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Technology Adoption, Adaptation and Growth

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Abstract

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. (JEL O11, O30, O33)

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).

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

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[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.

economies that took place during the industrial revolution (see Timmer 1998), and more recently in the case of transitional economies (see Shaw and deCosta 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 appropriate technology notion 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

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[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.

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, depending on the framework in question. It is therefore instructive to revisit the idea as it was first articulated in the economics literature by Atkinson and Stiglitz (1969).

Atkinson and Stiglitz (henceforth AS) explain the concept graphically by comparing two ways in which technological progress can take place, captured in Figures 2.1 and 2.2 below. In the first case, technological progress occurs through a shift in the production function whereby output per worker increases for *all possible techniques*. However, as pointed out in AS, each point on the production function represents a different technique or process, and there is knowledge that is specific to each of these techniques. In that case, if technological progress improves only one of these processes and not others, we would expect a localized shift of the production function, as indicated in Figure 2.2.

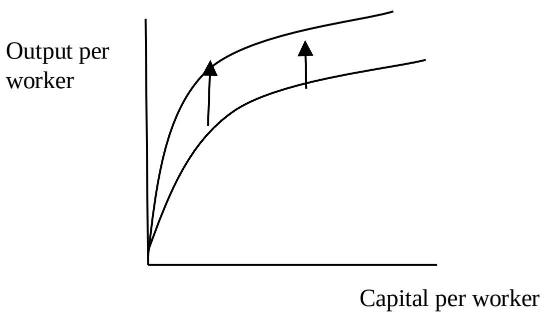

Figure 2.1

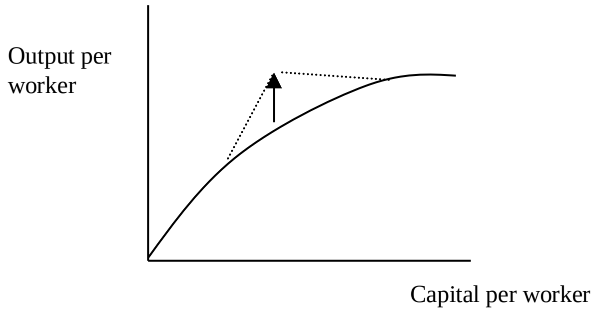

Figure 2.2

Based on the above, one can further distinguish between two types of technical progress. Technical progress of the type described in Figure 1 would, for example, be associated with an *invention* of a new technology that led to an increase in productivity for all possible levels of capital intensity, other things being equal.[4] The second type of progress would be through *innovation*, i.e. through “learning by doing” or R&D associated with one (or a few) of the techniques associated with a given technology, (depending on whether there were spillovers to

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[4] Note that Atkinson and Stiglitz refer to each point on the production function as a “technique”. Generalizing this idea, one could then refer to the production function as a set of techniques associated with a given technology.

techniques of capital intensity in the neighbourhood of the one that was associated with that learning).

Essentially, this means that the shape of a production function associated with a given technology in capital and output space would depend on its *location*. Specifically, AS suggest that "where technical progress is 'localized,' technical progress in the advanced countries, whether from research or learning by doing, will leave relatively unaffected the less capital-intensive techniques that the underdeveloped country would choose in light of its factor endowment." (Atkinson and Stiglitz, 1969, page 576).This is, then, the sense in which a technology from a developed country may not be 'appropriate' for a less developed one. Another study, that closely reflects this notion of 'appropriateness', is that of Basu and Weil (1998) (henceforth BW). According to an assumption of the BW model a country will benefit from (and therefore adopt) a new technique developed elsewhere only if its current level of its capital intensity is similar to that of the innovating country.

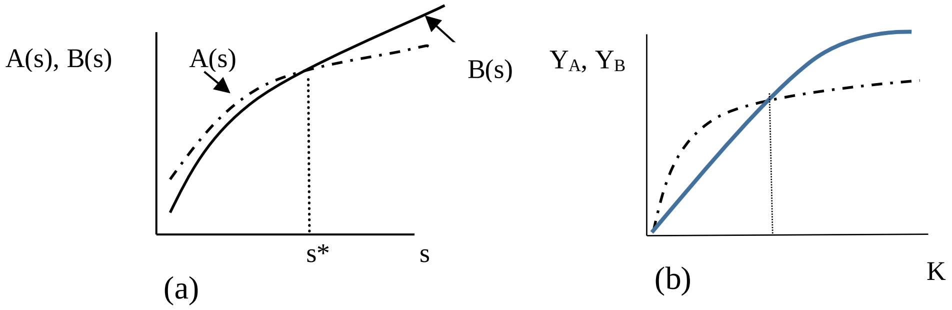
The model of this paper, however, explicitly models the choice of technology, which in turn depends on the extent of capital deepening an agent undertakes. Agents in the model are heterogeneous in their initial endowment of resources, and this endowment limits the capital intensity they can choose to operate at. Whether or not the agent adopts new technologies depends on the parameters of the model and the action of the agents, who undertake both capital-deepening and learning by doing. Outcomes similar to the BW model emerge in our model as a special case we label the "appropriate technology scenario", although our notion of appropriate technology has some nuances that warrant further discussion.

Our model embeds the 'AK' style of technology, just as in the BW model, and while our framework is that of two-period overlapping generations of heterogeneous agents rather than infinitely lived agents, the presence of bequests makes it reasonably similar in spirit to the BW paper. However, we consider an agent's choice between two technologies, A and B, of the following form:

$$Y = A(s)K^{\gamma}; \quad Y = B(s)K^{\gamma}; \quad A' > 0, A'' < 0; \quad B' > 0, B'' < 0; \quad 0 < \gamma \leq 1.$$

In the above, 'Y' is output, 's' represents resources spent on learning-by-doing and research, while 'K' represents a composite good comprising of human and physical capital. The “productivity functions” A(.) and B(.) allow for “localised” technical progress in the sense of AS; for a given level of capital stock, improvements in efficiency are possible through learning and research. However, in our model, the agents determine the allocation of resources towards capital accumulation and research a period in advance of the production taking place. Given standard assumptions about preferences this means that these activities are chosen in proportion to each other.

Obviously, the above assumptions are consistent with a wide variety of possibilities for the relative productivities of the two technologies. The focus of this paper, however, is one the case depicted in Figure 2.3 below:



(a) (b)

Figure 2.3

In Figure 2.3(a) we have a case which the relative productivities of A and B depend on the level of resources invested in learning and research. Beyond a critical level of research and learning, represented by ‘s*’, productivity of B is higher than that of A. This would, under some parametric conditions, also imply crossing production functions of the type depicted in Figure 2.3(b). In the ‘story’ of our model, technology B is the ‘inappropriate’ technology if a country/agent does not have sufficient resources to support the level of learning and research effort commensurate with s*. This scenario also connects with the BW model in that there is also a corresponding level of capital intensity which makes the switch to Technology B. In contrast to BW, however, the choice of technology, capital accumulation, investment in learning-by-doing are all explicitly modelled.

In contrast, consider another of the possibilities consistent with the technological assumptions of our model, depicted in Figure 2.4 below:

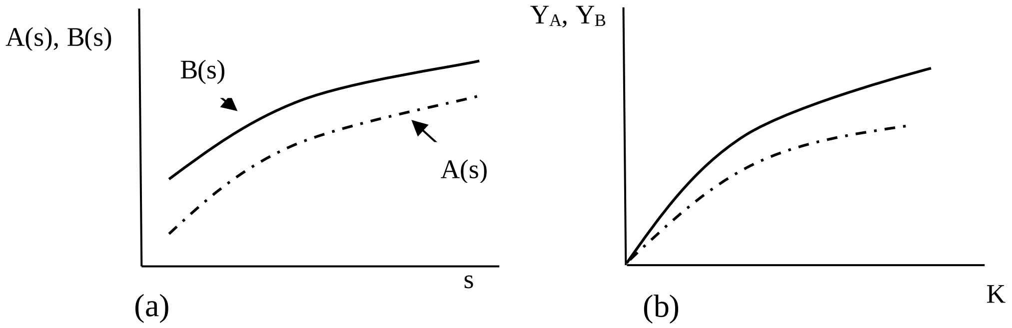


Figure 2.4

In this figure technology B is superior to that of A for all levels of learning and research effort. Given that resources are allocated proportionally to capital deepening and learning, this also translates to an outward shift of the production function in the event the agent adopts B. In our interpretation this case corresponds to one in which technology B is a ‘new’ and ‘more advanced’ technology, imported into a country that has a similar level of development to that of the country of the technology’s origin.

Put differently, in our view the production function associated with technology B can have a different position and shape depending on the country in which the technology is located. This position and shape depends on the extent to which agents located in a country can devote resources to learning and research, in addition to the level of development, capital intensity and other local conditions that may be of relevance in determining the production possibility frontier of a technology. In terms of our model, the position and shape depends on the parametric assumptions of the model, which govern the whether the “appropriate technology scenario” of Figure 2.3 with crossing productions or the standard scenario of Figure 2.4 occurs. However, even in the case represented by Figure 2.3, the new technology eventually becomes appropriate. Nevertheless, we can show that poverty traps and other unfavourable long-run outcomes are possible.

Acemoglu and Zilibotti (2001) also make a point somewhat similar to this and other appropriate technology literature. They suggest that productivity differences are observed even when the same technology is used in different countries, and that these differences are the result of economic conditions and factor prices. Their argument is based on a ‘mismatch’ between technology and skill that can occur when a technology invented in a developed economy is imported into a less developed economy. Given the scarcity of skill in a less developed economy, it must use unskilled workers to operate the technology that was operated by skilled workers in the country of origin. While our paper does not model such skill shortages explicitly,

Figure 2.3 can perhaps be interpreted in a similar vein. Since the variable ‘s’ represents resources devoted to learning and research, there is, implicitly, a dimension of skill associated with it.[5]

Productivity differences of the type that occur when identical technologies are used in different locations can also be the result of incomplete diffusion of knowledge. For example, only a very limited and succinct set of instructions accompany the manuals or handbooks that accompany a new technology, and much of the requisite skills and knowhow can be acquired through learning by doing (Los and Timmer, 2005). This view is an alternative to the ‘appropriate technology’ idea, and has considerable empirical support. See for example, Fagerberg (1994) and references therein. However, to the extent these alternative theories offer an incomplete explanation of productivity differences, the notion of appropriate technology is certainly a viable candidate among the numerous hypotheses that have been proposed in the literature. In recent years, particularly, there has been growing empirical support for the appropriate technology explanation of international income non-convergence (see, for example, Jerzmanowski, 2007).

The theoretical literature cited above focuses on some additional issues and implications that are somewhat different to those considered in this paper. Our primary focus is on the extent to which the appropriate technology feature delays or prevents the adoption of new technologies, and the nature of long run outcomes associated with it. Of course, this inevitably implies that we are, in common with other literature, concerned with international income differences and convergence. Our contribution lies in exploring the various forms in which this feature can manifest, and the implications of those forms for transitional and long run outcomes.

Furthermore, choosing a more general structure for the technological side of the model introduces some important considerations that have not been previously explored in the literature. Sometimes, technological change is radical rather than incremental in nature with political economy implications for the adoption of new technologies. In the popular/inter-disciplinary literature mentioned earlier, for example, the phrase “small is beautiful” coined by

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[5] Acemoglu (2009) suggests three distinct reasons as to why technology invented in a developed economy may not be ‘appropriate’ for a less developed one and these relate to capital intensity, skill intensity and geographical/local conditions.

Schumacher (1975) is associated with the “appropriate technology movement” which led to several debates surrounding the adoption of technologies with increasing returns to scale. While we do not directly address such political economy issues, our model provides an exploratory framework for the choice between technologies of a different nature, in terms of their returns to scale. As mentioned earlier, in the context of agricultural technologies, the technology adoption decision often entails a switch between technologies with different returns to scale, an aspect which our model introduces, albeit in an exploratory manner.

3. The Framework and Analytical Results

The model has some similarity in spirit with the endogenous growth models developed in Khan and Ravikumar (2005), Lahiri and Ratnasiri (2012, 2013) and Chinzara and Lahiri (2013). It also incorporates elements similar to Basu and Weil (1998) and is a more general framework relative to the above models in that it assumes a more general technological structure, and produces some of their outcomes as special cases. It consists of two-period lived overlapping generations of agents. Time is discrete, and there is no population growth, with N_t agents in any given period *t*, where *t=0, 1, 2,...*. The agents are heterogeneous in their wealth levels, and any agent born in period t has preferences of the following form:

$$U(c_{t+1}, x_{t+1}) = \ln(c_{t+1}) + \theta \ln(x_{t+1}) \tag{1}$$

As is evident from (1), an agent does not consume in the first period of her life and her lifetime utility is derived from her household’s consumption in the second period of her life, c_{t+1} and the bequests x_{t+1} she leaves for her offspring.[6] We suppress the agent-specific subscripts for notational convenience. The parameter θ represents the extent of inter-generational altruism in the model. Apart from the resources she inherits from her parents, each agent is born with a unit of unskilled labour endowment that may be used to earn a subsistence wage $\bar{w}$.

Agents of the younger generation make a technology adoption decision in the first period of their life, which entails choosing one of two technologies, and we label these ‘Technology

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[6] Note that consumption here is ‘household consumption’ – the consumption when young is subsumed in the parent’s utility function.

A' and 'Technology B' for ease of reference. Technology B is the 'new' technology and may *potentially* have a higher productivity relative to Technology A, depending on the level of human capital and skill development in the economy. There is also some investment that may be undertaken for the purpose of improving the productivity of the technologies that are adopted, through "learning-by-doing" and adaptation of the technology to local conditions.

The output produced by an agent in period *t*, labelled y_t, equals $A(s_t)k_t^\gamma$ if the agent invested the amount k_t in the previous period of her life in *Technology A*, and invested an amount s_t for the purpose of improving the productivity of that technology. The variable s_t may be interpreted as expenditure made by the agent to improve or 'adapt' the technology to local conditions, or funds spent on education that enhances the ability of the agent to operate the technology in question. Note that we also allow for an element of skill and learning that is subsumed in k_t, since we have interpreted it as a composite of human and physical capital. This learning, however, is more representative of general education embodied in the human capital, acquired prior to its use in production. In contrast, s_t includes learning expenditures that are technology-specific. These could be the monetary equivalent of the effort required to learn and adapt a new technology, or taking special courses to understand and implement national or firm-level research and development associated with the technology. They could also include research undertaken by the agent that is specific to the technology.

Likewise, the production function equals $B(s_t)k_t^\gamma$ if the agent instead chose to adopt Technology B. Here, we assume that the functions A(s) and B(s) are increasing and concave with $A(s) = A_o s^\alpha$, where $0 \le \alpha < 1$, and $B(s) = B_o s^\beta$ where $0 \le \beta < 1$. We further assume $0 < \gamma \le 1$. There may or may not be a fixed adoption cost δ_b associated with the adoption of Technology B.[7]

As is evident from the above assumptions, the production functions associated with the two technologies are fairly general and nest all of the three possibilities in relation to returns to

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[7] Note that we include the notion of a fixed cost only to preserve the generality of the model and its comparability with other literature. In what follows we assume fixed costs to be zero as our focus is on the appropriate technology case, which can create barriers to technology adoption even in the absence of fixed costs.

scale, namely, constant, increasing or decreasing returns to scale. Also note that the above construct, depending on the values of the parameters A_o, B_o, α, β, γ and δ_b, nests a variety of models within it as special cases. For example, with $A_o < B_o, \alpha = \beta = 0$, and with $\delta_b = \delta > 0 \ \forall t$, the model is essentially similar to that of Lahiri and Ratnasiri (2012). If, instead, we have only a "one time" adoption cost with $\delta_b = \delta > 0$ only for $t=s$, where s is the time of adoption along with $A_o < B_o, \alpha = \beta = 0$, we are in a framework that is similar to Khan and Ravikumar (2005).[8] Our focus, however, is on the model characterized by $B_o<A_o$, $\beta > \alpha$ and with no fixed adoption costs so that $\delta_b=0$. That is, we deliberately abstract from fixed adoption costs in our model to shift the focus towards the "appropriate technology" feature intrinsic to it.

Our interpretation of the "appropriate technology" notion is captured by the latter set of parameters in the sense that, under these assumptions, Technology B is only *potentially* more productive than Technology A; there is a critical amount of learning, R&D investment and capital deepening that needs to take place before Technology B has greater productivity relative to Technology A. While we have elaborated on this assumption in Section 2, we reiterate it here to cement the idea in the context of our model. Consider Figure 3.1, which illustrates the productivity functions A(.) and B(.) under the above mentioned parametric assumptions.[9] However, for the "appropriate technology" scenario to emerge we need the *production functions* of the two technologies to cross in such a way that Technology B becomes appropriate once a certain level of development has been achieved. Given that, in our model, the resources invested in the two technologies are endogenous, a further parametric assumption, discussed later, will be required for this scenario to occur.

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[8] Khan and Ravikumar (2005) use an infinite horizon AK model in which agents are faced with a choice of two technologies, while Lahiri and Ratnasiri (2012) do the same in the context of an overlapping-generations model. Basu and Weil (1999) do not explicitly model choice between technologies, but have a productivity parameter that varies over time. We blend these two approaches by making the productivity parameter endogenous, so that productivity improvements are directly the result of agents' spending on learning and adaptation.

[9] Note that unlike figure 2.3(a), drawn under more general assumptions, the productivity functions must also intersect at the origin.

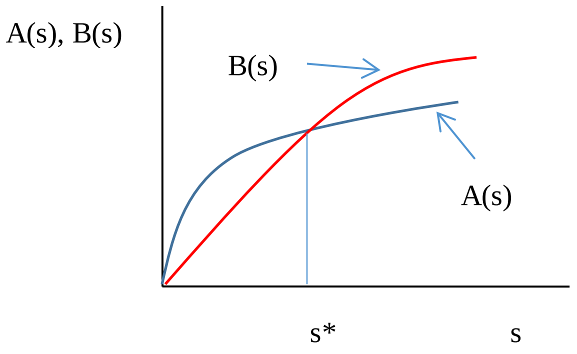

Figure 3.1

The agents born in period *t* use their wage-income and resource endowment for capital accumulation in the first period. They also set aside some of this endowment for learning and adaptation expenditures they will need to incur in the next period. In the second period, they use output created due to their capital and learning investment for consumption and bequests. Households adopting Technology A face the following budget constraints:

$$k_{t+1}^a = \overline{w} + w_t - s_{t+1}^a \tag{2}$$

$$c_{t+1}^a = A_0 (s_{t+1}^a)^\alpha \left(k_{t+1}^a\right)^\gamma - x_{t+1}^a \tag{3}$$

Here c_{t+1}^a and k_{t+1}^a refer to second period consumption and second period capital holdings of an individual adopting Technology A and the variable w_t represents her resource endowment in period *t*. We do not present the budget constraints of agents adopting Technology B, as they are symmetric in form, given that we have abstracted from fixed adoption costs. That is they are similar to equations (2) and (3) above with ‘b’ replacing ‘a’, ‘B_0’ replacing ‘A_0’ and the parameter β replacing α. In this model, the resource endowment of an agent depends on the technology that was adopted by the agent’s parents. This means that $w_t = w_t^a = x_t^a$ if the agent’s parent adopted Technology A and $w_t = w_t^b = x_t^b$ if the agent’s parent adopted Technology B.

Agents adopting Technology A maximize (1) subject to constraints (2) and (3). It is easy to show that the optimal consumption, bequest and investment plans of these agents are given by:

$$c^{a*}_{t+1} = \frac{\mathrm{A}}{1+\theta}\left(\overline{w} + w_t\right)^{\alpha+\gamma}; \tag{4}$$

$$x^{a*}_{t+1} = \frac{\theta\mathrm{A}}{1+\theta}\left(\overline{w} + w_t\right)^{\alpha+\gamma}; \tag{5}$$

$$s^{a*}_{t+1} = \frac{\alpha}{\gamma+\alpha}\left(\overline{w} + w_t\right); \tag{6}$$

$$k^{a*}_{t+1} = \frac{\gamma}{\gamma+\alpha}\left(\overline{w} + w_t\right), \tag{7}$$

where $\mathrm{A} = \frac{A_0\alpha^{\alpha}\gamma^{\gamma}}{(\alpha+\gamma)^{\alpha+\gamma}}$. The optimal plans corresponding to Technology B, can be derived by symmetry, with ‘b’ replacing ‘a’, ‘B_0’ replacing ‘A_0’, β replacing α and with B replacing A where $\mathrm{B} = \frac{B_0\beta^{\beta}\gamma^{\gamma}}{(\beta+\gamma)^{\beta+\gamma}}$.

Agents make the technology adoption decision by comparing indirect utilities derived from the respective technologies.[10] Specifically, an agent will adopt Technology B *iff* $U^B(c^{b*}_{t+1}, x^{b*}_{it+1}) \geq U^A(c^{a*}_{t+1}, b^{a*}_{t+1})$, where U^A and U^B are the indirect utility functions for the agents adopting Technology A and Technology B respectively and the asterisk denotes the optimal choice of the variable in question. It is then possible to make the following proposition (See proof in the Appendix).

Proposition 1: *Let* $w^* = \left(\frac{\mathrm{A}}{\mathrm{B}}\right)^{\frac{1}{\beta-\alpha}} - \overline{w}$, *where* $\mathrm{A} = \frac{A_0\alpha^{\alpha}\gamma^{\gamma}}{(\alpha+\gamma)^{\alpha+\gamma}}$ and $\mathrm{B} = \frac{B_0\beta^{\beta}\gamma^{\gamma}}{(\beta+\gamma)^{\beta+\gamma}}$.

An agent will adopt Technology B iff $w_t \geq w^*$.

Note that for the above proposition to have relevance in the “appropriate technology” context we need w* to be positive – otherwise, technology B will always be appropriate. We therefore need to assume the following:

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[10] Here, as in Khan and Ravikumar (2005), we implicitly assume that the firm is owned by the household. Since production is based on inputs provided by the household, and supplied to the household, modelling the firm as a separate entity would yield similar results. This is because the utility based choice entails comparison of a monotonic transformation of resources available to the agent. Other models which focus on technology adoption as a firm’s decision are structurally very different from ours, and in that sense not comparable. (See for example, Besley and Case, 1993 and Parente and Prescott, 1994).

$$\frac{\mathrm{A}}{\mathrm{B}} > \left(\overline{w}\right)^{\beta-\alpha} \qquad (A1)$$

Some comparative static analysis with regard to various parameters is presented in Appendix B. The results are intuitively appealing. The critical endowment *w** is increasing in A_0 and decreasing in B_0, highlighting the role of “appropriateness” in a quantitative sense –the larger the difference between these two parameters, the less appropriate is the new technology relative to existing conditions. The impact of the parameters α and β is, however, ambiguous.

The dynamics of the model are characterized by equilibrium versions of the bequest plans for those adopting Technology A and Technology B respectively. These are given by:

$$w_{t+1} = \frac{\theta \mathrm{A}}{1+\theta}\left(\overline{w} + w_t\right)^{\alpha+\gamma} \qquad if \quad w_t < w^*; \qquad (8)$$

$$w_{t+1} = \frac{\theta \mathrm{B}}{1+\theta}\left(\overline{w} + w_t\right)^{\beta+\gamma} \qquad if \quad w_i \geq w^*. \qquad (9)$$

In the above equations, A and B are as defined in Proposition 1.

It is easy to see that the dynamics of the model depend on two main features: (i) the parameters that determine the curvature of the curve of equation (8) relative to those that determine the curvature of the curve of equation (9), and (ii) the positions of these two curves relative to the 45^0 line, which shows all the points where $w_t = w_{t+1}$. Together, these features determine where these two curves intersect (i.e. *w**) relative to the 45^0 line, and where the curves cross the 45^0 line. Depending on these features, a variety of long run outcomes and transitional dynamics are possible. These outcomes may be broadly characterised by the labels *poverty trap*, *dual economy*, and *sustained growth*. However, even within these labels the nature of the long-run outcomes and the transitions towards them can be different. The cases to be considered, based on various assumptions about the parameters of the model are as follows:

(i) Increasing returns to both technologies with $\gamma + \beta > \gamma + \alpha > 1 \quad or \quad \beta > \alpha > 1-\gamma;$

(ii) Increasing returns to Technology B, decreasing returns to Technology A with $\gamma + \beta > 1 > \gamma + \alpha \quad or \quad \beta > 1-\gamma > \alpha;$

(iii) Decreasing returns to both technologies: $1 > \gamma + \beta > \gamma + \alpha \quad or \quad 1-\gamma > \beta > \alpha;$

(iv) Increasing returns to Technology B and constant returns to Technology A with $\gamma + \beta > \gamma + \alpha = 1 \quad or \quad \beta > \alpha = 1-\gamma;$

(v) Constant returns to Technology B, and decreasing returns to Technology A $1 = \gamma + \beta > \gamma + \alpha \quad or \quad 1 - \gamma = \beta > \alpha$.

Note that we have assumed $A_0 > B_0$ and assumption (A1) is also in place; otherwise, the bequest lines and production functions of the two technologies would not intersect, making the technology adoption decision a trivial one with all agents choosing Technology B. The cases presented above are then consistent with our interpretation of appropriate technology.

At this point, it is useful to briefly digress and note that, at first glance, the assumption regarding a choice between only two technologies may seem unrealistic. In reality, there may be a range of technologies to choose from, ranked in ascending order of potential productivity. Such issues are considered in recent models of technology adoption and diffusion, such as the framework in Comin and Hobijn (2010), who consider a continuum of "vintages" that are available for adoption once production costs associated with them are no longer prohibitive. In their model, embodied productivity of vintages is exogenous, and they only consider technologies with constant returns to scale. In the context of our model, one could incorporate additional technologies, but it would significantly add to the complexity of the model, making it less tractable, while the insights we are derive would essentially remain the same.

To elaborate, consider a situation in which a discrete, finite range of technologies is available to the agents. Given the nature of the model, the agent would first transition from Technology A to Technology B, and then from B to C, C to D, and so on. (One could not jump from A to C since the critical level of resources to reach C would be higher than those required to reach C and resources in the model increase in a continuous fashion as evident from equations (8) and (9)). There would be a myriad possibilities depending on the returns to scale combinations, and there would an increasing number of returns-to-scale combinations to choose from. One way to address this issue in a simplified way would be to consider our model in its current form as applicable to a *stage of development*; once the economy has moved from A to B, the decision problem of the agent in the second stage involves comparing B and C. The "story" and implications of the model for this second stage would be the same, or at least similar in spirit, as will become clear when we analyse the dynamics of our model. Likewise, once the economy has moved from B to C, the decision becomes a choice between C and D and so on. Therefore, using the "stage of development" interpretation, we restrict ourselves to the case of two technologies.

4. Analysis of Dynamics and Long-run Outcomes

In what follows, we discuss the dynamics implied by equations (8) and (9) in the context of the cases (i)-(v) listed in the previous section. Figure 4.1 illustrates all the possibilities for case (i); however only four of the seven possibilities are distinct, as far as long-run outcomes are concerned.[11] Panel (a) of Figure 4.1 illustrates the first possibility, where all the three long run outcomes are possible depending on the initial distribution of income. The position and the curvature of the curves of equations (8) and (9) are such that w^*exists below the 45^0 line. In this case, $w_s^A < w^* < w_s^B$, where w_s^A and w_s^B denote the steady states characterising Technology A and Technology B, respectively. If the initial distribution of wealth is such that all agents are below w_s^B, then the economy will converge to a stable state w_s^A. In this case all agents in the economy will use Technology A. There is zero growth once this steady state is reached. If the initial distribution of wealth is such that some agents are above and others below w_s^B, a *dual economy* emerges as agents above w_s^B will experience continuous growth in wealth. In this case inequality sharply increases over time. Finally, if the initial distribution is such that all the agents are above w_s^B, all the agents adopt Technology Band the economy experiences *sustained growth*. Inequality increases sharply in this case too, as all agents switch to B at different times, and the technologies are characterised by increasing returns. We further interpret this sustained growth as “unbalanced” given all agents experience a different growth rate.

Viewing Panel (a) from a cross-country perspective, a relatively developed, middle-income economy would have initial conditions such that all agents lie above w_s^B while developing countries could be characterized by initial conditions in which either some or all agents lie below w_s^B, making it difficult to move out of the ‘poverty trap’ and ‘dual economy’ scenarios. In the case of dual economies, policy intervention in the form of redistributive taxation could move all agents to the sustained growth path. In the case of the poverty trap, however redistribution becomes irrelevant as all agents are poor. In that case institutional reform targeted at structural change would be important, entailing a shift of both production functions (i.e. technology A and B) upwards, so that the initial distribution of income does not matter, as

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[11] We split Figure 3.2 into two parts for the sake of clarity. Fitting all panels on one page entails sacrificing the readability of the graphs. We do so in the other cases as well, when there are a large number of panels associated with the figure in question.

in the case of other panels in Figure 4.1 (such as panels c, d, e and f), which we will analyse shortly.

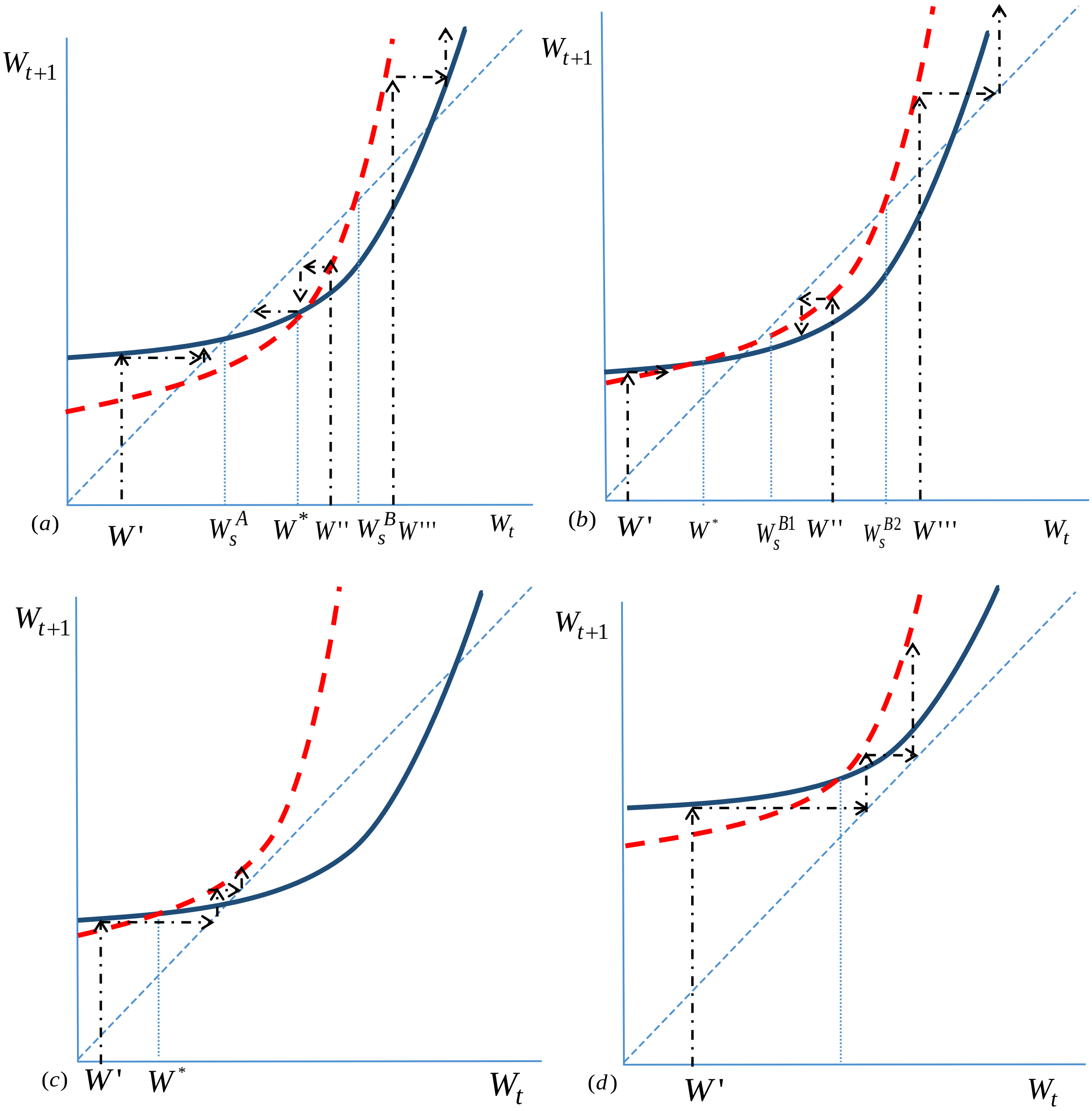

Figure 4.1, Panels (a)-(d): Increasing returns to both technologies

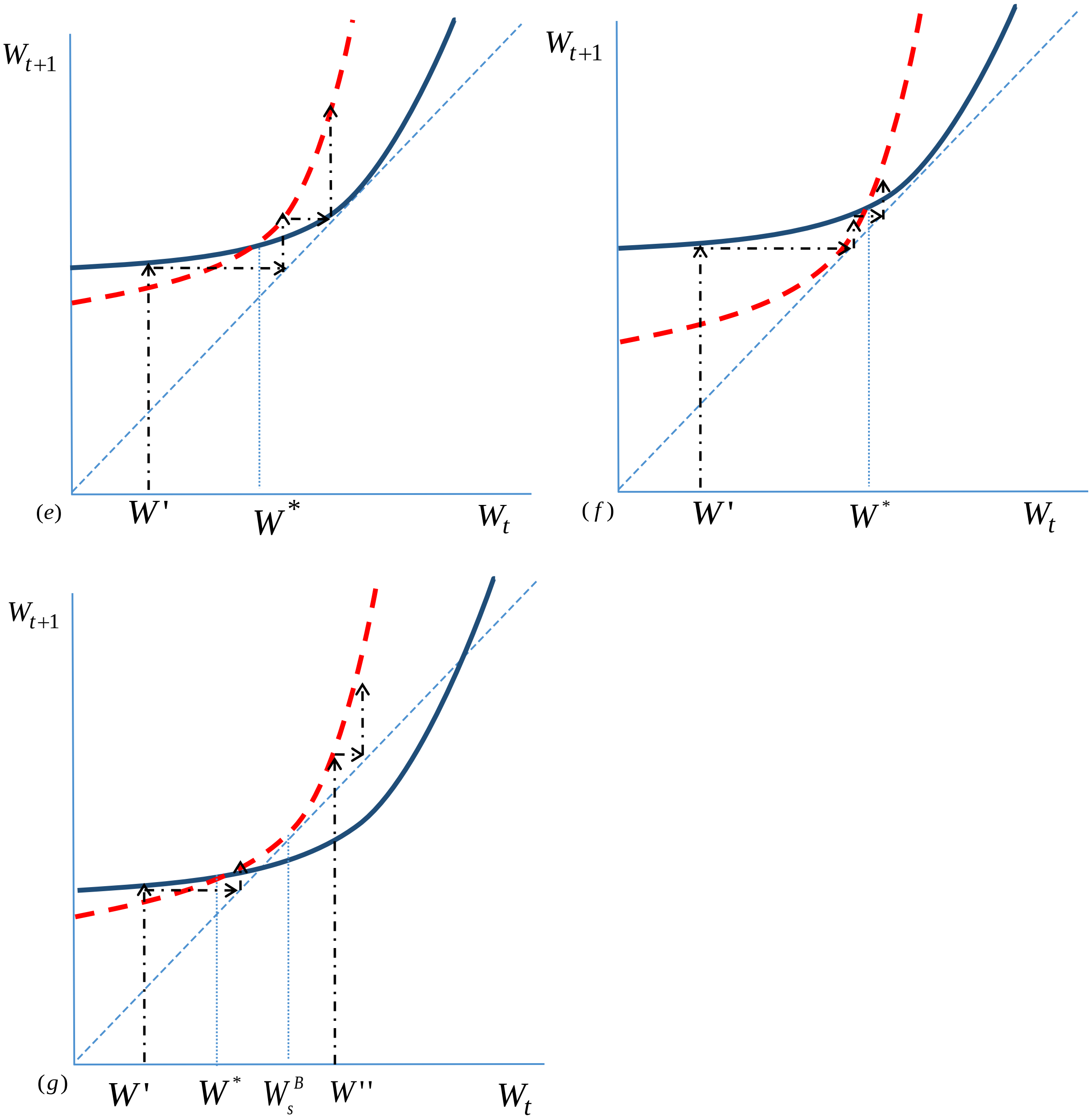

Figure 4.1, Panels (e)-(g): Increasing returns to both technologies

Panel (b) of Figure 4.1 illustrates another case where all the three long run outcomes are possible, albeit under different conditions. In this case, w^* is above the 45^0 line and there are two steady states associated with Technology B.[12] The poverty trap that arises in this scenario is associated with Technology B and it arises if the initial distribution is such that all the agents are below w_s^{B2}. As in Panel (a), this *poverty trap* is characterised by a zero growth rate and the

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[12] Note that only the "upper envelope" of the two intersecting curves is relevant for dynamic analysis. The "steady states" occurring through the intersection of the lower envelope with the 45^0 line are not relevant. We therefore do not label these points in our diagrams.

convergence of incomes of all the agents. In Panel (b), a dual economy is also possible if initial distribution is such that some agents are below and others above w_s^{B2}. In this case the former get caught in the steady state associated with w_s^{B1}, while the latter experience sustained growth. Finally, if all agents are initially above w_s^{B2}, all agents adopt Technology B and the economy will experience *sustained growth*. The growth and inequality patterns associated with the *dual economy* and *sustained growth* in Panel (b) are qualitatively similar to those associated with these outcomes in Panel (a); however the key difference here is that in the dual economy complete adoption of Technology B has taken place.

Panel (c), (d), (e) and (f) are associated with sustained growth regardless of the initial distribution of income. This is because the curves intersect above the 45^0 line and the upper envelope of the curves lies entirely above it.[13] Panel (g) has some similarity with (a) and (b) in that all three long run outcomes can occur, but it is unique in the sense that the steady state associated with Technology B is *semi-stable*. Agents with wealth levels above this steady state experience sustained growth, while those below get caught in it, although the likelihood of escaping is present given that even a small positive income shock can put them on the sustained growth path.

Figure 4.2 illustrates the possibilities for case (ii). Here Technology B experiences increasing returns while Technology A is subject to decreasing returns. As in case (i) the dynamic and long run outcomes depend on where the upper envelope of the two intersecting curves is placed relative to the 45^0 line. Panels (a), (d) and (e) of Figure 4.2 therefore correspond to the scenarios in which sustained unbalanced growth takes place with complete adoption of Technology B, regardless of the initial distribution of income. In Panel (b), however, outcomes depend on where the support of the initial distribution lies. If it is entirely below the steady state w_B^s, we have a poverty trap with all agents in the economy converging to the steady state w_A^s and adopting Technology A. If the support includes w_B^s, then agents below it converge to w_A^s while those above it experience sustained growth, leading to a dual economy. Finally, if

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[13] We could have chosen to present only one of these cases, given the outcomes are identical. However we have chosen to present all to ensure the analysis is 'complete'. Also, while all of these cases produce identical outcomes in the context of the model they provide the reader with a frame of reference for the hypothetical scenario in which only Technology A is available for adoption. In that case, of course, outcomes for the economy in all of these cases would have been different. We therefore follow this convention in the remainder of the analysis.

the support of the initial distribution lies to the right of w_B^s, all agents experience sustained growth. In the latter two cases, inequality increases over time.

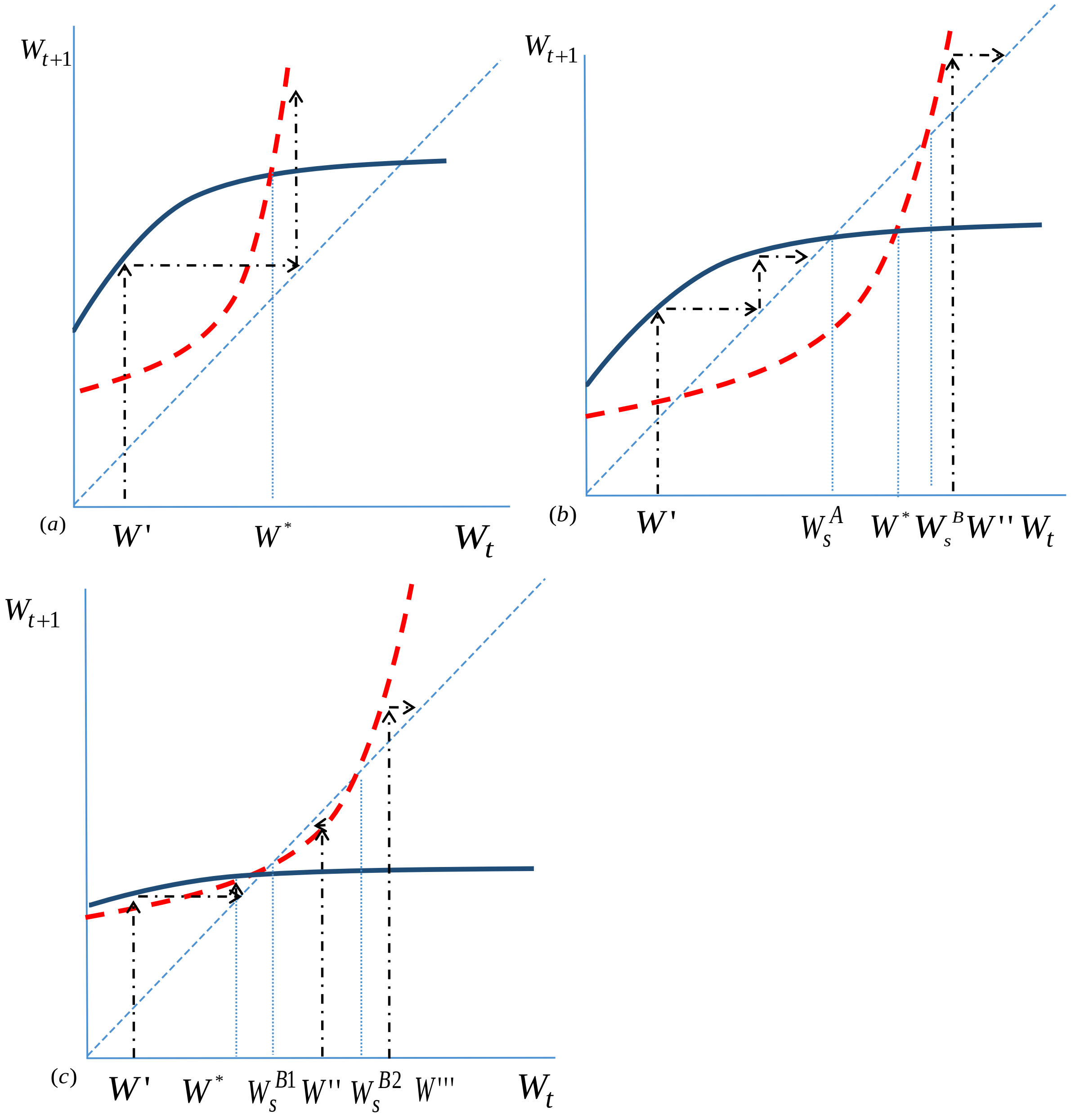

Figure 4.2, Panels(a)-(c): Increasing returns to Technology B and decreasing returns to Technology A

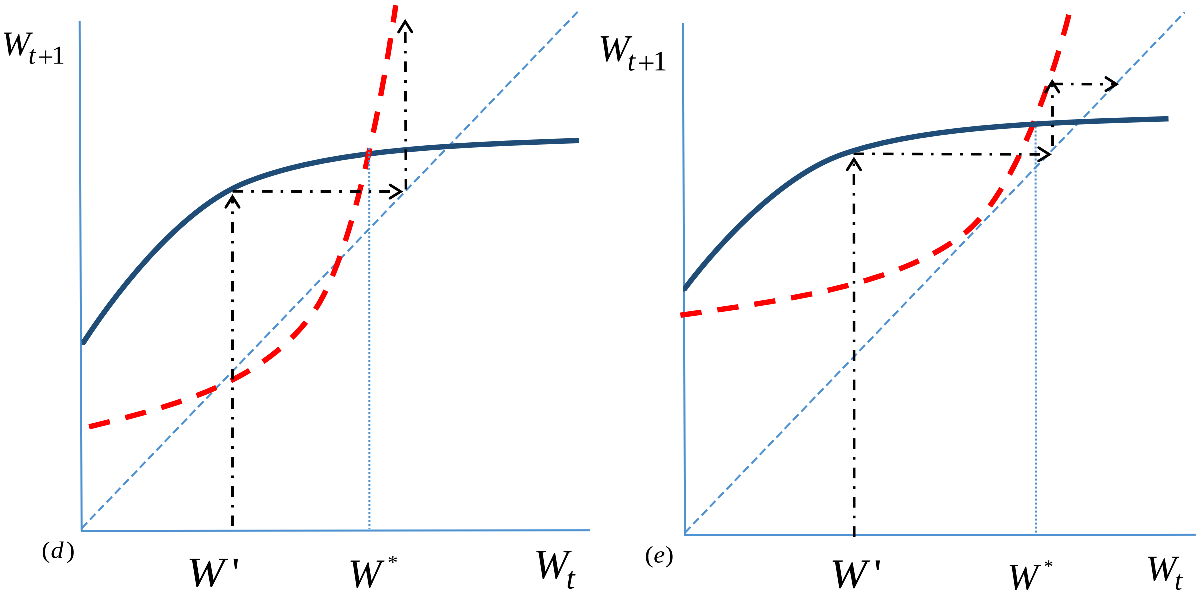

Figure 4.2, Panels(d)-(e): Increasing returns to Technology B and decreasing returns to Technology A

Panel (c) of Figure 4.2 also presents a situation where all three long run outcomes are possible, but with the distinction that the dual economy involves complete adoption of Technology B. This is because there are two steady states associated with Technology B, a stable one at w_B^{s1} and an unstable one at w_B^{s2}. Agents positioned below the unstable steady state converge to the stable one and experience zero growth, albeit they have adopted Technology B.

The latter case is an intriguing and unusual type of dual economy. Here, all agents in the economy have adopted B and yet only some experience sustained growth. Viewing this case from a cross-country perspective, it provides an additional dimension for the "appropriate technology" explanation for non-adoption. For example, in an economy where the initial distribution of resources falls to the left of w_B^{s2}, all agents adopt B and experience zero growth. Furthermore this outcome is reminiscent of the point discussed Acemoglu and Zilibotti (2001), that productivity differences are observed across countries even when the same technology is used across countries. Our model suggests a different explanation for this empirical phenomenon; here the lower productivity occurs because there is a switch from decreasing to increasing returns to scale, and there are multiple equilibria associated with the new technology. Note that, in a poor economy, where all agents fall below w_B^{s2}, they are not substantially better-off relative to the situation in which they were using Technology A; the steady state associated with A implies only a slightly smaller level of wealth relative to w_B^{s1}.

We now turn to case (iii), which is presented in Figure 4.3. Here we have both technologies exhibiting decreasing returns to scale, and there are only two possibilities. When the intersection of the bequest lines occurs above the 45^0 line, as in Panel (a), all agents adopt B, and when it occurs below it, as in panel (b), all adopt A. In both cases there is zero growth.

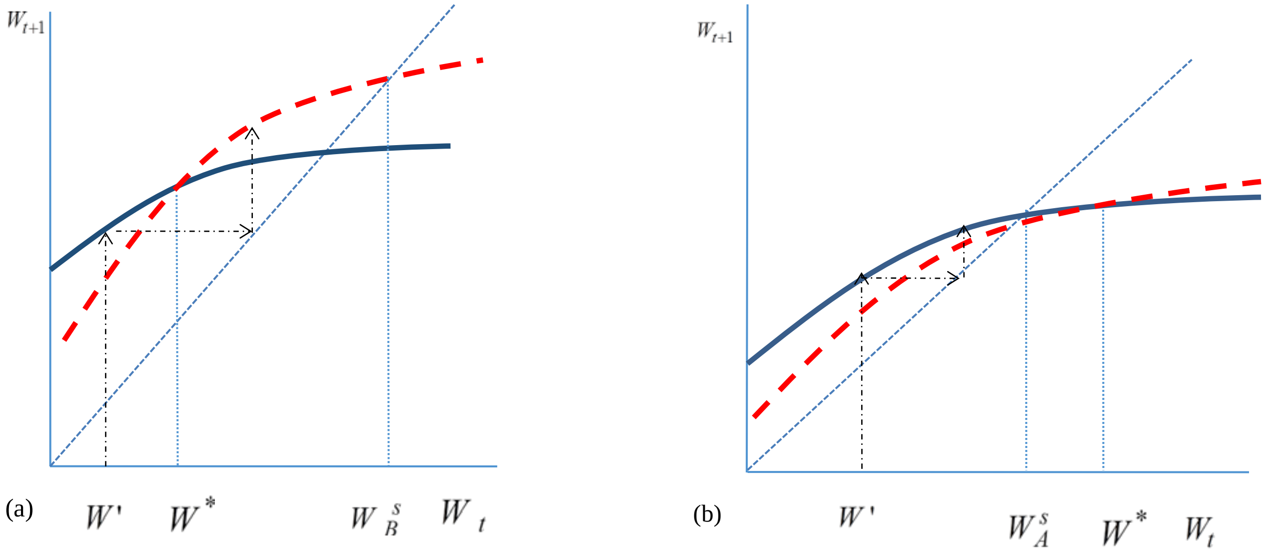

Figure 4.3: Decreasing returns to both technologies.

In case (iv), when Technology A has constant returns and Technology B has increasing returns to scale, there are six possibilities. Panel (a) of Figure 4.4 presents the only case in which all three possibilities, i.e. poverty trap, sustained growth and dual economy can occur. If the support of the initial distribution is to the left or right of w_B^s we respectively have the former two outcomes. If, however w_B^s is included within the distribution we have a dual economy in which agents below wealth level w_B^s adopt A and converge to w_A^s, while those above w_B^s experience sustained growth. Panels (b)-(f) are identical in the sense that they lead to sustained unbalanced growth. However, the transitional dynamics are slightly different depending on whether the slope of the bequest line for Technology A is greater or less than one.

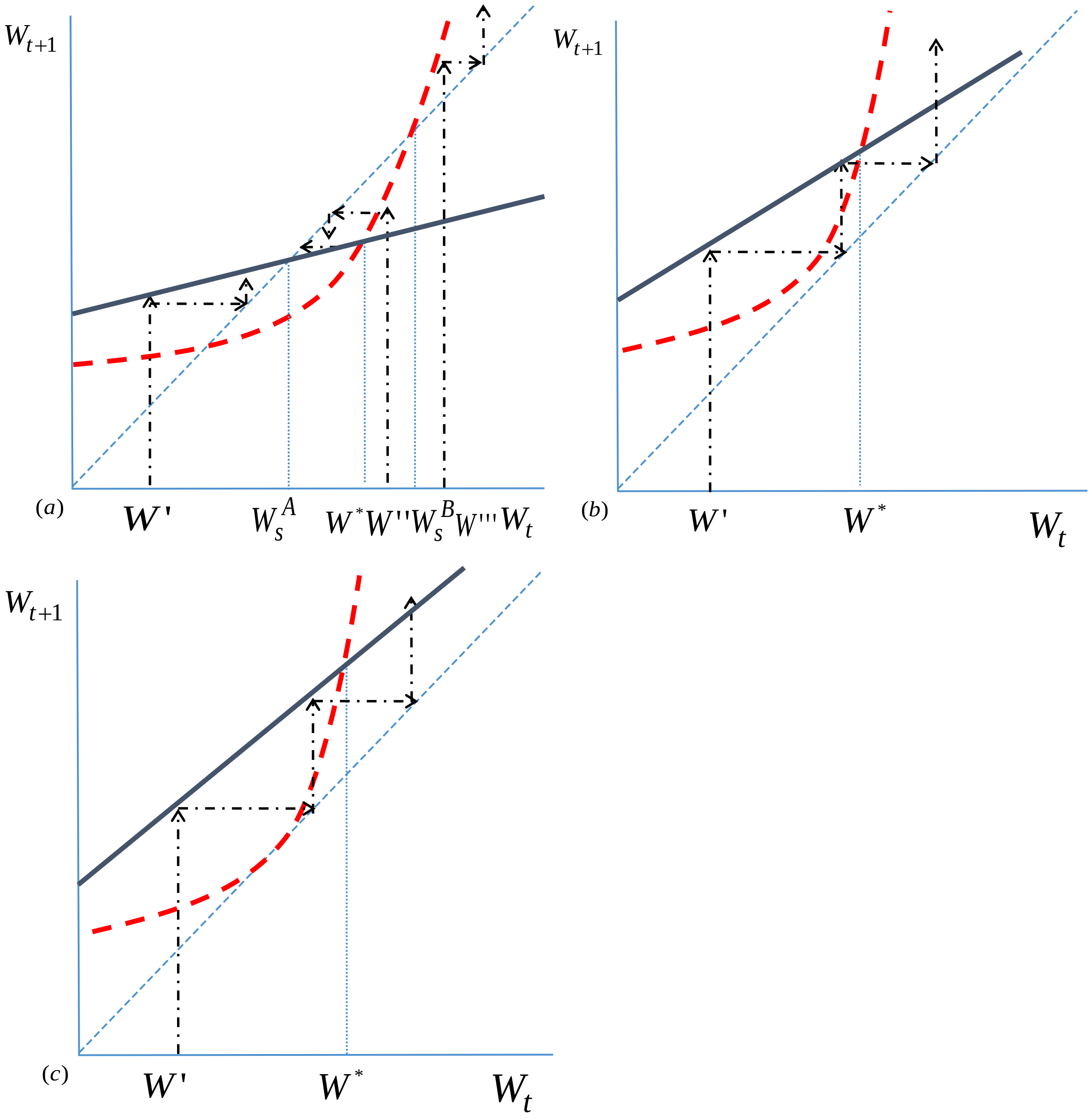

Figure 4.4, Panels (a)-(c): Constant returns to Technology A and increasing returns to Technology B

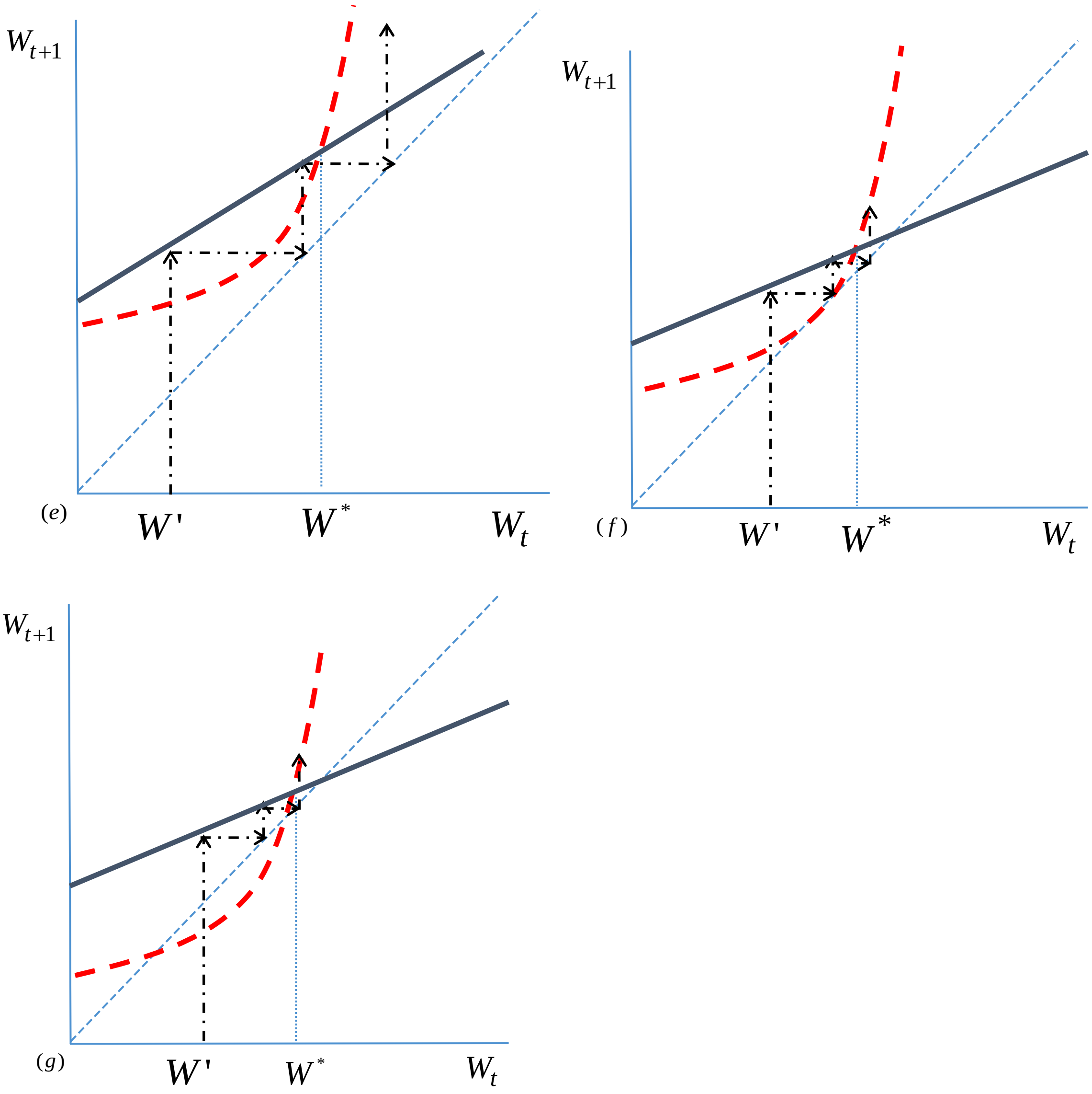

Figure 4.4, Panels (d)-(g): Constant returns to Technology A and increasing returns to Technology B

In panels (b), (c) and (d) of Figure 4.4, poorer agents initially adopt A, but since the slope of the linear bequest line is greater than one, experience sustained capital deepening and growth. The growth is faster once they adopt B. In panels (e) and (f) poorer agents initially grow slowly until w* is reached and then experience sustained growth.

Figure 4.5 presents case (v) in which Technology B is linear, with constant returns to scale, while Technology A experiences diminishing returns to scale. In this case we have three possibilities, represented graphically in panels (a), (b) and (c).

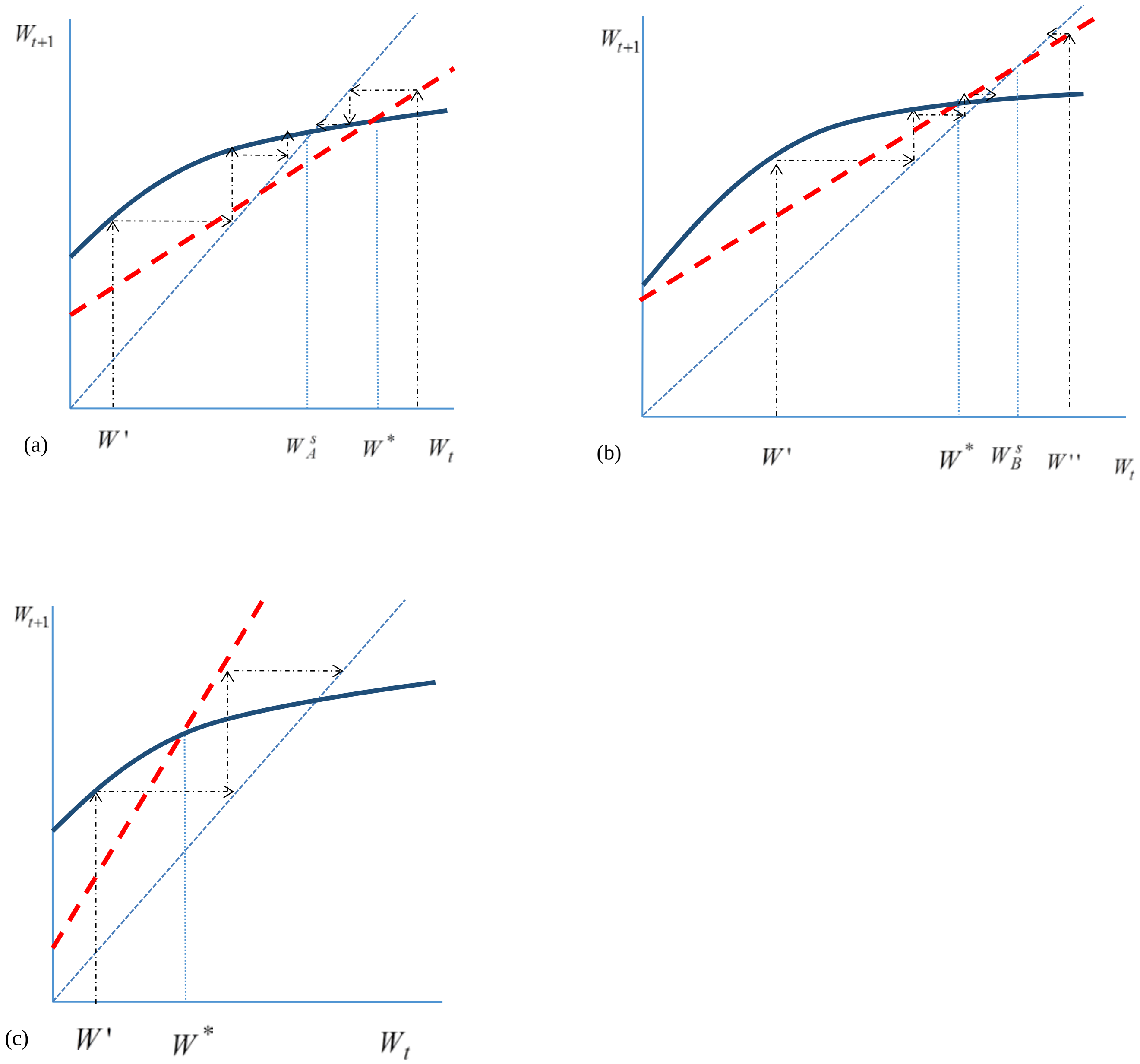

Figure 4.5: Decreasing returns to Technology A and constant returns to Technology B

In Panel(a) we have a case of no adoption with zero growth as all agents converge to the steady state w_A^S, regardless of the initial distribution. In Panel (b) there is complete adoption of B, but with zero growth as all agents converge to w_B^s. In Panel (c) there sustained growth with all agents adopting B. However we interpret this type of growth as "balanced" as all agents eventually grow at the same rate.

In summary, depending on the parameters and initial conditions there is a wide variety of possibilities for the growth and technology diffusion experiences of the economy.[14] These possibilities also suggest varying political economy implications. Specifically, it is interesting to note that, even in the cases where complete adoption of the "potentially better" technology takes place, catching points with zero growth can occur. These outcomes provide a rationale for why resistance towards the adoption of a different nature of technology, particularly in the context of a technology with non-diminishing returns, could occur for a given initial distribution of income.[15]

5. Concluding Remarks

The model we present above is a fairly general one and nests several models within it as special cases, allowing for a unified framework of growth and technology adoption. Our focus, however, is on the appropriate technology notion initially developed in Atkinson and Stiglitz (1969) and more recently in Basu and Weil (1999). This paper examines this notion as a potential candidate for explaining the diversity of growth and technology diffusion experiences of world economies, and for uneven development patterns within countries. We find that the appropriate technology concept is indeed worthy of further exploration given the richness of outcomes nested within the framework discussed above. Depending on initial conditions, there is the possibility of poverty traps and dual economies even in cases where the potentially more productive technology has been fully adopted in the economy. Furthermore, the model can explain situations where productivity differences arise across countries even in the case the same technology has been adopted across countries. Another interesting aspect of the model is that the nature of growth can be "balanced" or "unbalanced". This suggests that empirical work examining the diffusion of adopted technologies in the context of local conditions of development and skill depth is a fruitful area of research.

The model also highlights some dimensions along which political economy issues come into play, and have a bearing on the interdisciplinary literature surrounding the "appropriate technology movement" initiated by the work of Schumacher (1975). Specifically, while the model does not explicitly model politico-economic influences, it provides an indirect rationale

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[14] Table C.1 in the Appendix presents the list of outcomes and associated features in summary form.

[15] In the "appropriate technology movement" mentioned earlier, for example, the emphasis on the use of "small-scale" technologies was, in part, due the negative experiences of developing economies adopting technologies associated with increasing returns to scale.

for the emergence of resistance to more advanced technologies that involve higher returns to scale. In the context of our model such a resistance might occur in cases where adverse outcomes occur even when the potentially better technology has been adopted.

Appendix

A. Proof of Proposition 1

Since utility is logarithmic, and at the optimum bequests are proportional to consumption, we can write the indirect utility function as follows:

$U(c^{z^*}, x^{z^*}) = \ln(c^{z^*}) + \theta \ln(x^{z^*}) = \ln(c^{z^*}) + \theta \ln(\theta c^{z^*}) = (1+\theta)\ln(c^{z^*}) + \theta \ln \theta$.

Here $z = a, b$, denoting the technology adopted by the agent. Given that indirect utility function is a monotonic transformation of the optimal plan for consumption, comparing the indirect utilities of those adopting A or B amounts to comparing their consumption levels. That is, in period t an agent will adopt B iff

$$\frac{\mathrm{B}}{1+\theta}\left(\frac{\overline{w}+w_t}{1+\beta}\right)^{\beta+\gamma} \geq \frac{\mathrm{A}}{1+\theta}\left(\frac{\overline{w}+w_t}{1+\alpha}\right)^{\alpha+\gamma}.$$

Note that A and B are as defined previously. Straightforward manipulation of the above yields the result of Proposition 1.

B. Comparative Statics

For comparative static we begin by carrying out a logarithmic transformation of the expression in proposition 1 as follows:

$$\ln(w^* + \overline{w}) = \frac{1}{\beta-\alpha}\left(\ln \mathrm{A} \text{ - } \ln \mathrm{B}\right)$$

$$\ln(w^* + \overline{w}) = \frac{1}{\beta-\alpha}(\ln \mathrm{A} - \ln \mathrm{B})$$

Comparative static analysis with β

Differentiating the above with respect to, β we get:

$$\frac{1}{(w^* + \overline{w})}\frac{dw^*}{d\beta} = \frac{1}{\beta-\alpha}\left(\frac{d\ln \mathrm{A}}{d\beta} - \frac{d\ln \mathrm{A}}{d\beta}\right) - \frac{1}{(\beta-\alpha)^2}(\ln \mathrm{A} - \ln \mathrm{B})$$

Now using the functional forms for A and B, $\mathrm{A} = \frac{A_0 \alpha^{\alpha} \gamma^{\gamma}}{(\alpha+\lambda)^{\alpha+\gamma}}$ and $\mathrm{B} = \frac{B_0 \beta^{\beta} \gamma^{\gamma}}{(\beta+\gamma)^{\beta+\gamma}}$ we obtain the following:

$\frac{d\ln \mathrm{A}}{d\beta} = 0$; $\frac{d\ln \mathrm{B}}{d\beta} = \ln \mathrm{B} - \ln(\beta+\gamma)$

$$\Rightarrow \frac{dw^*}{d\beta} = \frac{w^* + \overline{w}}{\beta - \alpha}\left[\ln(\beta+\gamma) - \ln\beta\right] - \frac{w^* + \overline{w}}{(\beta-\alpha)^2}(\ln \mathrm{A} - \ln \mathrm{B})$$

Rearranging terms we see that

$$\frac{dw^*}{d\beta} > 0 \qquad \textit{iff} \;\; \ln(\beta + \lambda) - \ln\beta > \frac{\ln \mathrm{A} - \ln \mathrm{B}}{\beta - \alpha}.$$

Substituting for A and B this occurs *iff*

$$0 > \ln\frac{A_0}{B_0} + \alpha\ln\frac{\alpha}{\beta} + (\alpha+\gamma)\ln\frac{\beta+\gamma}{\alpha+\gamma}.$$

Note that the first and third terms of the RHS are positive while the second is negative. Therefore, the impact of β on w* is ambiguous.

Comparative static analysis with α :

Going through similar steps as in the case of β, we get:

$$\frac{1}{(w^* + \overline{w})}\frac{dw^*}{d\alpha} = \frac{1}{\beta-\alpha}\left(\frac{d\ln \mathrm{A}}{d\alpha} - \frac{d\ln \mathrm{B}}{d\alpha}\right) + \frac{1}{(\beta-\alpha)^2}(\ln \mathrm{A} - \ln \mathrm{B})$$

where

$$\frac{d\ln \mathrm{A}}{d\alpha} = \ln\alpha - \ln(\alpha+\gamma)\,; \;\; \frac{d\ln \mathrm{B}}{d\alpha} = 0.$$

$$\Rightarrow \frac{1}{(w^* + \overline{w})}\frac{dw^*}{d\alpha} = \frac{1}{\beta-\alpha}\left[\ln\alpha - \ln(\alpha+\gamma)\right] + \frac{1}{(\beta-\alpha)^2}(\ln \mathrm{A} - \ln \mathrm{B})$$

$$\Rightarrow \frac{dw^*}{d\alpha} = \frac{w^* + \overline{w}}{\beta-\alpha}\left[\ln\alpha - \ln(\alpha+\gamma)\right] + \frac{w^* + \overline{w}}{(\beta-\alpha)^2}(\ln \mathrm{A} - \ln \mathrm{B})$$

Therefore,

$$\frac{dw^*}{d\alpha} > 0 \qquad \textit{iff} \;\; \left[\ln(\alpha+\gamma) - \ln\alpha\right] > \frac{\ln \mathrm{A} - \ln \mathrm{B}}{\beta - \alpha}.$$

$$0 > \ln\frac{A_0}{B_0} + \beta\ln\frac{\alpha}{\beta} + (\beta+\gamma)\ln\frac{\beta+\gamma}{\alpha+\gamma}\,.$$

As in the previous case, the first and third terms on the RHS are positive, while the second is negative. Hence the impact of α on w* is ambiguous.

Comparative static analysis with γ

Again, starting with the expression for w* and differentiating, we get:

$$\frac{1}{(w^* + \overline{w})}\frac{dw^*}{d\gamma} = \frac{1}{\beta - \alpha}\left(\frac{d\ln \mathrm{A}}{d\gamma} - \frac{d\ln \mathrm{B}}{d\gamma}\right)$$

Furthermore,

$$\frac{d\ln \mathrm{A}}{d\gamma} = \ln\gamma - \ln(\alpha + \lambda) \; ; \; \frac{d\ln \mathrm{B}}{d\gamma} = \ln\gamma - \ln(\beta + \lambda).$$

$$\Rightarrow \frac{dw^*}{d\gamma} = \frac{w^* + \overline{w}}{\beta - \alpha}\left[\ln(\beta + \gamma) - \ln(\alpha + \gamma)\right] = \frac{w^* + \overline{w}}{\beta - \alpha}\ln\frac{\beta + \gamma}{\alpha + \gamma} > 0$$

Comparative static analysis with A_0

$$\frac{1}{(w^* + \overline{w})}\frac{dw^*}{dA_0} = \frac{1}{\beta - \alpha}\frac{d\ln \mathrm{A}}{dA_0} = \frac{1}{A_0(\beta - \alpha)}$$

$$\Rightarrow \frac{dw^*}{dA_0} = \frac{w^* + \overline{w}}{A_0(\beta - \alpha)} > 0 \, .$$

That is, the impact of A_0 on w* is positive.

Comparative static analysis with B_0 :

Likewise, we can show that the impact of B_0 on w* is negative, given that:

$$\frac{1}{(w^* + \overline{w})}\frac{dw^*}{dB_0} = -\frac{1}{\beta - \alpha}\frac{d\ln \mathrm{A}}{dB_0} = -\frac{1}{B_0(\beta - \alpha)}$$

$$\Rightarrow \frac{dw^*}{dB_0} = -\frac{w^* + \overline{w}}{B_0(\beta - \alpha)} < 0 \, .$$

C. Summary of Outcomes

Table C.1

Case	Possible long-run outcomes and features
Increasing returns to both technologies (case 1)	Poverty trap type 1: • All agents get caught in the *steady state associated with technology A*. For such a steady state to exist, the position of the functions determining wealth dynamics (equations (8) and (9) are relevant). • Occurs if, in the initial distribution all agents in the economy are below a certain level of wealth. Dual economy type 1: • Some agents get caught in the steady state associated with technology A, while some agents experience sustained growth using technology B • Occurs if the support of the distribution includes agents below and above a certain threshold level, and equations (8) and (9) are as in Poverty trap type 1 Poverty trap type 2: • All agents get caught in a stable or semi-stable steady state associated with technology B. The shape and position of equations (8) and (9) is relevant for existence of such steady states. • Occurs if, in the initial distribution all agents in the economy are below a certain level of wealth. Dual economy type 2 • Occurs if equations for wealth dynamics are as in Poverty trap type 2, and the distribution has agents below and below a certain threshold level of wealth Sustained unbalanced growth • All agents experience sustained growth • Growth is "unbalanced' in the sense all agents experience different growth rates • Conditional on the shape and position of functions determining wealth dynamics, this case can occur either independent of the initial distribution (as in panels (c)-(f) of Figure 4.1) or if the support of the distribution lies to the right of a certain threshold level of wealth (as in panel (a) of Figure 4.1) • Transition to sustained growth using B can be diverse; in some cases B is adopted immediately while in others some agents adopt A before transitioning to B
Increasing returns to Technology B, decreasing returns to Technology A (case 2)	Possible outcomes and their features similar to case 1, but transitional dynamics a little different.
Decreasing returns to both technologies (case 3)	There are only two possible outcomes. In one case all agents adopt A, while in the other all agents adopt B. In both cases we have zero growth, regardless of the initial distribution of wealth.
Constant returns to technology A, increasing returns to technology B (case 4)	Possible outcomes are Poverty trap type 1, dual economy type 1, and sustained unbalanced growth. They arise due to similar conditions as described for case 1, but transitional dynamics are different.
Decreasing returns to Technology A, constant returns to Technology B (case 5)	There are three possible outcomes. In one case agents adopt A and there is zero growth as they are caught in a steady state associated with A. In the second case agents adopt B but there is zero growth as they are caught in a steady state associated with B. In the third case there is sustained balanced growth; all agents adopt B, subsequent to which all of them experience the same growth rate. In each of these possible cases the outcome occurs regardless of the initial distribution of wealth.

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