by affecting the dimensionality of the dynamics, and quantitatively, by lowering the speed of convergence. If gross investment is the vehicle through which learning occurs, cumulative investment experience becomes an additional stock variable, and the dimensionality of the dynamic system rises by one. This has two implications. First, as soon as learning by investing becomes operative, the speed of convergence exhibits a discrete fall relative to its level in case of no learning at all. This appealing discontinuity is absent if net investment is the vehicle of learning. Second, the speed of convergence is lower when the vehicle is gross rather than net investment. The intuition is that there is more overhang from the past when the vehicle is gross investment.

Quantification by numerical simulation shows that the sensitivity of the speed of convergence with respect to parameter variations along the three considered dimensions is substantial.

The paper is organized as follows. Section 2 develops the gross-investment based version of the model, which we refer to as the ''benchmark model'' . This version leads to a three-dimensional dynamic system the steady-state and stability properties of which are studied in Sections 3.1 and 3.2, respectively. Different measures of the speed of convergence are introduced in Section 3.3. Section 3.4 introduces the distinction between decomposable and indecomposable dynamics which is the basis for the discontinuity mentioned above. Section 4 describes the case of learning based on net investment. This leads to only two-dimensional dynamics and the appealing discontinuity disappears. By numerical simulations, Section 5 quantifies the theoretical results. Section 6 concludes. Supplementary Content, published online alongside the electronic version of this article, contains tables documenting a series of numerical simulations based on a wide array of parameter specifications.

2. A benchmark model

2.1. Disembodied and embodied learning by investing

The learning-by-investing hypothesis is that variant of the learning-by-doing hypothesis that sees the *source* of learning as being primarily experience in the investment goods sector. This experience embraces know-how concerning how to

[2] For a survey, see Hornstein et al. (2005).