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Technology adoption, adaptation and growth

Radhika Lahiri[a,*], Juhong Ding[b], Zivanemoyo Chinzara[c]

[a] *Queensland University of Technology, Australia*
[b] *China Executive Leadership Academy Pudong, China*
[c] *The World Bank Group, Africa Region, Zambia*

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A B S T R A C T

We revisit the notion of "appropriate technology" considered in Basu and Weil (1998) whereby technologies that are more capital intensive are adopted only after a certain level of capital depth has been achieved. We incorporate the idea by explicitly modelling the choice between two technologies in a heterogeneous agent model with overlapping generations. Both technologies can be improved through 'learning-by-doing' and adaptation of the technology to local conditions. One of the technologies is an 'advanced technology' in that it has potentially greater returns to capital deepening, and also to learning-by-doing and adaptation. However, a critical level of development has to be reached before the technology becomes appropriate; for lower levels of development the less advanced technology is more productive. Depending on initial conditions, a variety of long run outcomes and transitional dynamics are possible, suggesting that "appropriate technology" provides a potential explanation for the diversity of growth and technology diffusion experiences observed in world economies.

1. Introduction

At the heart of most explanations for the non-convergence in international incomes across countries is the concept of technological change. Improvements in technology, whether through invention of new techniques or through the adoption of better technologies that have been invented elsewhere, are central to the process of growth and development. Any barriers that prevent such improvements are then the focus of theories that attempt to explain why poor countries have failed to catch-up with their rich counterparts, or why inequalities can exist *within* a country or region.

A large body of literature therefore focuses on barriers to technology adoption. See, for example, Parente and Prescott (1994), Greenwood and Yorokoglu (1997) and Leung and Tse (2001), in which the barriers take the form of costs incurred in the adoption of technologies. In some cases, this cost is of an implicit, "learning-by-doing" type (as in Khan and Ravikumar, 2002) and in others is of a pecuniary or contractual type (as in Acemoglu et al. 2007). At the empirical level there is evidence of delays in adoption and diffusion of new technologies; Comin and Hobijn (2010), for instance, suggest that there is an average lag of 45 years before a newly invented technology is fully adopted across countries. In particular, the pattern of technology diffusion involves invention and early adoption in advanced economies, followed by "trickle-down" diffusion in economically lagging, developing countries (see Comin and Hobijn 2004). Empirical studies also suggest different rates of technology adoption as a source of productivity differences and inequalities within countries (see Chanda and Dalgaard, 2008).

A new and growing body of literature, not entirely unrelated to the above-mentioned adoption-cost related studies, stresses the notion of "appropriate technology" as an underlying rationale for the slow diffusion of technologies, and the resultant productivity differences across countries. The aim of this study is to examine the implications of this idea, which suggests that a technology may not be "appropriate" in a country if the conditions that are needed for the realization of its potential level of productivity are not met. In Basu and Weil's (1998) model, for example, the barrier to technology adoption arises due to the localized nature of learning-by-doing. Specifically, a follower country can adopt a leading country's technology only if the capital intensity of the new technology falls in a range that is close to the capital intensity of existing technologies in the follower country. In Acemoglu and Zilibotti (2001) the reason for productivity differences occurring when the same technology is used in different locations (e.g. in developed vs developing economies) is attributed to skill shortages in the developing economies. This suggests a 'skill bias' (which may be a low-skill or high-skill bias) in the *choice* of technology, which may explain the slow diffusion of the capital and skill intensive technologies in the developing world (see Caselli and Coleman, 2006).

* Corresponding author.
E-mail address: r.lahiri@qut.edu.au (R. Lahiri).

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Our approach to addressing these issues is to explicitly model the choice of technology in a framework that incorporates the idea of appropriate technology in the sense that is closest to the framework of Basu and Weil (1998). In contrast to Basu and Weil we make the localized "learning by doing" aspect in the model endogenous by allowing the agent to improve the productivity of the adopted technology. This is done through investment of resources associated with learning how to use the technology and adapting it to local conditions.[1] A typical agent, who belongs to an overlapping-generations economy, has to decide whether to adopt one of two technologies, both of which can be improved via learning-by-doing and adaptation.[2] The model is rich enough to incorporate a variety of specifications for the two technologies, in relation to functional forms and parameter values which determine the shape and positioning of the respective production functions in capital-output space. However, in a special case, one of the two technologies is potentially more productive than the other – it has a higher level of productivity only after a certain level of skill depth has been achieved. Specifically, the appropriate technology scenario arises in this special case of our model, as will become clear shortly. In this paper we restrict our focus on the long run and transitional dynamics associated with this special case.

Even under the appropriate technology scenario, the model remains a fairly general one in that it allows for *all* possibilities regarding the nature of returns to scale of the technologies. This is particularly important in the context of technology adoption, since a switch to a new technology often implies a change of the nature of returns to scale in production, which also influences the decision to adopt a particular technology. For example, in the case of agriculture, switching from labor-intensive to highly mechanized forms of production essentially involves a change of returns to scale, as evidenced in the structural transformations of extant developed economies that took place during the industrial revolution (see Timmer 1998), and more recently in the case of transitional economies (see Shaw and daCosta, 1985, and Zilberman et al. 2014).

We find that there are many different long run outcomes and transitional dynamics in the model, in terms of which technology is adopted, and in terms of the growth experience of the economy. There can be scenarios somewhat similar to "poverty traps" in that there can be zero growth with either no adoption or complete adoption of the potentially more productive technology. There are also scenarios that may be described as "dual economy" with some agents in the model caught in a low-level wealth trap, while others escape and experience sustained growth. Within this scenario too, there is some variety; the dual economy can occur with full adoption of the potentially more productive technology and with partial adoption as well. This is because, in the former case, some of the agents can get caught in an equilibrium in which there is no further capital deepening and skill development, albeit involving the use of the more productive technology given the minimum level of skill required to adopt it has been achieved. Finally there is a possibility of sustained growth with full adoption. In this case growth can be either "balanced" or "unbalanced" depending on the nature of returns to scale of the technology.

We find, therefore, that the notion of appropriate technology has the potential to explain the diversity of long run outcomes and growth and inequality patterns that are observed in various economies (as suggested, for example, by Pritchett 1997 and Barro 2000). It is also consistent with the diverse patterns of technology diffusion observed in the empirical literature (see Caselli and Coleman 2006 and Comin and Hobijn 2004, 2010). Given this diversity, the implication is that there can be no "one size fits all" prescriptions to the problem of development and structural change in transitional countries. Any developmental reforms would then need to take into account local conditions and "appropriateness" of technology.

Given, the heterogeneous agent structure of our model, our model also has interesting implications for within-country convergence; depending on initial conditions, there can be an increase an inequality due to two reasons. Firstly, the timing of adoption matters. Inequality increases even in the event all agents eventually adopt and experience the growth rates associated with more productive technologies, since agents who had adopted earlier were richer to begin with, and have a longer period of sustained growth relative to late adopters. Secondly, in the event there is only partial adoption, some agents may get caught in poverty traps while some enjoy sustained growth. These "dual economy" outcomes of the model are of particular interest, since we have not explicitly modelled the existence of multiple sectors intrinsic to standard dual economy models (see Temple, 2005). In our model, the dual economy aspect arises due to *within-sector* heterogeneity of agents, and is reminiscent of real world scenarios where traditional and modern forms of technology coexist in the same sector. For example commercial agriculture, which typically uses high yield variety crops and plantation systems, exists in countries such as China and India along with traditional cropping systems associated with subsistence agriculture. There is also empirical evidence suggesting that such partial adoption may be a source of uneven development and increasing inequality in these sectors. (See, for example Ding et al. 2011).

Furthermore, the above-mentioned aspects in relation to inequality within countries have some interesting political economy implications. Given that unfavourable growth outcomes are possible even when better technologies are adopted, resistance towards their adoption can emerge given certain initial conditions. Such resistance would be reminiscent of the "appropriate technology movement" associated with Schumacher (1975), which emphasized small-scale technologies as more appropriate, in part due to the poor economic consequences in some developing countries that adopted large-scale industrial or agricultural technologies from the developed world.[3]

The remainder of this paper is organized as follows: Section 2 presents a discussion of related literature and the "appropriate technology" concept as it is interpreted in the context of our paper. Section 3 presents the model and key analytical results. Section 4 presents further analytical results based on the dynamics of the model, along with a discussion of various long-run outcomes in the model. Section 5 concludes. The Appendix presents some proofs and derivations, and a table summarizing the long-run outcomes of our model.

2. Background and motivation

There is a multi-disciplinary aspect to the idea of "appropriate technology", which has different shades of meaning across various fields and applications, and broadly speaking, refers to technology that is "small-scale, decentralized, labor-intensive, energy efficient, environmentally sound and locally controlled" (Hazeltine and Bull, 1999). In this paper we are concerned with the concept as it appears in the mainstream economics literature, which focuses primarily on one of these dimensions, namely that of capital intensity, albeit this dimension may have links with (or implications for) some of the others mentioned above. Furthermore, even in the case of economic models, there can be alternative nuances to the dimension of capital intensity,

[1] In Basu and Weil the learning-by-doing aspect is exogenous, as productivity improves over time according to deterministic process specified by the authors, but is limited to a neighbourhood of capital stock appropriate to the technology in question. As the capital stock increases, new techniques are adopted, and again subject to improvement in learning-by-doing via a deterministic process within a neighbourhood of that capital stock.

[2] We consider a binary choice between two technologies in the interest of tractability, noting here that it is not germane to the key insights derived from this study. A detailed discussion of the implications of this assumption are considered in Section 3.

[3] The notion of appropriate technology attributed to Schumacher is however, much broader than considered in our model. In what follows we occasionally refer to this alternative idea, but our focus is on the concept as it appears in the Atkinson and Stiglitz (1969), Basu and Weil (1998) and strands of literature emerging from these papers.