Identifying Threshold Effects and Typologies in Economic Growth: A Panel Approach

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I. Introduction

Many earlier empirical works on economic growth are based on the assumption that there is an underlying common linear specification as required by the Solow model and its variants (Barro, 1991; Mankiw, Romer and Weil (MRW), 1992; Barro and Salai-i-Martin, 1995). However, it has been increasingly recognized (Rodrik, 2003) that the long list of policies identified by the traditional linear growth regressions offers little practical advice to developing countries, in particular under the context of the Millennium Development Goals (MDGs). Halving poverty and hunger in developing countries by 2015 are two of the ambitious targets of MDGs. Achieving these objectives requires uncovering a country's binding constraints and designing appropriate development strategies. As governments and international donors hammer out national development strategies to achieve these goals, they face difficult choices about where and how to invest their limited resources. Therefore there is increasing demand to map out country and regional typologies so that the investment can be better targeted.

The idea of nonlinearity is not new and dates back at least to Hirschman (1958) and Adelman and Morris (1967) who argue that the economic development process reflects complex interactions between social, economic, political and institutional changes and experiences different stages. In recent years, the interest on nonlinearity in the growth empirics has been rekindled in part by the seminal paper of Durlauf and Johnson (1995) who powerfully demonstrate the existence of multiple locally stable steady states growth model in per capita output. Based on a cross-sectional data set covering 1960 to 1985, in their study and several following up studies, per capita output and the initial literacy rate are identified to be important threshold variables (Durlauf and

Johnson, 1995; Hansen, 2000; Papageorgiou, 2002). Papageorgiou (2002) further shows that trade share to GDP is also a threshold variable that can cluster middle-income countries into two distinct regimes. This finding is in favor of theoretical models in which trade and openness is a plausible source of multiple equilibria (Trejos, 1992; Azariadis, 1996).

More recently, questions of nonlinearity have been raised in many other dimensions in the context of growth empirics:[1] security, natural shocks, development stage, and institutions (Wan, 2004; Rigobon and Rodrik 2004; Zhang, 2004). Wan (2004) argue that the growth rates depend upon the development stage in which a country is located. In the taking off stage from an agricultural society to an industrial society, the growth rate can be rather high because of a country can easily borrow the know-how technologies from the leading nations, however they are also more likely to subject to shocks. When a country reaches to the frontier, its growth rate tends to slow down due to difficulties of innovation. Therefore, according to this theory, income gap with the leader (the U.S.) could be a potential threshold variable in defining the economic growth rate. Rigobon and Rodrik (2004) split a cross-national dataset into sub-samples according to colonies and geographical locations to estimate the interrelationships among economic institutions, political institutions, openness, and income levels and found that the two sub-samples do perform differently. Using Uganda as an example, Zhang (2004) shows that public investment does not have a noticeable impact on economic growth until security reaches a certain minimal level.

[1] Papageorgiou (2001) tests the threshold effects of corruption, inflation, political instability and finds no significant splitting for their cross-sectional data set. Papageorgiou and Masanjala (2002) proposed using life expectancy, ethnicity and openness as threshold variables to test for nonlinearities and parameter heterogeneity.

In summary, this review indicates that nonlinearity and threshold effects have been increasingly recognized to be present in many dimensions of development process. A weakness of these studies is that each study usually tackles only one or two threshold effects although overall the literature has revealed a wide range of potential threshold variables. To fill in the knowledge gap, this study reviews the large body of threshold variables in the literature and attempts to take all the potential variables into account within the same analysis.

Another limitation is that most of these studies make use of only cross-sectional data despite its inefficient utilization of available information. Because of increasing data availability, a panel data approach has been more widely used in empirical growth models. Islam (1995) compared the results of growth regression using cross-section, pooling, minimum-distance panel and least square dummy variables approaches. He shows that by allowing for differences in the aggregate production function across economies, the panel results can be significantly different from those obtained from single cross-country regressions. He argues that the steady state income levels differ across countries not only because of differences in investment, and population growth, but also because of differences in the constant term, which reflects not just technology but also resource endowments, climate, institutions, and so on. Lee, Pesaran and Smith (1997) estimate a stochastic Solow growth model for growth and convergence using panel data and also show that the results from the panel estimation significantly differ from the cross-sectional estimations.

Considering the limitation of cross-sectional data, in this paper, we attempt to examine the threshold effects using a panel data set. We supplement the Summers-Heston data set (PWT6.1) with data from other sources. The data set covers 40 years from 1960 to 1999. We employ the newly developed approaches, such as sample splitting, by Hansen (2000) and Caner and Hansen (2004) to identify thresholds variables in the panel setting.[2]

Our results show that there are a wide range of threshold effects in the growth process. In the short, medium and long term, the threshold effects can be different and the results are fragile to the number of observations included and the way of variable defined. Because of the multitude of threshold effects detected, principle component analysis is used to reduce the dimension of splitting possibilities. Using a five-year panel as an example, we show how to find threshold variables with the factors and to classify countries into different typologies.

The paper is arranged as follows. The next section presents an empirical framework and describes the data used in the analysis. Section 3 presents the major empirical results. In Section 4, we first conduct a principle component analysis to reduce the number of factor considered in the threshold analysis and then show how to cluster countries into different groups according to the identified threshold factor. To check the robustness of the results, we also plot the curve of convergence rate against the threshold factors using the nonparametric local linear polynomial method based on a five-year panel. Section 5 ends with conclusions.

II. Empirical Framework

[2] Johnson and Papageorgiou (2005) have used the same Caner and Hansen (2004) method to tackle the problem of endogenous explanatory variables in the threshold model using a cross-sectional dataset from 1960 to 1985.

The model is based on a Solow type growth model and assumes a Cobb-Douglas production function that describes the relationship between changes in per capita output and a set of variables that includes physical and human capitals, population changes, and initial conditions (Mankiw, Romer and Weil (MRW), 1992; Durlauf and Johnson (DJ), 1995; Islam, 1995). In line with most empirical growth literature, we consider the following regression equations:

$$\log(Y/L)_{i,1} - \log(Y/L)_{i,0}$$
$$= a_0 + a_1 \log(Y/L)_{i,0} + a_2 \log(I/Y)_{i,ave} + a_3 \log(SCH)_{i,ave} + a_4 \log(n_{i,ave} + g + \delta) + \varepsilon_{i,1} \qquad (1)$$

$$\log(Y/L)_{i,t} - \log(Y/L)_{i,t-1}$$
$$= a_0 + a_1 \log(Y/L)_{i,t-1} + a_2 \log(I/Y)_{i,ave(t-1,t)} + a_3 \log(SCH)_{i,ave(t-1,t)} + a_4 \log(n_{i,ave(t-1,t)} + g + \delta) + \eta_i + \varepsilon_{i,t} \qquad (2)$$

Equation (1) is for cross-section data analysis. In this model, the left hand variable represents the growth rate of per capita output from period zero to period one. Equation (2) is the heterogeneous panel setting with η_i as a country effect dummy variable.

The key variables are:

(Y/L): real GDP per capita calculated by the chain index method;
(I/Y): real investment share of real GDP;
n: population growth rate;
g: exogenous rate of technological progress;
SCH: percentage of "secondary school attained" in the total population at five - year interval, 1960-1999[3].

On both equations, the output per capita is the value in the initial period and other variables are the average over the whole sample period. We follow MRW (1992), DJ

3 This variable is denoted as LS in the Barro and Lee (2001) data set. TYR and SEC are also used in our analysis. TYR denotes average schooling years in the total population (age 25+) at 5-year interval, 1960-1999; and SEC, school enrollment, secondary (%gross) at five-year intervals, 1970-1985; annually from 1990-2000. All the results are robust to these two other human capital proxies. To set up the panel of 1960-1999, LS is used. Most data for SEC are missing in the 1960s but they are more readily available later on.

(1995), and Islam (1995) assuming that g=0.02 and δ=0.03. ε is a random error term. We can empirically test whether the growth patterns obey a uniformed path or exhibit multiple regimes in the sense that the subgroups of countries identified by initial conditions obey different Solow-type regressions.

In addition to the standard variables listed above, we also examine a large set of relevant economic and social indicators as possible threshold variables based upon the literature review. Specifically, the variables include security (the number of years that a country is at war), the number of natural disasters (drought, insect, epidemics, slide and flood during the testing period), geography and agricultural potential variables (coastline, tropics, arable land), ethnic diversity measures, health indicators (life expectancy, mortality rate under five), macro policies (the percentage of debt in GDP, foreign aid per capita, inflation etc), and trade (openness, term of trade, exchange rate).

Table 1 describes potential threshold variables and their data sources. The countries and country codes are included in Table 2. Appendix I offers a more detailed description of the key variables.

We follow Hansen's (2000) and Caner and Hansen's (2004) threshold regression methods to search for multiple regimes. Hansen (2000) develops a statistical theory to identify and estimate the thresholds of either cross-section or time series observations. The threshold regression model takes the form

$$y_i = \theta_1^{'} x_i + \varepsilon_i \qquad q_i \leq \gamma \tag{3}$$

$$y_i = \theta_2^{'} x_i + \varepsilon_i \qquad q_i > \gamma \tag{4}$$

where q_i is the threshold variable; γ is the critical value of the threshold variable which can be used to split the sample into two groups and ε_i is a regression error. The distribution of the threshold estimate is nonstandard. Since it is based on an asymptotic distribution theory, a confidence interval of the test statistics can be constructed. Monte Carlo simulations can be used to assess the accuracy of the asymptotic approximations. While Hansen's method (2000) is commonly used in cross-sectional analysis, it can also be extended to a fixed effect panel provided that no endogenous problem exists. In specific, the variables in equation (2) are first demeaned to eliminate fixed effects. The threshold level γ is estimated using the least-square method developed in Hansen (2000). After a threshold variable is found, a simple regression can be used to yield consistent estimation for the remaining parameters within each group. This approach is denoted as Hansen (2000) panel approach in this study.

The above method requires that all right-hand-side variables are exogenous. In certain circumstances, the variables on the right hand side may be endogenous and the Hansen (2000) approach will not be applicable anymore. Caner and Hansen (2004) further develop a model in which the explanatory variables are allowed to be endogenous. The model can be written as

$$y_i = \theta_1' z_i + \varepsilon_i \qquad q_i \le \gamma \tag{5}$$

$$y_i = \theta_2' z_i + \varepsilon_i \qquad q_i > \gamma \tag{6}$$

$$z_i = g(x_i, \pi) + \mu_i \tag{7}$$

z can be endogenous but q_i is required to be exogenous. π is the unknown parameter vector and $g(.)$ is a presumed known function that maps exogenous variables and the instrumental variables from X to Z vector. The threshold test is a Sup Wald statistic.

Similar to Hansen (2000), the estimation of this model involves the following steps. First, one needs to take first-differencing of the panel equation (2) to eliminate the fixed effect. Second, the lagged differenced dependent variable is replaced by its predicted value from an appropriate reduced-form equation. A 2SLS estimator can be used to estimate the threshold parameter. Afterwards, a GMM estimator can be applied to estimate the slope parameters. The estimators are consistent, and the threshold estimate has the same nonstandard distribution as in the case of Hansen (2000) but with different scale. The lagged dependent variable up to two periods and other exogenous variables used in equation (2) are treated as instruments in the estimation. This approach is denoted as Caner and Hansen (2004) panel approach.

III. Empirical Results

A. Replication of the Cross-Sectional Analysis

We first run single cross-sectional regressions analogous to those conducted by MRW (1992), DJ (1995), and Hansen (2000) to see whether results based on our new data set differ significantly from theirs. In their papers, *Y/L* is measured as real GDP divided by the working-age population; *I/Y* is measured as the average share of real investment (including government investment) in real GDP over the 1960-1985 period; *n* is the average growth rate of the working age population from 1960-1985; and SCH is the average percentage of working age population (population between the age of 15 and 64) in secondary education over the period 1960-1985. In our new panel data set, *Y/L* is per capita real GDP; *I/Y* is measured as the average share of real investment (including government investment) in real GDP; *n* is the total population growth rate. These three variables are from PWT6.1. SCH is the percentage of "secondary school attained" in the total population available at five-year interval from 1960-1999. This variable is from Barro and Lee (2001). The choice of these variables is limited by the difficulty of getting a panel using exactly the same variables as those used in the cross-section[4]. There are 98 non-oil countries included in Durlauf and Johnson (1995) data set[5]. The number of countries included in our new panel reduced to 80 countries when PWT6.1 and Barro and Lee schooling data set are used (see footnote 3 for the reason of choosing LS). Missing schooling observations in the panel are the main reason for losing sample size[6].

The cross-sectional data formed from our new panel data set using LS as the human capital proxy has 76 observations[7]. Table 3 compares the estimation results based on different sample size and time span with those in DJ's (1995). The upper panel presents estimation results in an unrestricted form, while the lower part contains results when a restriction is imposed: the sum of the coefficients for investment and schooling is equal in magnitude to the coefficient for population growth but with opposite signs.

The second column of Table 3 replicates DJ's results using the same definitions for variables. Under the same variable definitions, the number of observations used in the regression of the third column is reduced to 75, which is equal to the number of cross-sectional observations included in the panel data set. The last three columns report the regression results based on updated data set with different time period. The results across the columns are rather consistent and robust to the number of observations included and

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[4] Per capita real GDP was used in Islam (1995), Lee, Pesaran and Smith (1997) and Liu and Stengos (1999) respectively; the total population growth rate was used in Islam (1995) and Liu and Stengos (1999); secondary school enrollment rate were used in Stengos (1999). More details are explained in the Data Appendix I.

[5] Botswana (BWA) and Mauritius (MUS) are excluded because of missing LIT60 variables. Hence the total number of countries in their analysis is 96.

[6] The sample size is reduced from 98 to 77 because of missing observations for the key variables, especially the schooling variable. The excluded countries are AGO BEN BFA CIV COG DEU DOM ETH HTI LBR MAR MDG MMR NGA SDN SOM SYR TCD TGO TZA and ZAR. Our panel data set includes three additional countries: CHN, HUN, and POL, and hence increase the sample size to 80.

[7] SGP, SLE, HUN and POL are excluded because of missing observations in getting the 1960-1985 cross-sectional data set.

[9] We also try estimations with different education variables. To save space, these results are not listed here.

the update of variables. The estimation is also robust to different human capital proxies when secondary school education indices are used (LS, TYR and SEC).[9]

Table 4 reports the threshold test *p*-values less than 10% for analysis based on the updated dataset of 1960-1999. The test results are robust to the different choices of human capital proxies. For the 40 years from 1960 to 1999, shocks (war, epidemics, and natural disasters) can cluster countries into different groups.

Unlike the previous studies, the initial output variable is not a significant threshold in our slightly smaller cross-sectional data set. There are two potential reasons for this: one is the construction of the new key variables, and the other is the reduction of sample size since only 76 countries are included in our new cross-section. To check the sources, we undertake the following replication exercise.

First, using the same data set and variables, we can replicate the results by DJ (1995) and Hansen (2000). In the next step, we use the variables with the same definitions as in previous studies but on the basis of a smaller data set which is determined by the consideration of creating a panel data set. Hence, we further test the DJ (1995) data with 74 countries.[10] Finally, we do the test using the updated variables and the smaller data set. The results with threshold test *p*-values less than 10% for the DJ (1995) data set and the new cross-sectional data set from 1960 to 1985 are reported in Table 5. For comparison purpose, Table 5 also includes the initial value of per capita GDP (gdp60) and education valuable (lit60) although they are not significant as threshold variables with a *p*-value of 0.63 and 0.67, respectively.

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[10] The DJ (1995) or Hansen (2000) dataset with 92 or 87 countries are also tested respectively. The test p-value for initial output is 0.278 and 0.145 respectively. HUN and POL are not included in DJ (1995) or Hansen (2000) data set, thus the sample size is 74.

One striking finding from Table 5 is that the tests are sensitive to the countries included and variables constructed. Once the sample size is reduced, the initial GDP per capita and the education variable become less significant as a threshold variable. Table 5 column 1 is the result using the same definition on *Y/L*, *I/Y* and SCH, but different number of countries of DJ (1995) 1960-1999 data. Comparing the two columns with different definition of variables, the threshold variables differ markedly. In the next section, we use the panel data to see whether the panel approach yields any different results from the cross-sectional analysis.

B. Panel Threshold Approach with Fixed Effects

The panel analysis can be generally categorized into four groups (Pesaran and Smith, 1995). The first estimates separate regressions for each group and average the coefficients over groups. The second combines the data by imposing common slopes, allowing for fixed or random intercepts, and estimates pooled regressions. The third involves averaging the data over groups and estimating aggregate time-series regressions. The fourth averages the data over time and estimates cross-section regressions on group means. If the regressors are exogenous, all four procedures provide consistent and unbiased estimates of the coefficient means. However when some explanatory variables are endogenous, pooling, aggregating, or cross-sectioning may give inconsistent and misleading estimates of coefficients. Under this case, the model developed by Caner and Hansen (2004) is more appropriate.

The switch from a single cross section to a panel framework is made possible by dividing the total period into several shorter time spans. Islam (1995) argues that short-term disturbances may be too noisy in annual time spans. Therefore he considers the smallest time interval of five years. Forbes (2000) uses both five-year and ten-year panels in her analysis on the relationship between income inequality and economic growth, showing that the results are not robust to the selection of panel length.

We empirically estimate a fixed effect model at ten-year, five-year and one year intervals to examine whether the results are robust to the number of observation included. Table 6 provides the results using alternative estimation methods. For fixed effect estimations, R-square decreases as the sample frequency increases. The sum of squares errors increases as we go from the ten-year panel to the annual panel. The coefficients for initial output and investment share are significant. The magnitude of the coefficient lowers as the sampling frequency increases. When using the secondary school attained rate (logLS) as a regressor, the coefficients for the logarithm of initial output ($\log Y/L_{t-1}$), the logarithm of investment share (logI/Y) and LogLS are significant for the 10-year and annual panel. Overall, the basic results in terms of sign and significance levels are rather robust to the various specifications.

The Hansen (2000) method is used for ten-year, five-year and one-year panels. The Caner and Hansen (2004) method is also used for one-year panels because of the larger likelihood of the presence of endogeneity issues. The results of the two different methods are summarized in Table 7.[11] It presents the *p*-values of the nonlinearity tests which are significant at less than 10% level. Table 4 and Table 7 show that threshold effects are present in the short, medium and long run. As the data period increases from 40 years to ten years, five years and one year, so are more threshold effects detected. Moreover, in the short, medium and long run, the threshold effects can be very different.

[11] We also use the Caner and Hansen (2004) method for the five-year and ten-year panels. The results are comparable. For save space, they are not reported here.

In the cross-sectional analysis from 1960 to 1999 as shown in Table 4, natural disaster and war are among the most important splitters. In the medium run of ten years, geographic locations, trade share and inflation become important. For the annual panel, much more variables become splitters. The presence of large number of potential threshold variables poses a question on the selection of threshold variables and challenges the way of dealing with threshold variables in previous studies which usually take one or two threshold variables into account. Omitting some critical threshold effects may lead to biased estimations in the growth regression.

C. Principle Component Analysis and Threshold Test with the Composite Factors

To reduce the dimension of such large number of threshold variables, we employ the principal component analysis (PCA). PCA is an inductive statistical method that helps to discern a minimum set of underlying principle components from a large data set of variables, so that these components are essentially independent subgroups from the fuller data set. In essence, the principal components are linear functions of the initial variables, and thus, although they are far fewer, they can explain much of the original variables. To decide on the relevant components to retain, a threshold criterion, known as the *eigenvalue*, can be used. In this study, it is set to one. PCA is an appropriate tool in the analysis to capture the variability of the potential threshold variables.

Principal component analysis (PCA) requires that there is no missing observation in the analysis. Hence 21 potential threshold variables with fewer missing observations are included in the analysis. They are income gap, agriculture/GDP, industry/GDP, rural population %, literacy rate, arable land per capita, arable land %, percentage of a country's total land area within 100km of the ocean coastline (Ind100km), percentage of land within 100km coast or river (Ind100cr), openness (exports plus imports divided by GDP) measured in current price (openc), openness measured in constant price (openk)[12], trade/GDP, inflation, GDP deflator (inf), inflation of consumer prices (infc), number of epidemics, drought, insect, flood, slide, war and ethnic diversity[13]. We conduct PCA for cross-sectional data of 1960-85 and 1960-99, ten-year panel, five-year panel, and annual panel, respectively. The composite factors generated from the PCA are similar at different period lengths.[14] Among them, development stage is the most important factor to explain the variations of the data, followed by natural disaster & war and geography & natural resources. Openness and inflation are the remaining factors. Table 8 summarizes the major factors and their significance in threshold test.

D. First Round Threshold Test Results Using Factors

A. Cross Section

For the cross-sectional estimation based on part of the DJ (1995) data set and their variables, none of the factors turns out to be significant although there are a few individual threshold variables as shown in Table 4. Neither do the tests on other two-cross-sectional data yield any significant threshold factors.

The development stage factor is shown to be an important splitter for the annual panel data set. For the five-year panel, the factor of natural disaster and war, which

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[12] Papageorgiou (2002) defines trade share as the ratio of imports plus exports to real GDP in 1985, which is OPENK from PWT-5.6.

[13] Institutional variables are dropped. These data are collected for 1998 and onwards. Instead of being the initial conditions, they are more likely to be the outcome of development. The use of split variables which are known at the beginning of the sample under study is necessary to avoid the selection bias problem.

[14] The detailed PCA results are available upon request.

primarily captures the shocks, is the only significant threshold splitter. The degree of openness becomes a major threshold in the ten-year panel.

Once again, the tests based on different lengths of panel yield different results when using the factor generated from the PCA. Interestingly, individual variables which are used to create the natural disaster and war factor are insignificant as a threshold but they are jointly significant. One isolated shock may be not big enough to affect the course of growth, but a combination of back lucks (shocks) can exert big threshold effects.

IV. Country Typology and Nonparametric Analysis

Typologies Based on Five-Year Panel

In this section, we use the results from the threshold analysis based on the five-year panel to show how to classify countries into different typologies. The results using the Hansen (2000) method are listed in Table 9[15]. Factor 4, natural disaster and war, can split the sample of 513 into two groups. Threshold estimate is -0.889, with a 95% confidence interval of [-0.987, 0.117]. The likelihood ratio is plotted in Figure 1. Group one with factor 4 less than or equal to the threshold level has 25 observations; group two with factor 4 greater than the threshold level has 488 observations. Within group two, the second round test results show that no further splitting with p value less than 10% exists from the 4 composite factors. Thus, two regimes are obtained from the 5-year panel. Regime I is a group of poor countries in years of few natural disasters and wars. The 25

[15] For 5-year panel, the endogenous problem is less serious than the annual panel. The Caner and Hansen (2004) method gives similar results.

[18] POL, AUS, AUT, BEL, CAN, CHE, DNK, FIN, FRA, GBR are from DJ(1995); HKG, KOR, PNG and SLE 1960 is from DJ(1995), and the most recent ones are from CIA website; EGY 1997 to 1999 are set as EGY 1996; BWA, CHN, CRI, HUN, MUS MWI NIC and SGP are from DJ(19995) and WDI (2004); others are from WDI2004. Missing data between non-missing data are interpolated using cubit spine method.

observations in regime I are Botswana (4), Central African Republic (2,4, and 6), Cameroon (2), Egypt (5,6 and 8), Mozambique (2,3), Malawi (3), Nicaragua (3), Papua New Guinea (2), Portugal (3), Rwanda (3,5 and 6), Sierra Leone (2,3,4,5), Tunisia (2), Uganda (3,4) and Zimbabwe (6). The number *i* in the parentheses is a country's half-decade index, ith 5-year from 1960-99. Table 10 presents the estimation results within each regime. The coefficients of initial GDP in the two regimes are significantly different. The coefficient of initial output in regime one (poor countries with few natural disaster and war group) is positive, hence convergence does not hold. In regime two, the coefficient is negative and convergence hypothesis holds (Table 10).

Local Linear Polynomial (LLP) Estimation for Five-Year Panel

The above analysis has shown that the shock factor is a major important splitter for the 5-year panel. To check the robustness of the results, in this section, local linear nonparametric estimation method is employed to illustrate how the convergence coefficients vary as the threshold variables change. The method enables us to check the robustness of the splitting results that we found in the previous section. And it is especially interesting for the case where more than one threshold level exists for one specific threshold variable.

LLP is a nonparametric local weighted least squares estimation technique (Fan and Yao, 2003). It is a nonparametric curve estimation, which does not require knowledge of the functional form beyond certain smoothness conditions of the underlying function. It gives different weighting to the observations in an interval containing some threshold level. The sum of local weighted least squares is minimized, and the estimates of the regressors are obtained. The coefficient of the explainable variable is a function of the potential threshold variable; hence vary depending upon the level of the threshold variable. Specifically, a nonparametric LLP can be applied to a fixed effect panel model by removing the mean values from the original variables.

Figure 2 plots the convergence coefficients (coefficients of initial output) versus the two possible threshold variables, natural disaster and development stage. It indicates that development stage factor may not have nonlinear effect on the coefficient while the natural disaster and war factor exert a nonlinear effect on the coefficient. This result is consistent with the threshold test results for the five-year panel in the previous section.

V. Conclusion

In this paper, we apply the recently developed threshold estimation approaches to a panel data set to identify threshold effects in the growth empirics. Both analyses based on panel and cross-sectional data sets reveal a large number of threshold effects, highlighting that development is not a linear process. However, the threshold estimations are neither robust to the selection of panel lengths nor to alternate selections of variables.

To reduce the dimensions of a large number of threshold variables, we apply the principle component analysis to create a smaller set of composite factors and then use them to test the threshold effects. A smaller number of thresholds are found when factors are used. Once again, the results are fragile to the number of observation included.

Using five-year panel as an example, we show how to classify countries into different growth regimes based on the results of threshold estimations. The estimation results differ markedly across the regimes and the convergence results do not hold in the sub group.

We also employ a local linear nonparametric estimation method to check the robustness of our threshold estimation results. The plot shows that for the five-year panel, there is indeed a nonlinear relationship between the shock factor and the convergence coefficient. The analysis poses more questions rather than answers: why are threshold estimations so sensitive to the number of observation included and variable defined? If there are multiple thresholds, how to select them sequentially?

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Table 1 Description of Split Variables and Data Source

Category	*Threshold Variable*	*Description*	*Source*
aid	aidpc	Aid per capita, the average of 1960-1962	WDI2004
debt	debtgdp	External debt, total (DOD, current US$) devided by GDP (current US $)	WDI2004
debt	IBRD	IBRD loans and IDA credits (PPG DOD, current US$)	WDI2004
debt	ldebtgdp	long-term debt (DOD, current US $) devided by GDP (current US $)	WDI2004
debt	edtxgs	External debt (% of exports of goods and services)	WDI2004
debt	edtgni	External debt (% of GNI)	WDI2004
debt	tdsgni	Total debt service (% of GNI)	WDI2004
edu	LRnew	literacy rate	WDI2004, Durlauf and Johnson (1995) and CIA country profile[18]
edu	edugdp	public spendign on education, total (% of GDP)	WDI2004
eth	elf	Index of ethnolinguistic fractionalisation - 0.00 to 1 in 1960.	Alesina et al. (2003)
finance	fingdp	Domestic financing, total (% of GDP)	WDI2004
finance	fdigdp	Gross foreign direct investment (% of GDP)	WDI2004
geo	arbl	land use, arable land (% of land area)	WDI2004
geo	arblpc	land use, arable land (hectares per person)	WDI2004
geo	lnd100km	proportion of a country's total land area within 100 km of the ocean coastline, excluding coastline in the artic and sub-artic region above the winter extent of ice.	Gallup, Sachs and Mellinger (1999)

Table 1 Continued

Category	*Threshold Variable*	*Description*	*Source*
geo	lnd100cr	% land w/in 100km coast or river	Gallup, Sachs and Mellinger (1999)
geo	tropicar	proportion of a country's land area within the geographical tropics	Gallup, Sachs and Mellinger (1999)
health	life	Life expectation	WDI2004
health	mort5	Mortality rate under 5	WDI2004
infastructure	road	roads, paved (% of total roads)	WDI2004
infastructure	tel	telephone mainlines (per 1,000 people)	WDI2004
inflation	inf	Inflation, GDP deflator (annual %)	WDI2004
inflation	infc	Inflation, consumer prices (annual %)	WDI2004
macro	Income gap	CGDP relative to the US, unit US=100	PWT6.1
macro	rgdpch0	initial output	PWT6.1
macro	agr	agricultural, value added (% of GDP)	WDI2004
macro	indgdp	Industry, value added (% of GDP)	WDI2004
macro	milgdp	Military expenditure (% of GDP)	WDI2004
macro	rpop	Rural population % of total	WDI2004

Table 1 Continued

Category	*Threshold Variable*	*Description*	*Source*
macro	savgdp	Gross national savings, including NCTR (% of GDP)	WDI2004
stability	EMD	Number of natural disasters: epidemics, drought, famine, flood, slide and insects.	EM-DAT
stability	epid	Number of epidemics, 1960-1999	EM-DAT
stability	WAR	number of years of war during testing period	Pottebaum and Kanbur
stab policy	voice	Voice and accountability index in 1998	Kaufmann, Kraay and Mastruzzi (2003)
stab policy	stab	Political stability and absence of violence index in 1998	Kaufmann, Kraay and Mastruzzi (2003)
stab policy	goveff	Government effectiveness index in 1998	Kaufmann, Kraay and Mastruzzi (2003)
stab policy	regq	Regulatory policy index in 1998	Kaufmann, Kraay and Mastruzzi (2003)
stab policy	rulelaw	Rule of law index in 1998	Kaufmann, Kraay and Mastruzzi (2003)
stab policy	ccont2	Control of corruption index in 1998	Kaufmann, Kraay and Mastruzzi (2003)
stab policy	corruptm	Mauro measure of corruption (1980-83)	Easterly and Levine (1997)
trade	openc	Exports plus Imports divided by CGDP, the total trade as a percentage of GDP	PWT6.1
trade	openk	openness in constant prices, unit: %	PWT6.1
trade	tot	Net barter terms of trade (1995=100)	WDI2004
trade	trdgdp	trade (% of GDP)	WDI2004
trade	xrat	Exchange rate	PWT6.1

Table 2 Countries in the Unbalanced Panel and Country Codes

number	code	country	number	code	country	number	code	country
1	ARG	Argentina	28	GTM	Guatemala	55	NZL	New Zealand
2	AUS	Australia	29	HKG	Hong Kong	56	PAK	Pakistan
3	AUT	Austria	30	HND	Honduras	57	PAN	Panama
4	BDI	Burundi	31	HUN	Hungary	58	PER	Peru
5	BEL	Belgium	32	IDN	Indonesia	59	PHL	Philippines
6	BGD	Bangladesh	33	IND	India	60	PNG	Papua New Guinea
7	BOL	Bolivia	34	IRL	Ireland	61	POL	Poland
8	BRA	Brazil	35	ISR	Israel	62	PRT	Portugal
9	BWA	Botswana	36	ITA	Italy	63	PRY	Paraguay
10	CAF	Central African Republic	37	JAM	Jamaica	64	RWA	Rwanda
11	CAN	Canada	38	JOR	Jordan	65	SEN	Senegal
12	CHE	Switzerland	39	JPN	Japan	66	SGP	Singapore
13	CHL	Chile	40	KEN	Kenya	67	SLE	Sierra Leone
14	CHN	China	41	KOR	Korea, South	68	SLV	El Salvador
15	CMR	Cameroon	42	LKA	Sri Lanka	69	SWE	Sweden
16	COL	Colombia	43	MEX	Mexico	70	THA	Thailand
17	CRI	Costa Rica	44	MLI	Mali	71	TTO	Trinidad and Tobago
18	DNK	Denmark	45	MOZ	Mozambique	72	TUN	Tunisia
19	DZA	Algeria	46	MRT	Mauritania	73	TUR	Turkey
20	ECU	Ecuador	47	MUS	Mauritius	74	UGA	Uganda
21	EGY	Egypt	48	MWI	Malawi	75	URY	Uruguay
22	ESP	Spain	49	MYS	Malaysia	76	USA	United States
23	FIN	Finland	50	NER	Niger	77	VEN	Venezuela
24	FRA	France	51	NIC	Nicaragua	78	ZAF	South Africa
25	GBR	United Kingdom	52	NLD	Netherlands	79	ZMB	Zambia
26	GHA	Ghana	53	NOR	Norway	80	ZWE	Zimbabwe
27	GRC	Greece	54	NPL	Nepal			

Table 3 Comparing Cross-Section Regression Estimations

Specification	*DJ (1995)* *1960-85* *obs[b]=98*	*DJ (1995)* *1960-85* *obs=75*	*Updated Dataset* *1960-85* *obs=87*	*Updated Data* *1960-99* *obs=91*	*Updated Data* *1960-99a* *obs=76[c]*
Unrestricted					
Constant	3.040**	2.773**	3.108**	2.559**	2.701**
$Log(Y/L)_{1960}$	-0.289**	-0.302**	-0.330**	-0.518**	-0.498***
Log(I/Y)	0.524**	0.487**	0.360**	0.341**	0.525***
Log(n)	-0.505	-0.581	-0.396	-1.256**	-1.350***
Log(SCH)[a]	0.233**	0.193**	0.301**	0.562**	0.317***
R^2		0.456	0.564	0.639	0.61
Adj R^2	0.460	0.424	0.543	0.621	0.59
Restricted					
Log(I/Y)	0.431**	0.476**	0.353**	0.355**	0.549***
Log(LS)	0.241**	0.195**	0.294**	0.577**	0.335***
R^2		0.455	0.561	0.636	0.60
Adj R^2	0.420	0.432	0.545	0.622	0.59

Note: ** reject at 5% significant level; *** reject at 1% significant level.

a. SCH is the percentage of "secondary school attained" in the total population in 1960 and is drawn from. from Barro and Lee (2001). The cross-section 1960-99 has fewer observations when LS is used.

b. DJ's (1995) data set includes 98 non-oil countries. The cross-sectional data set 1960-85 obtained from our updated dataset has 87 observations and the cross-section 1960-99 obtained from our updated data set has 91 observations when WSEC is used. The cross-section 1960-99 obtained from our updated data set has 76 observations when LS is used. To compare results, DJ (1995) with 75 countries are estimated (CHN is included in our updated dataset but not in DJ's (1995) data set).

c. The estimation is robust to different human capital proxies when secondary school education indices are used (LS, TYR and SEC). Primary schooling measures (LP and SEP) are not statistically significant in the model and result in lower R2.

Table 4 First Round Threshold Test for the Cross-sectional 1960-99 Date Set[a].

Variables[b]	*num obs*	*P value*
epidemic	76	0.040
war	76	0.140a
flood	76	0.097

Note: "a"--10%-15% significant level;

Table 5 First Round Threshold Test for the Cross-sectional 1960-85 Data

Variables	60-85 (DJ)	60-85 (Update Var)	60-99 (Update Var)
GDP in 1960	(0.631)	(0.59)	
Exchange rate			
Inflation			
Arable land %			
Epidemic Years			
Drought Years			
Flood Years			
Land new coast or river %			
Tropics			

Note: The colored cell means a significance level of 10 percent.

Table 6 Panel Estimations (Pooled and Fix Effect Estimation) at Different Period Lengths[a]

Dependent Variable: Growth Rate								
	10-Year Panel		5-Year Panel		Annual Panel		Annual Panel	
POOL								
Intercept	1.012	***	0.491	***	0.105	***		
$Log(Y/L)_0$	-0.115	***	-0.053	***	-0.011	***		
Log(I/Y)	0.204	***	0.098	***	0.023	***		
Log(n)	-0.220	**	-0.098	***	-0.021	***		
Log(LS)[b]	0.034	**	0.016	***	0.003	***		
number of obs	305		606		2975			
R-square	0.304		0.186		0.070			
Adj. R-Sqr	0.294		0.181		0.069			
FIXED EFFECT								
De-mean method							Differencing Method	
$Log(Y/L)_0$	-0.283	***	-0.152	***	-0.031	***	-0.694	***
Log(I/Y)	0.242	***	0.125	***	0.025	***	0.002	
Log(n)	0.015		-0.071		-0.019	**	-0.022	**
Log(LS)	0.027	*	0.008		0.000		0.014	**
number of obs	305		606		2975		2894	
R-square	0.687		0.480		0.158		0.352	
Adj. R-Sqr	0.568		0.397		0.134		0.352	
DW					1.85		2.129	
1st autocorrleation					0.08		-0.065	
Sum of Squares Error	4.190		4.991		6.202		7.355	
SSE/n	0.014		0.008		0.002		0.003	

Note: * reject at 10% level; ** reject at 5% significant level; *** reject at 1% level.
a.Balanced panel shows similar pattern; b. Using TYR as schooling variable shows similar results. To save space, these results are omitted.

Table 7 Summary of the Significant Threshold Test P Values for the Panels

Threshold Variable	Hansen (2000) Method			Caner and Hansen (2004) Method
	10-Year Panel	5-Year Panel	Annual Panel	Annual Panel
Debt/gdp		■		
IBRD		■	■	■
Long debt/gdp			■	
debt/exports			■	
Debt/GNI				■
Debt service/GNI	■			
Public Education Spending/GDP				■
Literacy rate (new)		■	■	■
Ethnolinguistic Fractionalization				■
Domestic Financing/GDP				■
Foreign direct Investment/GDP			■	
Arable land %	■		■	■
Arable land per capita	■			
Land within 100 km coast or river			■	
Land within Tropics		■	■	■
Life expectancy			■	
Road, paved %			■	
Telephone per 1000 people			■	■
Inflation	■	■		
Inflation, Consumer price				■
Income gap			■	■
Initial output			■	
Rural population%				■
Savings/GDP			■	■
Epidemic years				
Natural disaster			■	■
War	■			
Exchange rate				■
Openness		■	■	
Openness (constant price)	■	■	■	■
Trade/GDP		■	■	

Table 8 Summary of the Principal Component Analysis and First Round Threshold Test P Values for the Composite Factors at Different Period Lengths

	Cross 60-85	Cross 60-85	Cross 60-99	10-year Panel	5-year Panel	5-year Panel	Annual Panel	Annual Panel
Dataset	DJ (1995)	New	New	New	New	New	New	New
Hansen (2000) Caner and Hansen (2004)	2000	2000	2000	2000	2000	2004	2000	2004
Development Stage								
Natural Disaster and War								
Geography & Natural Resource								
Openness								

Table 9 Threshold Test P Values Using Composite Factors for the 5-Year Panel, Hansen (2000) Method

Factor	Factor Number	First Round Obs=513	Second Round Obs=25	Second Round Obs=488
			Regime I	Regime II
Development Stage	1	N	--	N
Natural Disaster and War	4	0.053	--	N
Geography & Natural Resource	3	N	--	N
Openness	2	N	--	N

Note: "N"—not significant at 10% level; "-"—not tested due to too few observations.

Table 10 Comparison of Pooled and Subgroup Estimation Results for the 5-Year Panel Using Hansen (2000) Method.

Dependent Variable: Growth Rate

	Global		Regime I		Regime II	
$dmlog(Y/L)_0$	-0.167	***	0.162	***	-0.180	***
dmlog(I/Y)	0.124	***	0.156	**	0.126	***
dmlog(n)	-0.070		0.088		-0.088	
dmLog(LS)	0.010		-0.061		0.014	
number of observations	513		25		488	
SSE	4.202		0.263		3.813	
R-square	0.244		0.243		0.264	

Note: Dependent Variable: Growth Rate; * reject at 10% level; ** reject at 5% significant level; *** reject at 1% level.

Figure 1 First Round Threshold Variable Confidence Interval Factor 4 (Natural Disaster & War) for 5-Year Panel (Hansen 2000 method)

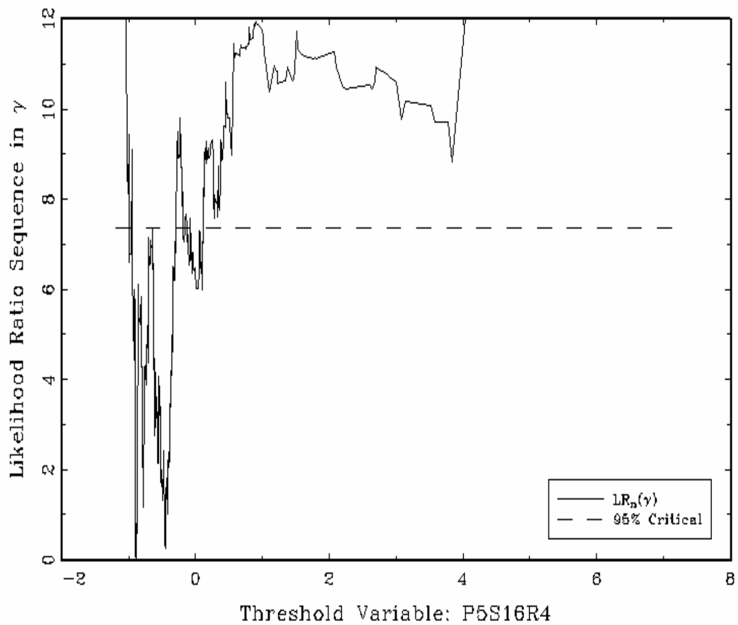
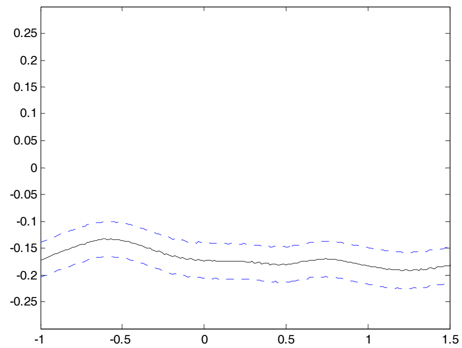
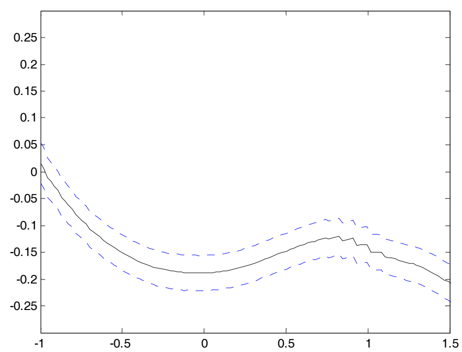


Figure 2 Convergence (lngdp0) Coefficients versus Threshold Variables for 5-Year Panel[19]



(7a) Development Stage (factor 1); c=3.



(7b) Natural Disaster (factor 4); c=3

[19] The smoothing were chosen as $c*std(z)*n^{-1/5}$, c=3. c=1,2 and 3 have similar curves. Cross-validation needs to be done.

Appendix I Key Variables: Data and Comparison

Y/L=RGDPCH. RGDPCH is the real GDP per capita (Chain) from Summers-Heston PWT6.1. Mankiw, Romer and Weil (1992) measure Y/L as real GDP in 1985 or 1960 divided by the working-age population in that year. Papageorgiou (2002) following Durlauf and Johnson (1995) and Hansen (2000), uses real GDP, per working-age population. Liu and Stengos (1999) use real GDP per capita from King and Levine (1993). Islam (1995) and Lee, Pesaran and Smith (1997) use real per capita GDP for their panel studies.

N= Population growth rate from Summers-Heston PWT6.1. Mankiw, Romer and Weil (1992) measure n as the average rate of growth of the working-age population, where working age is defined as 15 to 64**.** Durlauf and Johnson (1995), Hansen (2000) and Papageorgiou (2002) use the same measure. Because of the difficulty to get a panel data on working age population, Islam (1995) takes n as the rate of growth of the total population available in the Summers-Heston data set. Liu and Stengos (1999) use population growth.

I/Y= Investment share of real GDP from Summers-Heston PWT6.1. Mankiw Romer and Weil (1992) measure investment share as the average share of real investment (including government investment) in real GDP. Durlauf and Johnson (1995), Hansen (2000) and Papageorgiou (2001) define I/Y as the fraction of real GDP devoted to investment (including government investment). Liu and Stengos (1999) use investment share of GDP from King and Levine (1993), which cites a source from World Bank National Account.

SCH =LS, TYR and SEC respectively. In Mankiw, Romer and Weil's (1992) paper, WSEC, the percentage of the working-age population that is in secondary school in 1960 is used; it is the fraction of the eligible population (age 12-17) enrolled in secondary school multiplied by the fraction of the working-age population that is of school age (age 15-19). Durlauf and Johnson (1995), Hansen (2000) and Papageorgiou (2002) uses secondary-school enrollment of the working-age population. Liu and Stengos's (1999) human capital is measured as the enrollment rate in secondary schools. In our paper, LS, TYR and SEC are used because it is difficult to get panel data on the working population. LS and TYR are from Barro and Lee (2001). LS is the percentage of "secondary school attained" in the total population available at a 5 -year interval from 1960 to 1999; TYR is the average schooling years in the total population (age 25+) available at a 5-year interval, 1960-1999; and SEC is the school enrollment, secondary (%gross) from WDI (2004) available at 5-year intervals for the period 1970-1985, while for the period 1990-2000, it is available annually. SEC has larger sample size but the data in the 1960s are missing. Hence, the total sample size is limited by a lack of missing observations from LS and TYR.

In summary, real GDP and population growth rate in this paper follow Islam (1995), Lee, Pesaran and Smith (1997), and Liu and Stengos (1999). Secondary school enrollment rate is used as a proxy for human capital as in Liu and Stengos (1999). The choice of variables is influenced by the difficulty of getting panel data, especially the working age population, and the schooling variables in the Barro and Lee's (2001) data set.