QUT School of Economics and Finance

Discussion Paper and Working Paper Series

Concerning Inequality, Technology Adoption, and Structural Change

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Working/Discussion Paper # 207

November 2007

Abstract:

Empirical evidence suggests that there has been a divergence over time in income distributions *across* countries and *within* countries. In this paper we study a simple dynamic general equilibrium model of technology adoption which is consistent with these stylized facts. In our model, growth is endogenous, and agents are assumed to be heterogeneous in their initial holdings of wealth and capital. We find that in the presence of barriers or costs associated with the adoption of more productive technologies, inequalities in wealth and income may increase over time tending to delay the convergence in international income differences. The model is also capable of explaining the observed diversity in the growth pattern of transitional economies. According to the model, this diversity may be the result of variability in adoption costs, or the relative position of a transitional economy in the world income distribution.

1. Introduction

Empirical evidence suggests that there has been a divergence over time in income distributions *across* countries and *within* countries. For example, based on the work of Quah (1996, 1997), there is strong evidence to suggest an emergence of “twin-peaks” in cross-sectional world income distributions. There is also substantial evidence to suggest that this type of polarization is present in income distributions within countries. (See, for example, Sala-i-Martin 2006, Jappelli and Pistaferri 2000, Piketty and Saez 20031, and Schluter 1998, among others). Typically the empirics of economic growth support Baumol’s (1986) idea of “convergence clubs” emerging across and within countries.

Furthermore, Pritchett (1997) suggests that the growth patterns of countries that fall into the “developing economies” category exhibit a great deal of diversity. For example, some of these countries converge rapidly on the leaders, while others stagnate, or even experience reversals and declines in their growth processes. Pritchett cites the experience of Mozambique (-2.2 percent per annum), and Guyana (-0.7 percent per annum), as examples from a group of 16 developing economies which experienced negative growth rates in the period 1960 – 1992.

There is a large theoretical and empirical literature that seeks to explain cross country income differences. (For a collection of representative literature see Acemoglu 2004a, 2004b.) An interesting strand within this literature looks at the implications of technology adoption and the consequent structural change associated with the process of growth and development. Recent efforts in this direction, (e.g., Hansen and Prescott, 2002, Ngai, 2004, Parente and Prescott, 2004), suggest barriers to adopting more productive technologies as an explanation for cross-country income differences. There are studies that also suggest that inequalities in initial income distributions have a bearing on the issue of technology adoption. For example, in the work of Horii et al. (2005) credit market imperfections, in conjunction with inequality prevents the adoption of more capital-intensive technologies. In a model with an exogenous, fixed cost of adopting technology, Khan and Ravikumar (2001), show that income inequality within a country increases over time.

The model of this paper is similar in sprit to the literature on technology adoption discussed above. We construct a two-period overlapping generations model with heterogeneity in the levels of initial wealth and capital, and two available technologies. One of these technologies is associated with a fixed cost of adoption, but is much more productive than the other technology, which does not entail any costs of adoption. In our model there is a threshold level of capital for which the households in the economy switch to the more productive technology. The threshold level of capital is monotonically declining in the level of wealth of the household, a feature that is consistent with empirical evidence. (See for example, Wozniak 1987, Alauddin and Tisdell, 1991). We find that assumptions about the initial distribution can have very different implications for the date in which all households in the economy adopt the better technology. Inequality can therefore increase and remain persistent for very long periods of time, consequently delaying the process of structural transformation that is associated with development. Furthermore, this feature also has significant implications for divergence in incomes across countries.

We also conduct some thought experiments which allow some variability in the fixed cost of adoption across different time periods. Our experiments indicate that either *variable* or *increasing* adoption costs delay the process of transition to higher growth rates. Variability in adoption costs also has the effect of producing reversals in the growth process, a characteristic that has been observed in the case of several developing economies.

Another set of numerical experiments with our model involve assumptions about the level of inequality of the initial distributions of capital and wealth. We find that higher levels of initial inequality delay the process of transition and also lead to a higher level of inequality in the post-transitional distribution of income.

An interesting feature of the model revealed by our experiments is the diversity of growth patterns observed for different cohorts of households in the economy. Household dynasties positioned at the “rich”, “poor”, or median levels of the income distribution are all capable of experiencing reversals in the growth of income over time. The time of these reversals, which are temporary appear to be related to the timing of technology adoption, which is, of course, different across various income groups.

In the section that follows we describe the economic environment, which has some features in common with the model of Khan and Ravikumar (2001). Section 3 presents the results based on various numerical simulations of this model. Section 4 concludes.

2. The economic environment

The economy consists of two-period lived overlapping generations of agents who are heterogeneous in their holdings of wealth and capital, and have perfect foresight. Time is discrete, with t = 0, 1, 2, ..., and we assume that the *initial* distributions of capital and wealth are described by F(.), and G(.) respectively. Preferences of an agent in born in period t are described as follows:

$$U(C_t, C_{t+1}, W_{t+1}) = \ln(C_t) + \beta \ln(C_{t+1}) + \beta\theta \ln(W_{t+1}). \qquad (1)$$

Here, C_t and C_{t+1} denote the agents consumption in the first and second period of life, W_{t+1} represents bequests left to the next generation. In order to produce output individuals have to decide on adoption of one of two technologies, which will be henceforth referred to as Technology A and Technology B. Technology A is associated with lower productivity but does not involve any adoption costs. It is given by

$$Y_t = AK_t,$$

where K_t represents the period *t composite human and physical capital stock* held by old agents and supplied to the young for production. Technology B is more productive than Technology A, but involves a cost of adoption. It is therefore characterized by

$$Y_t = BK_t - \delta, \qquad B > A, \quad \delta > 0,$$

where δ represents the fixed cost of adopting Technology B. Households adopting Technology A face the following budget constraints:

$$C_t^A + K_{t+1}^A = AK_t + W_t, \qquad (2)$$

$$C_{t+1}^A = (1 + r_{t+1}^A)K_{t+1}^A - W_{t+1}^A. \qquad (3)$$

Households adopting Technology B, on the other hand, face the constraints:

$$C_t^B + K_{t+1}^B = BK_t - \delta + W_t, \qquad (4)$$

$$C_{t+1}^B = (1 + r_{t+1}^B)K_{t+1}^B - W_{t+1}^B. \qquad (5)$$

In the equations above $r_{t=1}^A$ and r_{t+1}^B refer to the rate of return on capital enjoyed by agents who had adopted technologies A and B respectively when they were young. The superscripts A and B applied to the other variables have an analogous interpretation. Note the "AK" structure of production functions we have assumed here is typically known to generate non- convergence in incomes across countries. See for example Mankiw, Romer, and Weil, (1992) and references therein.

Note that the model here has a structure similar to that of Khan and Ravikumar (2001), but with the key difference that a two-period overlapping-generations structure has been assumed[1]. Furthermore, we have an additional state variable in the form of bequests W_t left over from the previous generation, which can also cause inequalities to persist over time.

Agents using technology A maximize (1) subject to (2) and (3). The implied optimal plans for consumption, capital accumulation and bequests are:

$$C_t^A = \frac{1}{(1+\beta(1+\theta))}\left[AK_t + W_t\right] \tag{6}$$

$$C_{t+1}^A = \frac{\beta(1+r_{t+1}^A)}{(1+\beta(1+\theta))}\left[AK_t + W_t\right] \tag{7}$$

$$W_{t+1}^A = \frac{\theta\beta(1+r_{t+1}^A)}{(1+\beta(1+\theta))}\left[AK_t + W_t\right] \tag{8}$$

$$K_{t+1}^A = \frac{\beta(1+\theta)}{(1+\beta(1+\theta))}\left[AK_t + W_t\right]. \tag{9}$$

Likewise we can show that agents who adopt B will have:

$$C_t^B = \frac{1}{(1+\beta(1+\theta))}\left[BK_t - \delta + W_t\right] \tag{10}$$

$$C_{t+1}^B = \frac{\beta(1+r_{t+1}^B)}{(1+\beta(1+\theta))}\left[BK_t - \delta + W_t\right] \tag{11}$$

$$W_{t+1}^B = \frac{\theta\beta(1+r_{t+1}^B)}{(1+\beta(1+\theta))}\left[BK_t - \delta + W_t\right] \tag{12}$$

$$K_{t+1}^B = \frac{\beta(1+\theta)}{(1+\beta(1+\theta))}\left[BK_t - \delta + W_t\right]. \tag{13}$$

It is clear that agents will adopt technology *B iff*

$$U^B(K_t, W_t, r_{t+1}^B) \geq U^A(K_t, W_y, r_{t+1}^A)$$

Where U^A and U^B represent the indirect utility functions for agents adopting the *A* and *B* technologies respectively. It is then easy to show that this implies the following:

Proposition 1: *Let* $K_t^* = \frac{\delta + (\lambda - 1)W_t}{B - \lambda A}$, *where* $\lambda = \left(\frac{1+A}{1+B}\right)^{\frac{\beta(1+\theta)}{1+\beta(1+\theta)}}$. *For a given level of wealth* W_t *a household will adopt technology B iff* $K_t \geq K_t^*$.

[1] Khan and Ravikumar consider an infinite horizon model with non-overlapping generations and a one-time adoption cost, after which the old technology is never used. In our model, each generation faces a technology adoption problem, even if the previous generation belonging to the same cohort had adopted the B technology.

The above proposition defines a threshold level of capital required for a household with wealth W_t to find it worthwhile to adopt the more productive technology B. Alternatively we could have defined a threshold level of wealth needed to adopt the B technology for a given level of capital stock. The equations of Proposition 1 in fact define a "frontier" represented by a locus of combinations of wealth and capital that make the switch to technology B possible. As illustrated by Figure 1, this frontier shifts to the right in (*K*, *W*) space as the cost of adoption δ increases. Since $\lambda < 1$, higher levels of wealth are associated with lower levels of the threshold capital stock. The frontier is therefore downward sloping.

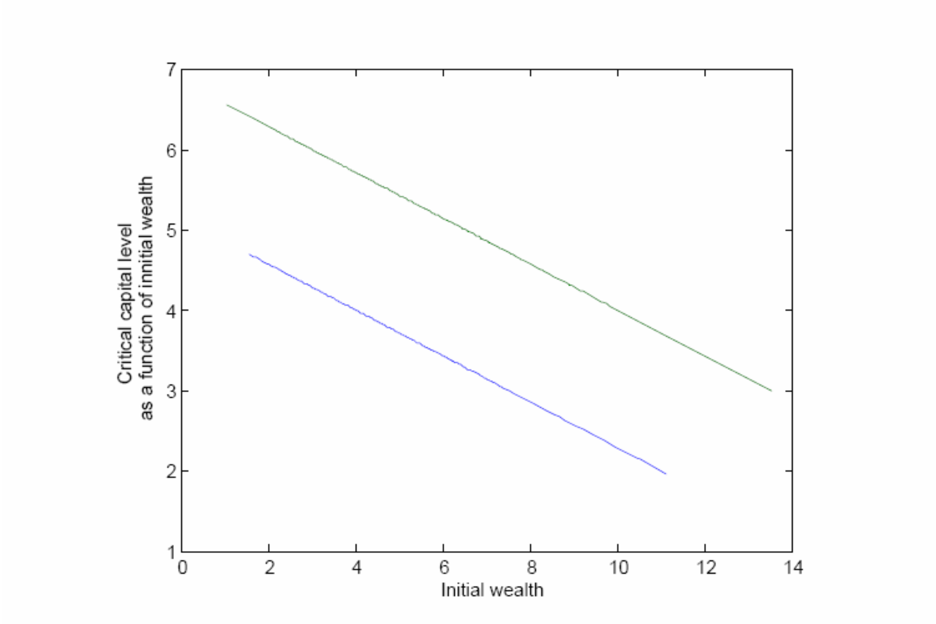

Figure 1: Frontier of initial wealth and critical capital for different adoption costs.

The dynamics of this model are then described by the following system of first order difference equations

$$\left.\begin{aligned} K_{t+1}^A &= \frac{\beta(1+\theta)}{(1+\beta(1+\theta))}\left[AK_t + W_t\right] \\ W_{t+1}^A &= \frac{\theta\beta(1+r_{t+1}^A)}{(1+\beta(1+\theta))}\left[AK_t + W_t\right] \end{aligned}\right\} \textit{for } K_t < K_t^*$$

$$\left.\begin{aligned} K_{t+1}^B &= \frac{\beta(1+\theta)}{(1+\beta(1+\theta))}\left[BK_t + W_t - \delta\right] \\ W_{t+1}^B &= \frac{\theta\beta(1+r_{t+1}^B)}{(1+\beta(1+\theta))}\left[BK_t + W_t - \delta\right] \end{aligned}\right\} \textit{for } K_t \geq K_t^*$$

where $K_t^* = \dfrac{\delta + (\lambda - 1)W_t}{B - \lambda A}$, with λ defined as in Proposition 1. Note that the threshold level of capital varies over time, which makes it difficult to characterize the dynamics of the system analytically. However, simply by inspecting the system we can draw on some intuitive insights. We know that before reaching the threshold level of capital stock the dynamics are determined by the first two equations; these dynamics are likely to be stable if the coefficients multiplying K_t and W_t are positive and less than 1. For plausible values of parameters, we would expect that this would indeed be the case. In the numerical simulations reported in the following sections, for most of the experiments we assume the following parameter values.

Table 1: Parameter values

β	θ	A	B	δ
.99	1	1	3	20

Note that $r_{t+1}^A = A$, and $r_{t+1}^B = B$, since under competitive conditions inputs are paid according to their marginal contributions to output. We have also conducted several experiments in which all of the parameters are varied, but we do not report all of them[2]. We do however report results relating to the variation of the adoption cost parameter, δ as these are significantly relevant to our analysis.

Of course, the coefficient of W_t in the second set of equations is greater than 1 for the above combination of parameter values. However, even if this coefficient is less than 1, which can be ensured by choosing an appropriately smaller value for the altruism parameter θ, our results do not appear to change in a qualitative sense. The system invariably involves a dynamic process whereby all households in the economy eventually adopt the more productive technology. As this is an endogenous growth model, the economy is on a balanced growth path in which all variables grow at a constant rate over time. The *date* of transition to the better technology is however sensitive to the adoption cost parameter.

In what follows, we report results of various numerical experiments that involve varying some of the parameters of the model and the initial distributions of capital and wealth. We focus our attention on the consequences of these experiments for the date of transition to higher growth rates, and the evolution of inequality within the economy over time. An obvious by-product of these experiments is the

[2] Results are available upon request.

implication for cross-country income differences and inequality in the world income distribution. We also examine the pattern of growth rates of various aggregates such as savings, per capita output, consumption and bequests over time. These patterns show a significant amount of diversity across different cohorts of households. We therefore also report these patterns for households that are in the lowest 20%, the highest 20%, and the mean and median positions in the income distribution.

3. Results of quantitative experiments

In the first experiment we examine the implications of the parameter combination in Table 1 for the transition process of the economy towards the adoption of Technology B. The total number of household in the sample is 501[3]. In Figure 2 we report how the number of households adopting Technology A, and the number adopting Technology B, evolve over time. For example the number of households adopting Technology B is represented by the increasing sequence of 2, 32, 129, 287, 420, 478, 495, and 501. The initial distributions of capital and wealth are assumed to be lognormal with mean 3.6 and variance 1.2, with the adoption cost parameter $\delta = 20$. In Figure 2 it is clear that all households adopt technology at date $T^* = 8$. Note that our model has a two-period overlapping-generations structure in which a single period is interpreted as approximately 35 years. (See for example Hansen and Prescott, 2001). Effectively, therefore, this means that the households completely adopt Technology B in 280 years.

[3] Results do not change qualitatively for larger samples – i.e. the date at which all households adopt B seems to be invariant to the number of households in the initial distribution. Note that since we do not have population growth in this model, the total number of households remains constant over time.

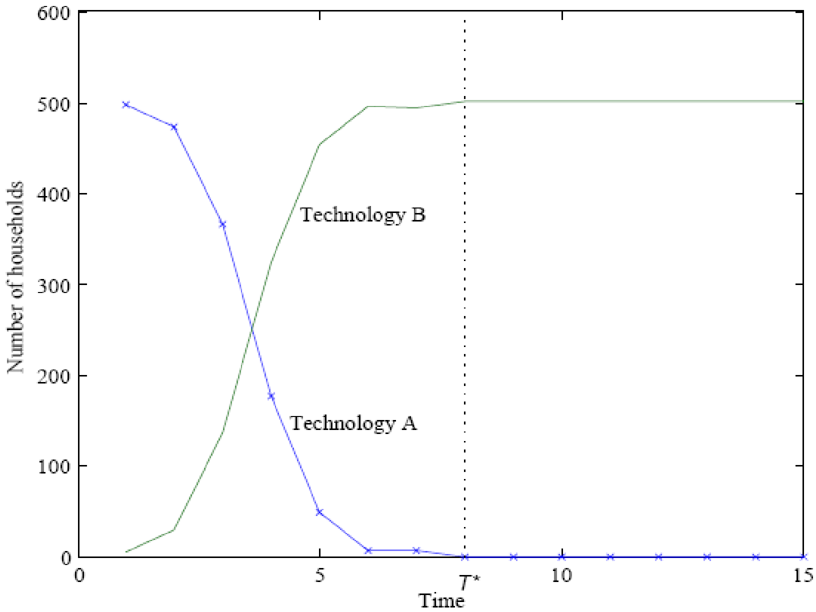

Figure 2: Number of households adopting Technology A or B in different time periods.

3.1. Experiments with the adoption-cost parameter δ

In Figure 3 we examine the effect of increasing the fixed cost of adoption on the date at which all households shift to using Technology B. We consider values of δ set equal to 20, 25, 30, 35. As illustrated in the Figure the corresponding dates of transition T^* are equal to 8, 9, 10, 14 respectively. In terms of our model this implies complete adoption after 280, 315, 350, and 490 years respectively. Higher adoption costs are interpreted to be the result of institutional or structural features that have not been explicitly modeled here. However, the implication for cross country differences in income is obvious. Furthermore, another implication for countries facing high adoption cost pertains to the level of inequality in the income distribution after the transition takes place. For example in Figure 4 we examine the Gini coefficients of capital and wealth over time for different adoption costs. It appears that the level of inequality of the post-transition capital and wealth distributions does not vary significantly as adoption costs increase.

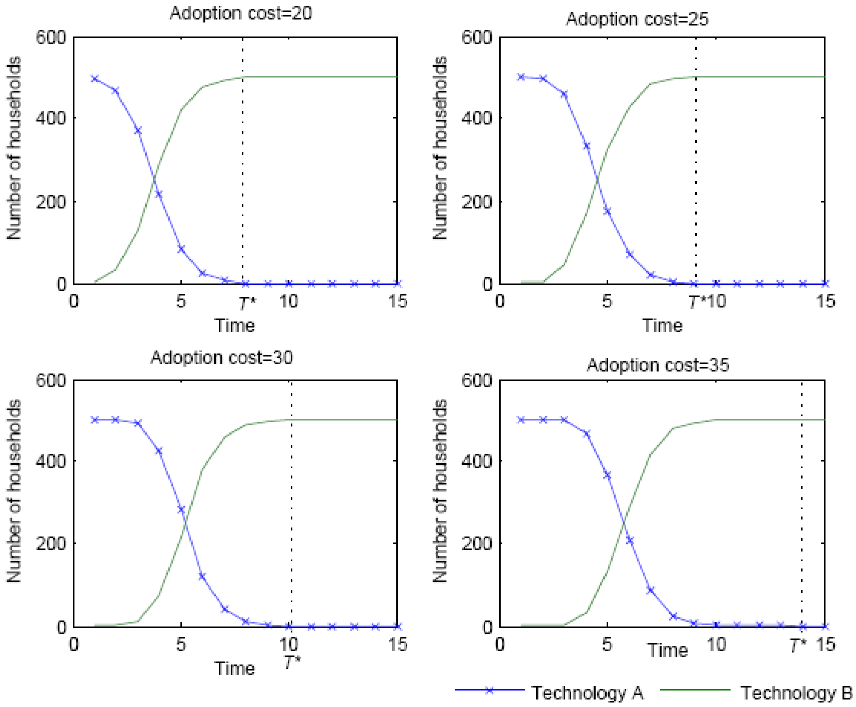

Figure 3: Number of households adopting Technology A or B in different time periods with varying adoption costs.

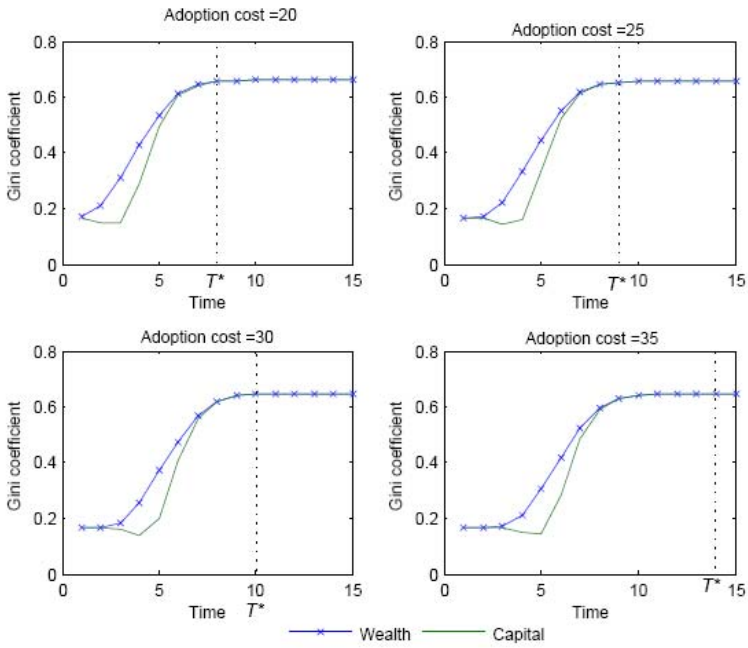

Figure 4: Gini coefficients of capital and wealth over time for different adoption costs.

The results above motivate some simple thought experiments. That is, based on the impact of the magnitude of adoption costs on transition dates and inequality levels eventually attained, it is of interest to examine the effect of (a) adoption costs that vary *randomly* over time, and (b) adoption costs that *increase* over time. These experiments are further motivated by the idea that the growth experience of transitional economies in cross-country data exhibits a lot of diversity. Pritchett (1997) suggests that while some countries that fall in the category of "developing economies" have experienced rapid growth and convergence to higher income levels, others have experienced an interruption of the growth process manifested in the form of stagnation or even *reversals*.

In Figure 5(a) we examine the impact of adoption costs that vary randomly over time. We constructed the adoption cost series by using a uniform random number generator with a transformation that generated positive values of δ between 10 and 60. We find that although there are some reversals in the adoption process during the transition period, eventually complete adoption takes place. The variability of adoption costs appear to impact significantly on the date of eventual transformation. The experiment therefore indicates that varying adoption costs may be a potential candidate for explaining reversals in growth process that has been experienced by some developing economies. Note that we assume that there is no uncertainty associated with the household's technology adoption decision – the decision to adopt a particular technology is taken after the cost is observed by the household. An interesting extension of the model would entail considering a "risky" technology adoption decision whereby the costs are observed after the adoption decision takes place, and only the distribution of adoption costs is known.

In Figure 5(b) we look at increases in adoption costs over time. We consider experiments in which adoption costs grow at a rate of 10%, 15%, and 20% over time, starting at a minimum value of 20. Again, we emphasize that this is simply a thought experiment based on a somewhat "ad-hoc" process for adoption costs. Ideally, the variability in adoption costs should be modeled as a process that is *endogenous* in the sense that it arises due to some institutional or structural features characteristic of developing economies, and that is explicitly modeled into the framework. However, our purpose here is simply to explore whether this may be fruitful direction of research. To that end, the results reported in Figure 5(b) appear to support the idea that this may indeed be the case. Increasing adoption costs appear to significantly delay the process of complete adoption. For example corresponding to the adoption-cost growth rates mentioned above the transition to Technology B takes place approximately after 420, 455, and 525 years respectively.

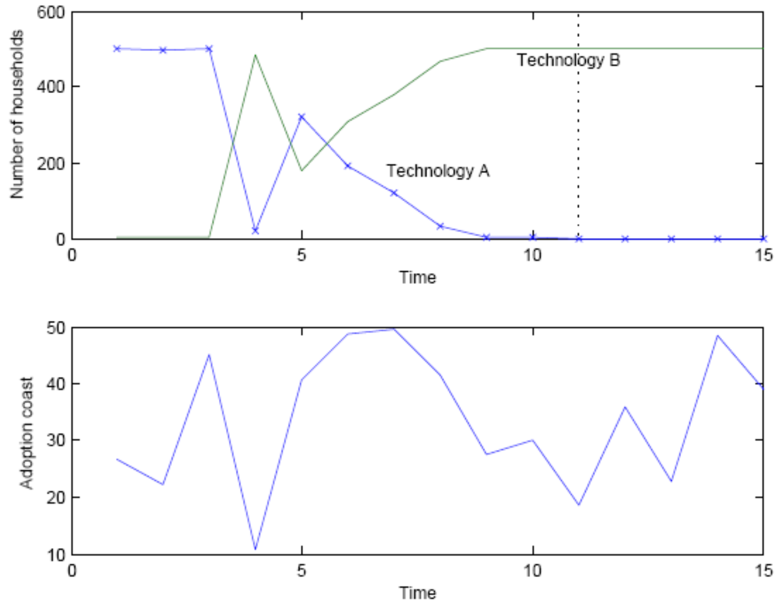

Figure 5(a): Impact of variability in adoption costs over time.

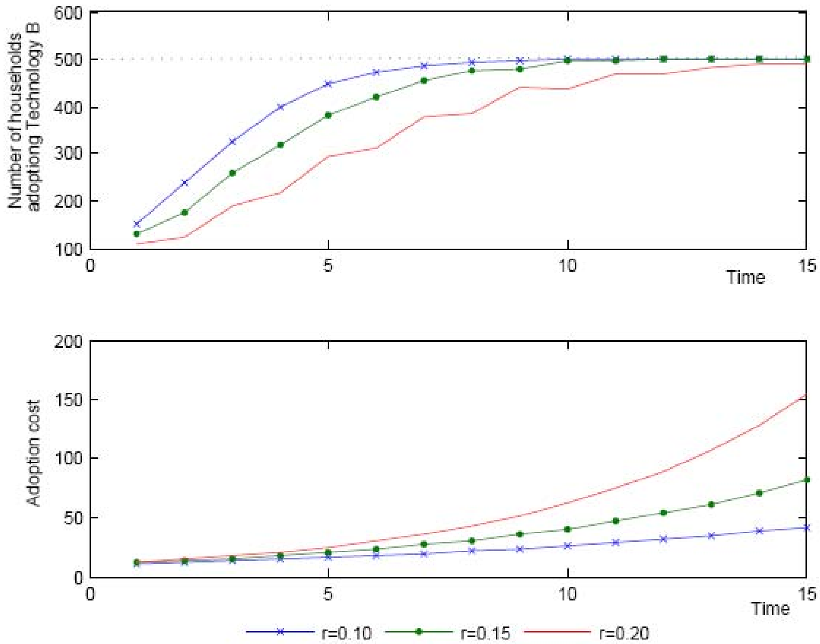

Figure 5(b): Impact of increases in adoption costs over time.

3.2. Experiments that vary initial inequality levels

Next we consider the implications for varying levels of inequality in the initial distributions of wealth and capital, on the date of transition and eventual inequality levels. Figure 6(a) reports four panels which correspond to four different initial distributions that are essentially mean-preserving spreads of the distribution corresponding to Figure 1. That is the mean of all of the initial distributions is 3.6 with variances given by 1.2, 2, 2.6, 3.2 respectively. (The corresponding Gini coefficients of the initial distribution of wealth are: 0.1586, 0.2149, 0.2371, and 0.2741 respectively). It seems that higher the level of initial inequality, later the date of complete adoption of Technology B. In Figure 6(b) we consider the impact on inequality levels in the post-transitional distributions of wealth and capital. (The initial levels of inequality are identical to those corresponding to the experiment in Figure 6(a)). Here, we find that higher levels of initial inequality translate into higher levels of post-transitional inequality.

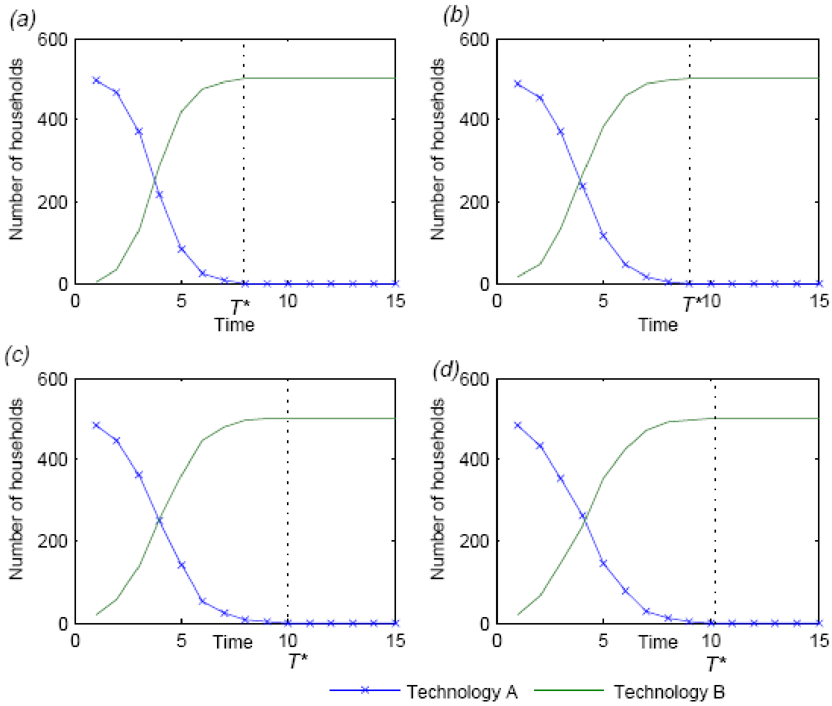

Figure 6 (a): Number of households adopting Technology A or B in different time periods with varying levels of initial inequality.

The results corresponding to Figures 6(a) and 6(b) have an interesting implication for future directions of research. Since the process of transition has such stark distributional implications political economy issues cannot be ignored. It is for example, reasonable to argue that social and political conflict may ensue in the process of transition leading to an interruption of the process. This issue is addressed, for example, in Krusell and Rios-Rull (1996).

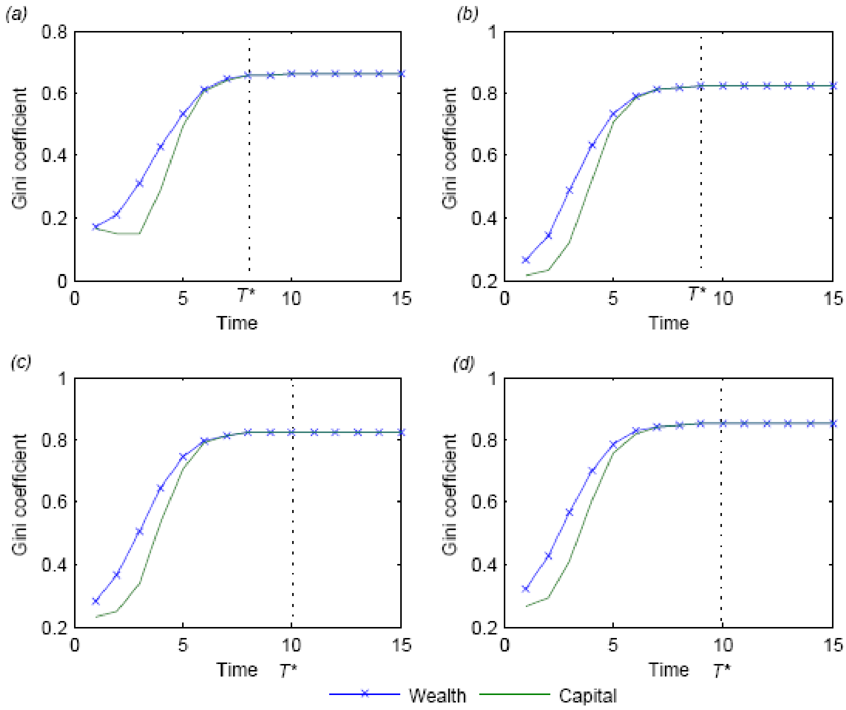

Figure 6 (b): Gini coefficients of wealth and capital in different time periods with varying levels of initial inequality.

3.3. Growth patterns across different cohorts in the income distribution

Figures 7(a), 7(b) and 7(c) examine the patterns in the evolution of wealth, saving, output, and consumption over time across different groups of household. Figures 7(a) and 7(b) looks at the rate of growth of these aggregates for the median of the income distribution, and the "average" household respectively. Figure 7(c) looks at the growth rate these variables for the richest 20% and poorest 20% of the households in the economy. The striking aspect of these figures is that the growth pattern for different cohorts of households is very diverse. For example, the timing of complete adoption, and the timing of reversals and upswings in the growth process vary significantly across different groups. Furthermore, in some cases the pattern of growth is monotonic, while it is non-monotonic for others. One may in fact infer that this characteristic would also translate into a corresponding diversity in the experiences of *countries* that are in different positions in the *world* distribution of income. This feature of the model suggests that multi-country extension of this model similar in spirit to the framework considered in Basu and Weil (1998) with different income distributions across countries and a sequence of technologies with varying levels of productivity might yield a diversity of patterns that have been observed in the data.

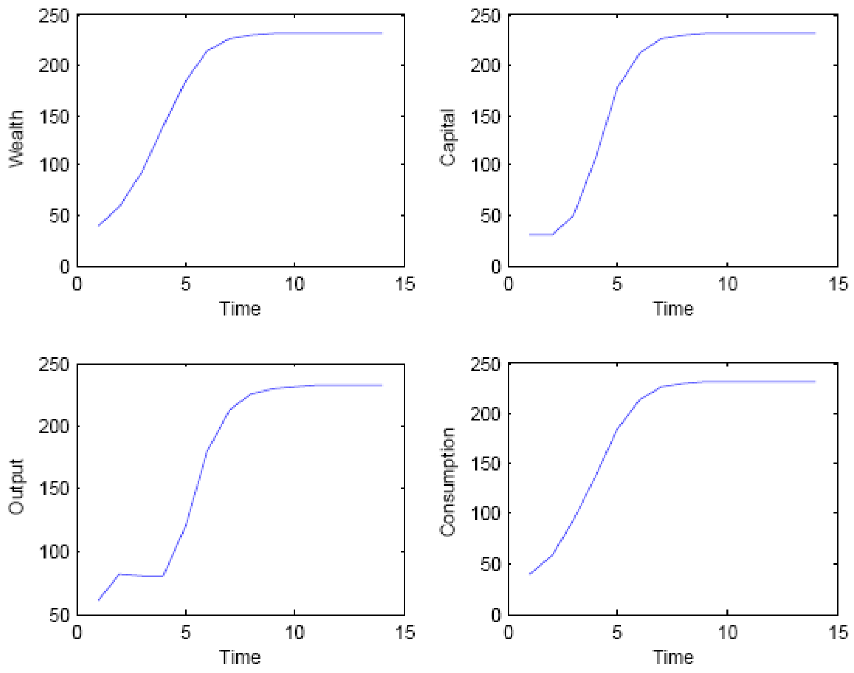

Figure 7(a): Average growth rates of variables in the economy

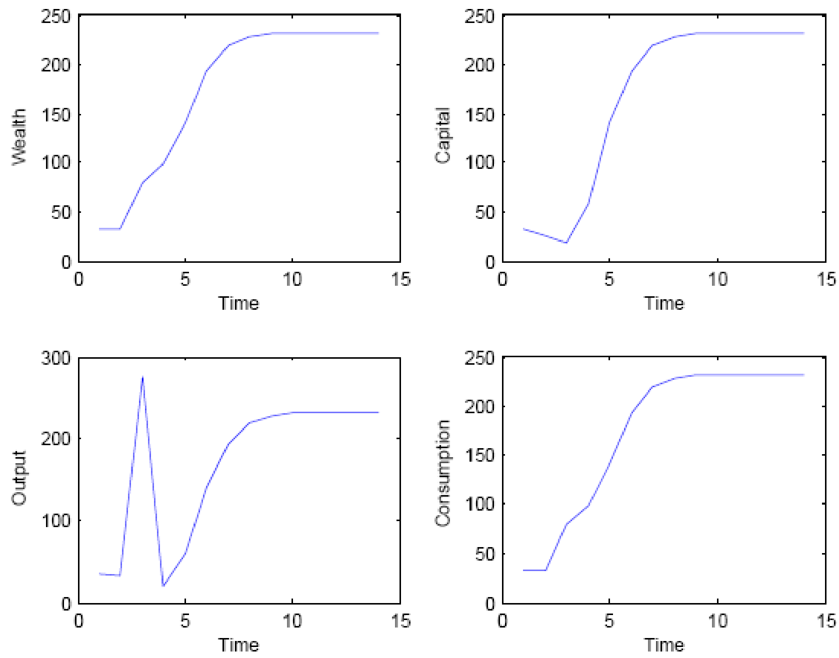

Figure 7(b): Growth rates experienced by the median household

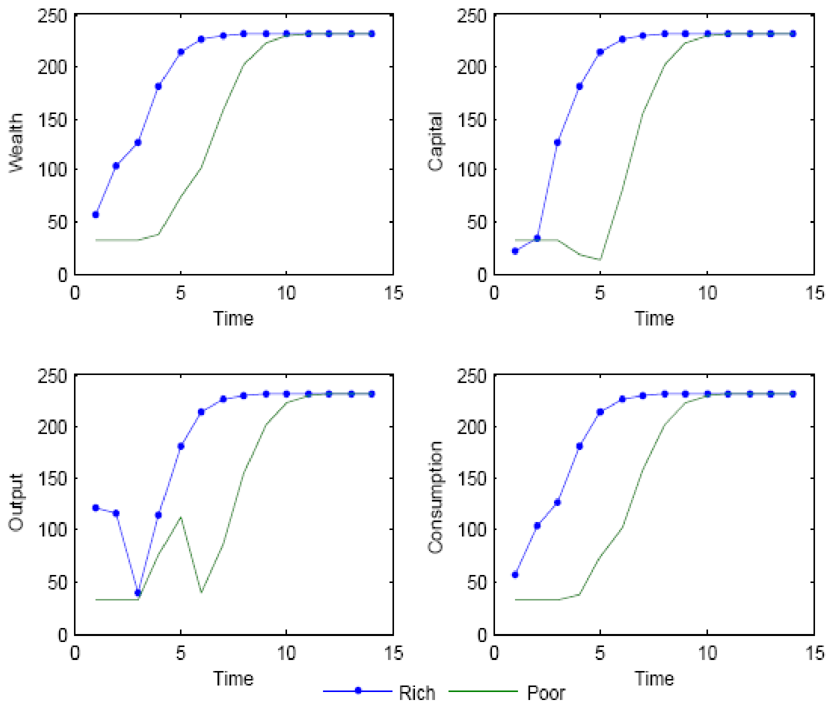

Figure 7 (c): Rates of growth experienced by rich and poor cohorts of households.

4. Concluding remarks

Empirical evidence suggests that there has been a divergence over time in income distributions *across* countries and *within* countries. In this paper we study a simple dynamic general equilibrium model of technology adoption which is consistent with these stylized facts. In our model, growth is endogenous, and agents are assumed to be heterogeneous in their initial holdings of wealth and capital. We find that in the presence of barriers or costs associated with the adoption of more productive technologies, inequalities in wealth and income may increase over time tending to delay the convergence in international income differences. The model is also capable of explaining the observed diversity in the growth pattern of transitional economies. According to the model, this diversity may be the result of variability in adoption costs, or the relative position of a transitional economy in the world income distribution.

Some of our quantitative experiments suggest some interesting directions for future research. Ideally, the variability in adoption costs should be modeled as a process that is *endogenous* in the sense that it arises due to some institutional or structural features characteristic of developing economies, and that is explicitly modeled into the framework. Furthermore, the inequalities that result from the process of transition indicate that political economy issues would also have a bearing on these issues. Risks associated with the variability of adoption costs may also be of importance.

References

Acemoglu D. (2004 a) Recent developments on growth theory Volume I. Edward Elgar Publishing Limited

Acemoglu D. (2004 b) Recent developments on growth theory Volume II Edward Elgar Publishing Limited

Alauddin M. and Tisdel C. (1991) The "green revolution' and labour absorption in Bangladesh agriculture: The relevance of the east Asian experience *Pakistan Development Review*, Vol 30 (2) 173-188

Basu S. and Weil D.N. (1998). Appropriate technology and growth *Quarterly Journal of Economics*, Vol 113 (4) 1025-1054

Boumal S. (1986), Productivity growth convergence and welfare, what long term data show? *The American Economic Review,* Vol. 76 (5)

Hansen G. and Prescott E. (2002) Malthus to Solow *American Economic Review*, Vol 92, 1205-17.

Horii R., Ohdoi R. and Yamamoto K. (2005) Finance, technology and inequality in economic development Discussion papers in economics and development, Graduate school of economics and Osaka school of international public policy.

Jappelli T. and Pistaferri L. (2000) .The dynamics of household wealth accumulation in Italy *Fiscal Studies*, Vol 21 (2) 269-295

Khan A. and Ravikumar B (2000) Costly technology adoption and capital accumulation Working paper, Federal Reserve Bank of Philadelphia.

Krusell P. and Rios-Rull J. (1996) Vested interests in a positive theory of stagnation and growth. *Review of Economic Studies*, Vol 63 (2) 301-329.

Mankiw N.G., Romer D. and Weil D.N. (1992) A contribution to the empirics of economic growth *Quarterly Journal of Economics*, Vol 107 (2) 407-437

Ngai, R. (2004). Barriers and the transition to modern growth J*ournal of Monetary Economics,* Vol 51 (7) 1353-1383

Parente S. and Prescott E. (2004) A unified theory of the evolution of international income levels. Federal Reserve Bank of Minneapolis, Research Department Staff Report 333

Piketty T. and Saez E. (2003) Income inequality in the United States *Quarterly Journal of Economics*, Vol 118 (1) 1-39

Pritchett L. (1997). Divergence, Big Time *Journal of Economic Perspectives*, Vol 11 (3) 3-17.

Quah D. (1996) Empirics for economic growth and convergence *European Economic Review,* Vol 40 (6) 1353-1375

Quah D. (1997) Empirics for economic growth and distribution *Journal of Economic Growth,* Vol 2 (1) 27-59

Schluter C. (1998). Income dynamics in Germany, the USA and the UK: Evidence from panel data, centre for analysis of social exclusion –CASE papers.

Wozniak G.D. (1987) Human capital, information and the early adoption of new technology *Journal of Human Resources*, Vol 22 (1) 101-112

Xala-i- Martin X. (2006) The world distribution of income: falling poverty and convergence, period. *Quarterly Journal of Economics*, Vol 121 (2) 351-397