Trade, FDI and Technology Diffusion in Developing Countries: The Role of Human Capital and Institutions

Nigel Driffield and Michael Henry
Economics and Strategy Group
Aston Business School
Aston University
Birmingham B4 7ET
UK

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Abstract

This paper examines the impact of inflows of foreign knowledge on economic development, in the context of different institutional development and differing levels of human capital. We employ threshold regression analysis based on Hansen (2000) to determine whether there is cross-country heterogeneity in the flows of foreign knowledge from advanced industrialised countries to a group of 57 developing countries based on the latter group's absorptive capacity and institutional quality over the period 1970-1998. In contrast to previous researchers employing this framework we examine two channels of international knowledge spillovers, namely trade and FDI. Initial results for the trade channel show that the differing productivity effects accruing to groups of countries as a result of differing levels of absorptive capacity and institutional quality are small at best and non-existent at worst.

1. Introduction

In the last decade, studies by Klenow and Rodriguez-Clare (1997), Prescott (1998), Hall and Jones (1999) and Easterly and Levine (2001) among others have demonstrated that most of the cross-country differences in the level and growth rate of per capita income are explained by differences in the level of TFP rather than by capital (physical and human) accumulation. Further, technology is seen as a key determinant of productivity. However, given the fact that a small number of rich countries account for most of world's creation of new technology, there is now widespread recognition that the international transfer of technology is an important source of domestic productivity growth and ultimately higher living standards (Eaton and Kortum, 1999; Saggi, 2002; Keller, 2004).[1] For example, Keller (2004) argues foreign sources of technology account for 90% or more of domestic productivity growth. In light of this fact, he further argues that international diffusion of technology is important because it determines the pace at which the world's technology frontier may expand in the future. Similarly, Eaton and Kortum (1999) estimate that foreign R&D contributed approximately 85% of productivity growth in France, Germany and the UK in 1988. In the context of developing countries, Coe Helpman and Hoffmaister (henceforth CHH, 1997), estimate that a 1 per cent increase in the R&D capital stock in the industrialised countries raises output in developing countries by 0.06 per cent.

Thus by engaging in economic activity with foreign partners, a country can access the R&D and related knowledge stocks of other countries and thereby benefit from those stocks of knowledge at a cost lower than that which would be incurred by developing the knowledge internally. Naturally, this has resulted in a rise in both academic and policy interest in the mechanism by which such international transfers occur, and on the size of the growth effects which may arise from them.

[1] According to Keller (2004), the G-7 countries (U.S.A., Japan, U.K., France, Germany, Italy and Canada) accounted for approximately 84% of the world's R&D expenditure in 1995.

The open economy endogenous technological change models of Grossman and Helpman (1991) and Rivera-Batiz and Romer (1991) provide the theoretical base upon which the empirical international technology diffusion literature is built. Drawing on the work of Romer (1990) and Aghion and Howitt (1992), they embed endogenous technological change theories into general equilibrium models to analyse the relationship between international trade, technological change and growth. For instance, Rivera-Batiz and Romer (1991) outline two channels for the transfer of technological knowledge: (i) the transmission of ideas which can be traded independently of goods, and (ii) trade in intermediate and capital goods that embody technology.[2] In terms of the first channel, this can be achieved directly through licensing, or indirectly through foreign direct investment (FDI). International knowledge flows raise growth in both models. In this paper we consider both channels. With respect to the first channel however, we are concerned with the indirect transmission of ideas through FDI.

In terms of the second channel of international knowledge spillovers identified above (i.e. trade in intermediate and capital goods), a number of studies (e.g. Coe and Helpman, 1995; Coe, Helpman and Hoffmaister, 1997; Xu and Wang, 1999; Keller, 2000; Mayer, 2001) have attempted to assess the importance of imports in transmitting foreign technology to domestic industries and in the process spurring productivity growth. Most of these studies find imports (particularly of capital goods) to be a significant channel of R&D spillovers and thus an important factor in explaining differences in TFP (levels and growth).

Although less robust in its findings than those examining trade channel, the dominant finding in empirical cross-country growth studies examining FDI as a medium for cross-border knowledge diffusion is that like trade, it is also a significant source for the international transfer of knowledge (see Blomström et al., 1992; Borensztein et al., 1999; van Pottelsberghe and Lichtenberg, 2001; Ram, 2002; Wang et al., 2004).

[2] In addition to the two channels identified by Rivera-Batiz and Romer (1991), Grossman and Helpman (1991) also identified the international movements of capital as another channel through which economic behaviour in one country may influence that in another.

However, there is also a recognition that countries are likely differ in the efficiency with which they use technologies (Fagerberg, 1994; Henry et al., 2003). As Blomström et al. (1992) indicated, "one might suppose that the rate of economic growth of a backward country would depend on the extent of technology transfers from the leading countries and the efficiency with which they are absorbed and diffused" (p.10). This suggests that having access to leading edge technologies through technology transfer may not of itself lead to productivity improvements if these technologies are not absorbed efficiently. Therefore the absorptive capacity of a country is a critical factor in its ability to "catch up" with countries at the technological frontier.

The notion of absorptive capacity refers to a country's effort and ability to adopt new technologies even if knowledge is global. Nelson and Phelps (1966), Abramovitz (1986) and Cohen and Levinthal (1989) all model technical adoption as depending on the level of human capital. On the other hand, in Verspagen (1991) and Fagerberg (1994) domestic innovation is shown to improve a country's capacity to absorb foreign technology. Empirical evidence in favour of absorptive capacity (measured by both R&D and human capital) for developed countries have been found by Griffith et al. (2004) and Kneller (2005). For developing countries, where absorptive capacity is usually proxied by the level of human capital since these countries perform little R&D, the evidence is more mixed.

In this paper we also consider the importance of absorptive capacity for facilitating the adoption of foreign technology. We do so for a sample of 57 developing countries for the period 1970-1998. Our main contributions to this literature lies in the fact that in addition to using human capital as a proxy for absorptive capacity, we also take into account a country's institutional quality for either facilitating or hindering the diffusion of foreign sources of technology. The importance of this latter variable for fostering economic growth is now well established in the cross-national trade and growth literature (Hall and Jones, 1999; Acemoglu et al., 2001; Knack and Keffer, 1995, 1997; Anderson and Marcouiller , 1999; Rodrik et al. 2002).

Additionally, previous papers that have examined the likelihood of cross-national heterogeneity in the effects of foreign knowledge flows through the channels of trade and FDI have generally done so either through an exogenous sample split (Blomström et al., 1992; Ram, 2002; Wang et al., 2004) or through interaction effects (e.g. Borensztein et al., 1998). The shortcomings of these methodological approaches have been highlighted in Girma et al. (2003). In contrast, we employ the endogenous threshold framework of Hansen (2000) to determine whether countries above and below some critical or threshold level (s) of human capital and institutional quality experience differing productivity effects from spillovers through trade and FDI. By considering these two channels of foreign knowledge flows (i.e. trade and FDI) based on threshold regression analysis, our paper builds on Falvey et al.(2005) who only considers the trade channel. The rest of this paper is organised as follows. Section 2 discusses the estimation and statistical issues associated with the methodology employed in the paper. It also specifies our estimating equations. Section 3 describes the data used for the empirical analysis and also outlines the sources of this data. Section 4 presents the results of the empirical exercise and discusses the findings. Section 5 concludes the paper.

2. Methodology and Estimating Equations

Since our aim is to determine whether the extent of knowledge spillovers from the donor countries in the North are influenced by the level of absorptive capacity and institutional quality prevailing in the countries of the South, we first specify a base equation for exploring these relationships. In this regard we specify the following:

$$\Delta \ln y_{it} = \alpha_0 + \alpha_1 \ln y_{it}^0 + \alpha_2 \ln GAP_{it} + \alpha_3 \ln Inv_{it} + \alpha_4 \Delta \ln POP_{it} + \alpha_5 \ln H_{it} + \alpha_6 \Delta \ln RD_{it}^m + \alpha_7 OPEN_{it} + \alpha_8 FDI + \alpha_9 INSTIT_{it} + \mu_{it}$$

(1)

where y is per capita GDP for each country for the period 1970-1999. y^0 is the initial the initial level of per capita GDP at the start of each five year period from 1970-1999 and represents a country's initial conditions; GAP is a variable that proxies for the technological distance of each country from the country at the technological frontier; Inv is the level of investment for each country; *POP* is population; H is the proxy for human capital and is the average level of schooling for the population 25 years and over.

OPEN is the Sachs & Warner (1995) indicator of openness to international trade (OPEN). This has been updated by Wacziarg & Welch (2002) to cover the data period up until 1998 and uses additional data sources to correct some of the misclassifications of countries in the original study. It is this updated index that we use in this study and is intended to capture the effects of policy openness on productivity. Its effect is expected to be consistent with the hypothesis that more openness (less trade distortions) is associated with higher levels of TFP. FDI is the level of inward foreign direct investment flows and INSTIT is a measure of institutional quality. We hypothesise that higher institutional quality will also be growth enhancing. The hypothesis of a direct institutions effect on growth is well established in the empirical literature (see Hall and Jones, 1999; Knack and Keefer, 1995, 1997; Rodrik et al. 2004). Dawson (1998) finds that economic freedom affects economic growth through its direct effect on TFP and indirectly through its effect on investment. Countries with better institutions, more secure property rights, and less distortionary policies will invest more in physical and human capital, and will use these factors more efficiently to achieve a greater level of income (e.g. North 1991).

Apart from the usual set of variables in 1, per capita output is also assumed to be a function of the total stock of knowledge in country *i* at time *t*. Following Griliches and Lichtenberg (1984) we assume this depends on the stock of R&D.[3] Given that most developing countries undertake little domestic R&D, the stock of knowledge is assumed to depend on the stock of foreign R&D. This is consistent with CHH (1997); albeit where the latter authors use a two-stage approach. Productivity estimates are generated as the residuals from a production function (where the parameters are either estimated or imposed) in a first stage. Then in the second stage these are regressed on foreign R&D stocks and measures of international trade.

[3] Nadiri and Kim (1996) model the stock of knowledge as a geometric mean of own and foreign R&D capital, with the latter constructed like CH (1995) as an import-share weighted sum of the R&D capital stock in other countries. Similarly, Kneller & Stevens (2002) assume that knowledge depends on domestic and foreign R&D, but is global in nature.

We measure the stock of frontier technology as the stock of machinery R&D in 15 OECD countries. [4] Following Lichtenberg and van Pottelsberghe de la Potterie (henceforth LP, 1998) we weight the foreign machinery R&D stock by the ratio of developing countries' machinery imports in the OECD countries' GDP.[5] The stock of foreign machinery R&D is therefore given by:

$$RD_i^m = \sum_{j \neq i} \frac{MM_{ij}}{Y_j} RD_j^m \qquad \textbf{(2a)}$$

where MM_{ij} is machinery imports of developing country *i* from developed country *j*, and Y is the GDP of the developed country. Our use of machinery imports rather than the broader class of capital goods imports - machinery and transport equipment - is influenced by the argument of Mayer (2001) over the amount of technology diffused by some of the goods contained in the latter group of imports.

The measure of inward FDI weighted R&D is then calculated in a similar manner:

$$RD_i^{FDI} = \sum_{j \neq i} \frac{FDIM_{ij}}{Y_j} RD_j^m \qquad \textbf{(2b)}$$

This then makes an important distinction. FDI per se into a developing country may be expected to have various impacts on that host country depending on the motivation for FDI. For example, FDI designed to exploit a particular natural resource may generate an increase

[4] The 15 OECD countries used to generate this measure are: Australia, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, Spain, Sweden, United Kingdom and the United States.
[5] Lichtenberg and van Pottelsberghe de la Potterie (1998) demonstrated that the import-share weighting scheme of Coe and Helpman (1995) is highly sensitive to a potential merger between countries. They contended that what really matters is the real R&D intensity embodied in the import flows of the home country from the foreign country. As such, they propose that the denominator of the weighting variable be foreign country GDP rather than the total imports of the home country. This was shown to significantly reduce the 'aggregation bias' associated with Coe and Helpman's measure and also to empirically outperform it.

in growth, but afford little technology transfer or generate any long run effects beyond the life of the project. As such, we focus on FDI that is linked to a significant developed country R&D stock, such that this is capturing a technology transfer effect, rather than a (potentially) short run output effect.

Finally, μ is the disturbance term; i indexes countries and t time periods; and Δ and $\ln$ indicate when the variables are in first differences and logs respectively.

2.1 *Modelling Threshold Effects*

Threshold regression models specify that individual observations can be divided into classes based on an observed variable. They allow us to determine whether regression functions are identical across all observations in a sample, or whether they fall into discrete classes. In our case, we postulate that they are heterogeneous; given our *a priori* belief that the effects of foreign R&D on domestic TFP differs across countries as the absorptive capacity and institutional quality that countries possess differ. We do not know however, how the coefficients on the trade and FDI weighted R&D variable vary with either of the two variables. In light of this, we employ the endogenous threshold regression techniques based on Hansen (2000) and estimate the unknown threshold or cut-off values. The standard econometric theory of estimation and inference is not valid, but Hansen (2000) provides an asymptotic distribution theory which enables one to make valid statistical inferences on the basis of threshold models.

To understand the issues involved in applying this estimation methodology, we assume for simplicity that the relationship between international technology spillovers (resulting from foreign R&D) and domestic productivity is captured by the single threshold model specified below in which human capital is the threshold variable.[6]

$$\Delta \ln y_{it} = \gamma X_{it} + \beta_1 RD_{it}^{m} I(H_{it} \le \alpha) + \beta_2 RD_{it}^{m} I(H_{it} > \alpha) + \varepsilon_{it} \qquad \textbf{(3)}$$

[6] Analogous specifications employing alternative threshold variables as well as the FDI weighted externality variable have also been estimated.

In Equation (3), I(.) is the indicator function and *X* is vector of other control variables which also includes the threshold variable. In estimating 3, there are three main econometric and statistical issues that must be addressed. The first is the joint estimation of the threshold value α and the slope coefficients γ, β_1, and β_2. The second involves testing the null hypothesis of no threshold (i.e. $H_0 : \beta_1 = \beta_2$) against the alternative of a threshold regression model (i.e. $\beta_1 \neq \beta_2$) and the third is the construction of confidence intervals for α.

To estimate the parameters of the equation we use the algorithm Hansen (2000) provides that searches over values of α sequentially until the sample splitting value $\hat{\alpha}$ is found[7]. Once found, estimates of γ, β_1 and β_2 are readily provided. The problem that arises in testing the null hypothesis of no threshold effect (i.e. a linear formulation) against the alternative of a threshold effect is that, under the null hypothesis, the threshold variable is not identified. Consequently, classical tests such as the Lagrange Multiplier (LM) test do not have standard distributions and so critical values cannot be read off standard distribution tables. To deal with this problem, Hansen (2000) recommends a bootstrap procedure to obtain approximate critical values of the test statistics which allows one to perform the hypothesis test. We follow Hansen (2000) and bootstrap the p-value based on a likelihood ratio (LR) test.

If a threshold effect is found (i.e. $\beta_1 \neq \beta_2$), then a confidence interval for the critical natural barrier level should then be formed. This will enable us to attach a degree of certainty as to which threshold a given country with a given level of transport costs (and institutional quality) is likely to lie. In this case one needs to test for the particular threshold value as: $H_o : \alpha = \alpha_0$. We require this confidence interval to be reasonably small, given countries within it cannot be confidently placed in either regime.

It should be noted that the test of the null hypothesis for forming the confidence interval is not the same as that for the second problem i.e. the test of no threshold effect. Under

[7] This is the value of α that minimises the concentrated sum of squared errors based on a conditional OLS regression.

normality, the likelihood ratio test statistic $LR_n(\alpha) = n\frac{S_n(\alpha) - S_n(\hat{\alpha})}{S_n(\hat{\alpha})}$ is commonly used to test for particular parametric values. However, Hansen (2000) proves that when the endogenous sample-splitting procedure is employed, $LR_n(\alpha)$ does not have a standard χ^2 distribution. Consequently, he then derives the correct distribution function and provides a table of the appropriate asymptotic critical values[8].

In the case of a threshold effect associated with human capital if for example $\beta_1 \neq \beta_2$, $\beta_1 > 0$ and $\beta_1 > \beta_2 > 0$; then the interpretation of this combination of results would be that there are higher productivity growth effects from openness for those countries with below the threshold level of natural barriers and lower, albeit positive, effects for those with above threshold level of barriers.

Equation (3) assumes that there exists only a single threshold. It is straightforward, however, to extend the analysis to consider multiple thresholds and this is allowed for in the estimations.

3. Data

Data on GDP, labour force and physical capital investment were taken from the World Bank's World Development Indicators (WDI) CD ROM 2000 for the period 1960 to 1998. This data is in constant 1995 US \$. The capital stock data were constructed using the perpetual inventory method. To avoid the problem of initial conditions, initial capital stocks were constructed for 1960 (or the earliest available year). Appendix A provides greater detail of the construction of variables used in the empirical exercise, as well as full data sources. Human capital is measured by mean years of schooling in the population aged 25 and over and is taken from Barro and Lee (2000).[9]

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[8] See Table I on page 582 of Hansen (2000).
[9] The data in Barro and Lee (2000) are in five-year averages.

R&D investment data on machinery for the 15 OECD countries were taken from the OECD's ANBERD Database. This data covers the period 1970-1995. Like the physical capital stock, the stock of R&D was computed using the perpetual inventory method. Data on machinery imports for our sample of developing countries were extracted from the United Nations COMTRADE database.

To assess the impact of institutional differences on the level of TFP we use alternative indexes of institutional quality from two different data sources. The first index that we employ is one proxying the countries' Legal Structure and Property Rights. This index is a sub-component of the composite economic freedom of the world (EFW) index (2001) developed under the auspices of the Fraser Institute of Canada and constructed by James Gwartney, Robert Lawson and associates[10]. Specifically, Legal Structure and Property Rights measure: (a) legal security of private ownership rights/risk of confiscation, and (b) rule of law i.e. legal institutions, including access to non-discriminatory judiciary, that is supportive of the principles of the rule of law. A 0-10 scale is used to assign country ratings, with countries having secure property rights structure receiving a higher rating.

Despite the use of a 11 point scale to determine individual country ratings, one significant advantage of our institutional measure is that it is constructed from data derived from quantitative (objective) measurements and not qualitative (subjective) assessments. Consequently, the data used to construct the index of legal structure and property rights are unlikely to be biased in favour of a positive relationship between this index and economic performance as would be the case if researchers tended to assign high legal structure and property rights ratings to more prosperous countries (see Klein and Luu, 2001).

The data are provided in 5 year intervals from 1970-1995, and for 1999 (our sample period extends from 1970 through 1998). Given that institutional arrangements are likely to change slowly through time and, thus the year to year variation may be rather small, then using data

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[10] Our use of Legal Structure and Security of Property Rights to proxy a country's institutional quality rather than the overall Economic Freedom index was informed by the fact that the former is the measure commonly used in the literature to proxy institutions (e.g. Barro, 1994; Knack and Keefer, 1995; Gwartney et al., 1998) as well as the fact that some openness/trade liberalisation (distortion)- most notably the Sachs and Warner index- are used as a basis for constructing the latter.

in 5 year periods may not be unreasonable[11]. In fact, similar reasoning was employed by Barro (1997) and Chong and Calderón (2000).

Alternatively, we employ two alternative measures of institutional quality – bureaucratic quality and law and order- obtained from the International Country Risk Guide (ICRG). This data are available annually and starts from 1984 through to the end of our sample period. The index of bureaucratic quality ranges from one (low quality) to four (high quality), with bureaucracies that are able to maintain the provision of government services during a change in government or regime receiving a high rating.

The Sachs-Warner index was obtained from Wacziarg & Welch (2002). Summary statistics of the variables used for our empirical exercise is shown in Table A5.1 of Appendix A.

4. Results

4.1 Threshold Results

4.1.1 *Using Trade Weighted R&D Stock as Channel of Technology Transfer*

In this section we employ alternative indices of institutional quality as threshold variables together with the two externality variables that capture knowledge diffusion through international trade and FDI respectively.

When we employ the legal structure and property rights index (the indicator most commonly employed in the empirical cross-country growth literature to capture institutional quality) as the threshold variable and the trade weighted R&D as the channel for international technology transfer, we obtain two significant thresholds which point to the existence of a double threshold model and consequently evidence of discrete breaks points in the relationship between knowledge spillovers and productivity occasioned by institutional

[11] Though the assumption that institutional factors change slowly through time has been used by researchers, Rodrik (2000) points to some countries (Chile, Korea and China) where there have been instances of rapid and dramatic changes in institutions.

quality. The first or upper threshold occurs at the 77th percentile which corresponds to a value of 6.96 of the LSPR index. The bootstrapped p-value associated with this threshold is highly significant (less than 1%) and has a value of 0.000[12], thus indicating that the null of no threshold, and by extension a linear specification as the model that best captures the relationship between knowledge transfers and per capita output, is overwhelmingly rejected.

Denoting the percentiles of the LSPR index by α, the 95% confidence interval for the threshold estimates is obtained by plotting the likelihood ratio sequence in α, LR (α), against α and drawing a flat line at the critical value (the 95% critical value is 7.35).[13] The segment of the curve that lies below the flat line is the confidence interval of the threshold estimate. Figure 1 below shows the 95% confidence interval for the first threshold, which is LSPR $\in$ [6.6608, 7.1451] or in terms of percentiles [p (76), p (90)].

The second or lower critical threshold is at the 67th percentile of the LSPR index which corresponds to a value of 5.77. This threshold also has a highly statistically significant bootstrapped p-value (0.000) which again indicates a rejection of the null hypothesis of no threshold effects in the relationship between knowledge transfer and output growth. The confidence interval for this threshold is constructed in an analogous manner to that described above for the first threshold. The threshold lies between the 64th and the 99th percentiles or LSPR $\in$ [5.299, 9.69879]

When we employ an alternative measure of institutional quality namely the quality of the bureaucracy as the threshold variable and interact it with the trade weighted stock of R&D, we obtain only one significant threshold which occurs at the 85th percentile or a value of 2.9500 in terms of the bureaucratic quality index. The bootstrapped p-value for this threshold is statistically significant below a 1% level of significance. Figure 2 shows that the confidence interval for this threshold extends from [p (80), p (99)] or Bur_Qual.$\in$ [2.6458, 3.5]

[12] All of the bootstrapped p-values in our endogenous threshold analysis are generated using 1000 bootstrap replications.

[13] Alternatively we show the confidence interval at a 99% level of significance (see Appendix B).

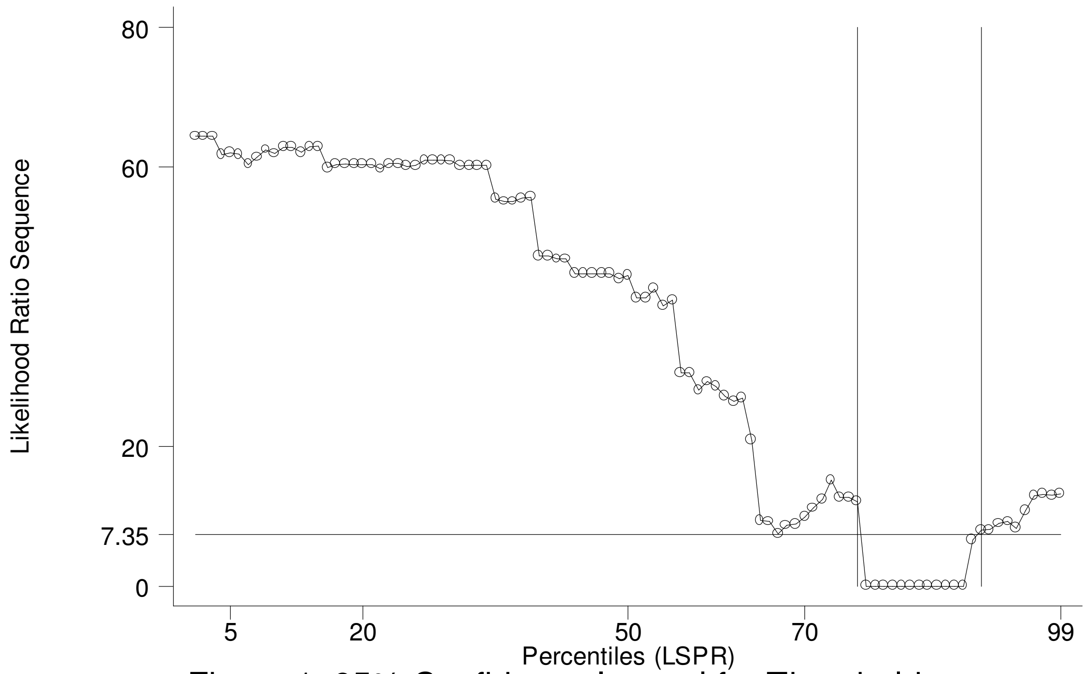

Figure 1: 95% Confidence Interval for Threshold

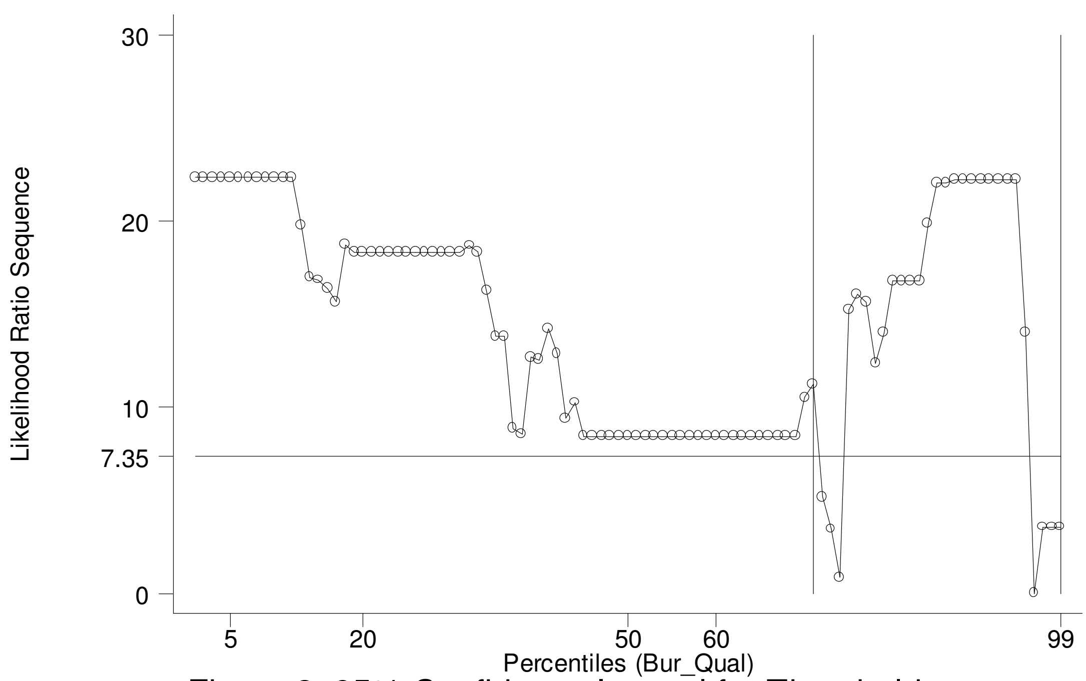

Figure 2: 95% Confidence Interval for Threshold

Table 1 shows the results of the estimation exercises based on the endogenously determined threshold values for the two measures of institutional quality and the growth rates of the trade weighted R&D variable. Regression 1 presents results for the double threshold model found when we employed the Legal Structure and Property Rights index as the measure of institutional quality. All the explanatory variables, with the exception of human capital, have the expected signs and are statistically significant at varying levels of significance at conventional levels. The main finding in this regression is that countries with higher levels of institutional quality i.e. higher values of the LSPR index, have higher rates of per capita income growth the higher their growth rates of imported capital goods. Thus countries above the upper threshold value of the LSPR index have the highest per capita growth rates associated with imports of capital goods among the three broad groups of countries.

When the quality of the country's bureaucracy (Bur_Qual) is used as an alternative measure of institutional quality (Regression 2), the finding is consistent with that of Regression 1 i.e. countries with higher levels of bureaucratic quality benefit more in terms of per capita growth from higher rates of capital goods imports. Indeed, the magnitude of the coefficient for the upper threshold group is more than three times that of the lower threshold group of countries.

4.1.2 *Using FDI Weighted R&D Stock as the Channel of Technology Transfer*

Using human capital (average years of schooling of the population 25 years and over) as the threshold variable and FDI weighted foreign R&D stock as the channel of technology diffusion, Hansen's (2000) endogenous threshold estimation technique identified two statistically significant cut-off (threshold) values which occur at the 95th and the 83rd percentiles respectively. This finding indicates the existence of a double threshold model. The first threshold corresponds to a value of H of 1.9726 and has a bootstrapped p-value of 0.0000 thus indicating a very high level of statistical significance for this threshold at conventional levels; the null of no threshold, and by extension the linear model, is rejected at less than a 1% level of significance. The second threshold corresponds to a value of human capital (H) of 1.7137 and has a bootstrapped p-value of 0.022: once again exhibiting a high level of statistical significance for the threshold value.

Table 1: Endogenous Threshold Regression Estimates with Institutional Quality and Trade Weighted R&D (1970-98)
5-Year Averages
Dependent Variable: Growth in per capita GDP

	(1)		(2)
y^0	-193.153***		-199.991***
	(10.82)		(9.32)
GAP	-202.324***		-198.995***
	(11.47)		(9.62)
Inv	7.258**		12.783***
	(2.51)		(3.89)
H	-56.632***		-55.779***
	(6.86)		(6.08)
OPEN	86.820***		67.840***
	(9.77)		(6.40)
POPGROWTH	0.000***		0.000***
	(6.79)		(3.77)
G_TWRD* I(LSPR <= 5.771)	**191.416*** **		
	(8.52)		
G_TWRD*I(5.771<LSPR<= 6.956)	**207.894*** **		
	(3.06)		
G_TWRD*I(LSPR> 6.956)	**290.840*** **		
	(7.41)		
LAC	-16.629*		-21.753*
	(1.69)		(1.75)
SSA	-2.977		-11.058
	(0.29)		(0.94)
ASIA	54.133***		50.416***
	(6.05)		(4.33)
Bur_Qual			2.605
			(0.63)
G_TWRD* I(BUR_QUAL <= 2.950)			**224.664*** **
			(9.13)
G_TWRD* I(BUR_QUAL > 2.950)			**767.095*** **
			(5.30)
Constant	1,965.302***		1,919.577***
	(10.03)		(8.18)
Observations	827		588
R-squared	0.666		0.682

NOTES: Estimates of threshold values are based on least squares estimation (see Hansen, 2000). Absolute value of (robust) t-statistics in parentheses; * significant at 10%; ** significant at 5%; *** significant at 1%.

Denoting the percentiles of the human capital variable (HUM) by α, the 95% confidence interval for the threshold estimates is obtained by plotting the likelihood ratio sequence in α, LR (α), against α and drawing a flat line at the critical value (the 95% critical value is 7.35). The segment of the curve that lies below the flat line is the confidence interval of the threshold estimate. Figure 3 below shows the 95% confidence interval for the first threshold, which is HUM $\in$ [1.08519, 2.04122] or in terms of percentiles [p (41), p (97)]. As can be seen from the Figure, the confidence interval for the threshold parameter is quite wide which means that there is some uncertainty regarding its value and consequently the proper division of countries into specific regimes. This is also the case for the second threshold parameter which as a result is not shown. Although the slope coefficients associated with the threshold values are not "invalid", they are less precise estimates of the population parameters. This is because some countries maybe incorrectly assigned to specific regimes. However, the standard errors are calculated under the mistaken assumption that the threshold is precisely known, when in fact it is not. This means that they understate the uncertainty of the threshold value[14]. The reader thus needs to bear this caveat in mind with regards to our predicted differentiated growth effects from increased FDI inflows.

Finally, we utilise an index which measures the investment profile (INVT_PROF) of the countries in the sample but this time interact it with the FDI weighted R&D stock calculated in the manner suggested by van Pottelsberghe and Lichtenberg (2001). Based on this combination of variables, Hansen's endogenous threshold procedure indicates the presence of one significant threshold value which occurs at the 54th percentile or 5.7333 in terms of the index measuring investment profile. The bootstrapped p-value for this threshold is also highly significant (less than 1%) at conventional levels. The 99% confidence interval for this threshold, which occurs between p[42, 55] or 5.3499 and 5.7666, is shown in Figure 4. The confidence interval is quite tight thus indicating a greater level of certainty about the precise location of the threshold parameter. Moreover, this certainty is obtained at a very high level of significance.

[14] Based on e-mail correspondence with Professor Bruce Hansen.

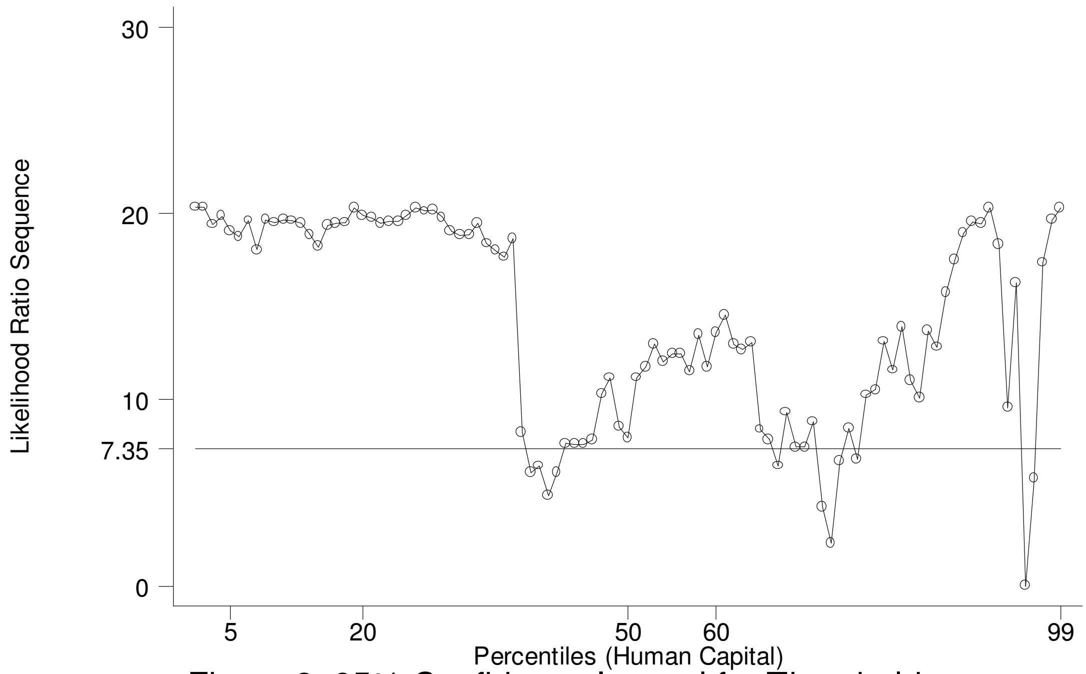

Figure 3: 95% Confidence Interval for Threshold

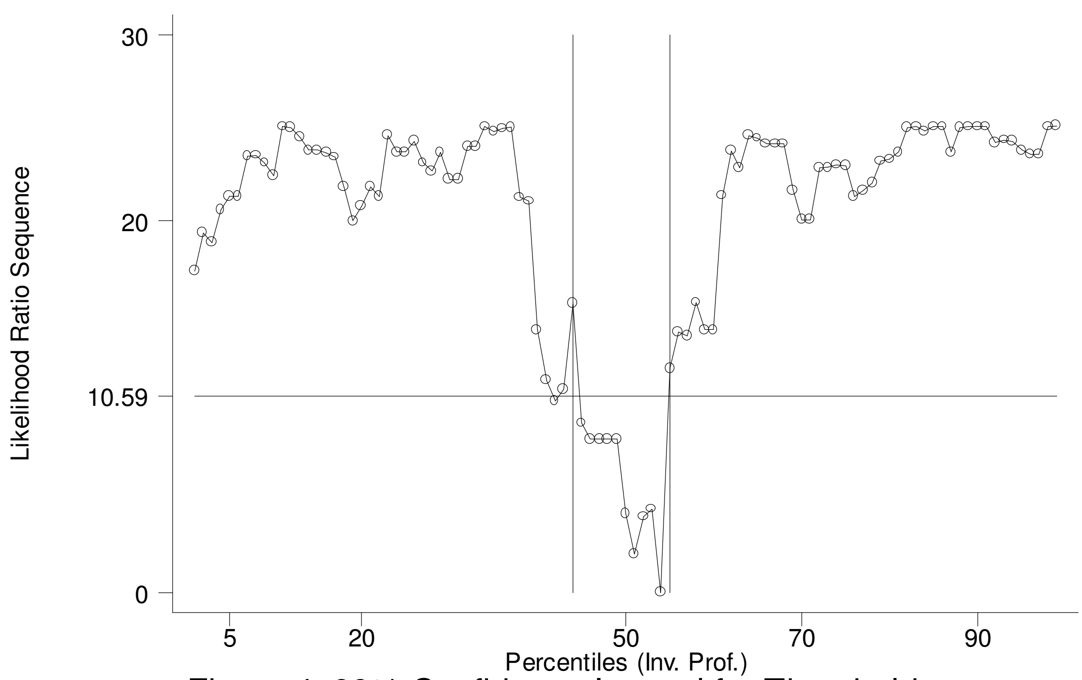

Figure 4: 99% Confidence Interval for Threshold

The threshold regression estimates with FDI weighted R&D stock as the channel of technology diffusion is shown in Table 2. In Regression 1, all variable meet our priors both in terms of signs and significance. The salient result of this estimation is the fact that there are differing growth effects from FDI associated with different threshold levels of human capital. Interestingly, only the middle threshold group of countries are shown to receive positive growth effects from FDI inflows when interacted with human capital. Our results indicate that once the upper threshold level of human capital is reached then further increases in FDI inflows are associated with negative growth effects in terms of per capita income. Below the lower threshold level of human capital there are no statistically significant per capita growth effects resulting from increased inflows of FDI.

Regression 2 seeks to investigate whether the potential benefits resulting from FDI inflows are mediated by the investment profile of a country. Somewhat surprisingly, the results show that for our sample of countries there are no statistically significant differing growth effects from FDI attributable to differences in a country's investment profile.

Table 2: Endogenous Threshold Regression Estimates with Human, Institutional Quality and FDI Weighted R&D (1970-98)
5-Year Averages
Dependent Variable: Growth in per capita GDP

	(1)		(2)
y^0	-94.920***		-195.709***
	(3.39)		(8.69)
GAP	-109.679***		-202.213***
	(3.76)		(9.15)
Inv	8.612***		13.384***
	(2.88)		(3.53)
LSPR	4.482***		
	(3.00)		
OPEN	74.226***		76.665***
	(8.23)		(7.08)
POPGROWTH	0.000***		0.000***
	(2.69)		(5.24)
FDI_WRD* I(H <= 1.7138)	**-11.387**		
	(1.63)		
FDI_WRD*I(1.7138<H<= 1.9727)	**22.919****		
	(2.44)		
FDI_TWRD*I(H> 1.9727)	**-50.832*****		
	(4.66)		
LAC	-38.517***		-8.415
	(4.33)		(0.68)
SSA	0.045		6.589
	(0.00)		(0.50)
ASIA	13.747		64.881***
	(1.57)		(5.04)
H			-63.633***
			(6.66)
INVT_PROF			-63.633***
			(6.66)
FDI_WRD* I(INVT_PROF<= 5.7333)			**-16.720**
			(1.58)
FDI_WRD* I(INVT_PROF> 5.7333)			**5.372**
			(0.53)
Constant	846.328***		1,719.071***
	(2.68)		(7.27)
Observations	656		588
R-squared	0.490		0.653

Robust t-statistics in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

5. Conclusion

Applying Hansen's endogenous threshold methodology to determine whether there is heterogeneity in international technology spillovers from developed countries to a sample of 57 developing countries based on the latter group's absorptive capacity and institutional quality, our results are more robust for the trade channel as a conduit for the transfer of technology. For the trade channel i.e. imports of capital goods, differences in institutional quality are shown to mediate the growth effects that are likely to accrue through this medium. Thus countries with high levels of institutional quality are found to have higher per capita growth rates vis-à-vis countries below this critical threshold value.

In terms of the FDI channel, human capital is found to be an important threshold variable but only for a limited group of countries.

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APPENDIX A

Data Construction

Gaps in the data were evident for six countries, Chad, Guyana, Madagascar, Mauritania, Pakistan and Syria. We chose to exclude Chad completely from the sample because of this missing data and excluded observations for Guyana (data period now 1976-1983), Madagascar (time period now 1984-1998) and Syria (time period now 1975-1998). Missing observations for Pakistan in 1982 and Mauritania in 1994 were interpolated using surrounding years as a guide.

Physical Capital and R&D Stocks

Estimates of the physical capital stock are generated using the perpetual inventory method using the following pair of equations. *K* refers to the physical capital stock, Δ the depreciation rate, *I* is investment and g^K the average annual growth rate of investment over the sample period. To overcome problems of the assumptions about initial capital stocks this value was estimated for the first available observation. For most countries this was 1960. This also informed our choice about the depreciation rate which set equal to 10 per cent.

$$K_{it} = (1-\Delta)K_{it-1} + I_{it-1}$$
$$K_{i0} = \frac{I_0}{(g^K + \Delta)}$$

Estimates of the stock of machinery R&D (R_{it}) in OECD countries necessary to measure technology transfer were calculated in a similar manner. Individual country R&D stocks in US $ PPP were calculated and then aggregated across the 15 available OECD countries. Machinery R&D investments were taken from the OECD ANBERD database for Australia, Canada, Denmark, Finland, France, Germany, Italy, Ireland, Japan, Netherlands, Norway, Spain, Sweden, UK and US. The German data were adjusted to take account of German reunification. For most countries this was available for the period 1970/3 to 1995. The R&D investment data were extrapolated forward (and in some cases backwards) for missing years by assuming that the rate of growth of R&D was the same in these missing years as the average over the sample period. The rate of depreciation (Δ) was again set to equal 10 per cent while the initial stock of R&D is estimated in the usual way (where the term g^{RD} is the average annual growth rate of R&D over the period).

$$R_{it} = (1-\Delta)R_{it-1} + RD_{it-1}$$
$$R_{i0} = \frac{RD_1}{(g^{RD} + \Delta)}$$

APPENDIX B

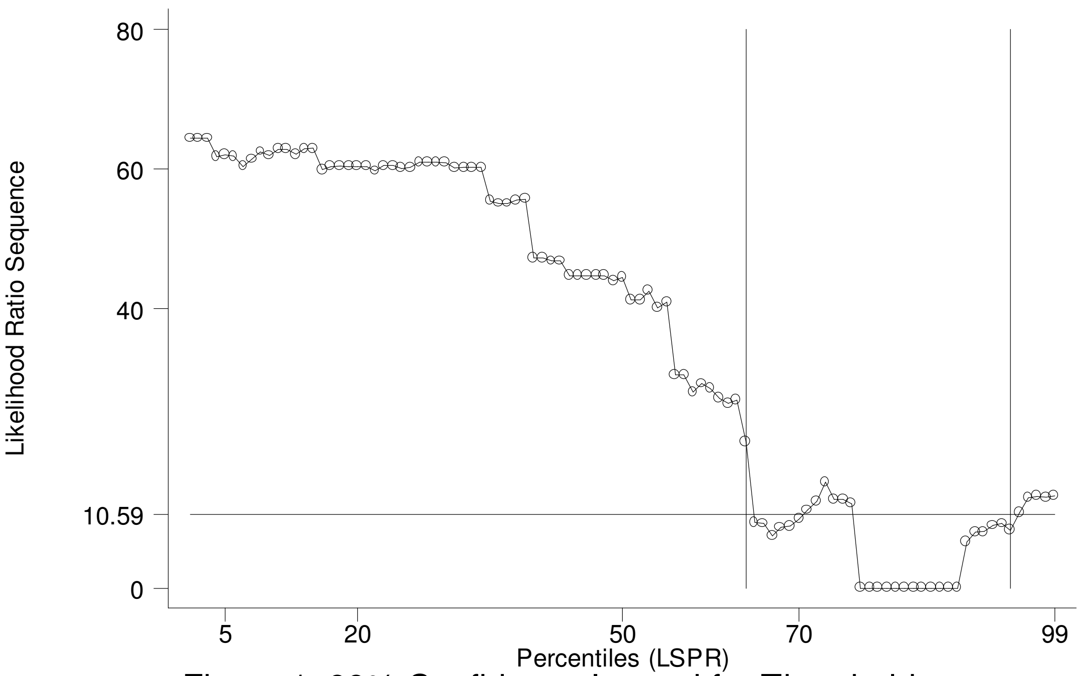
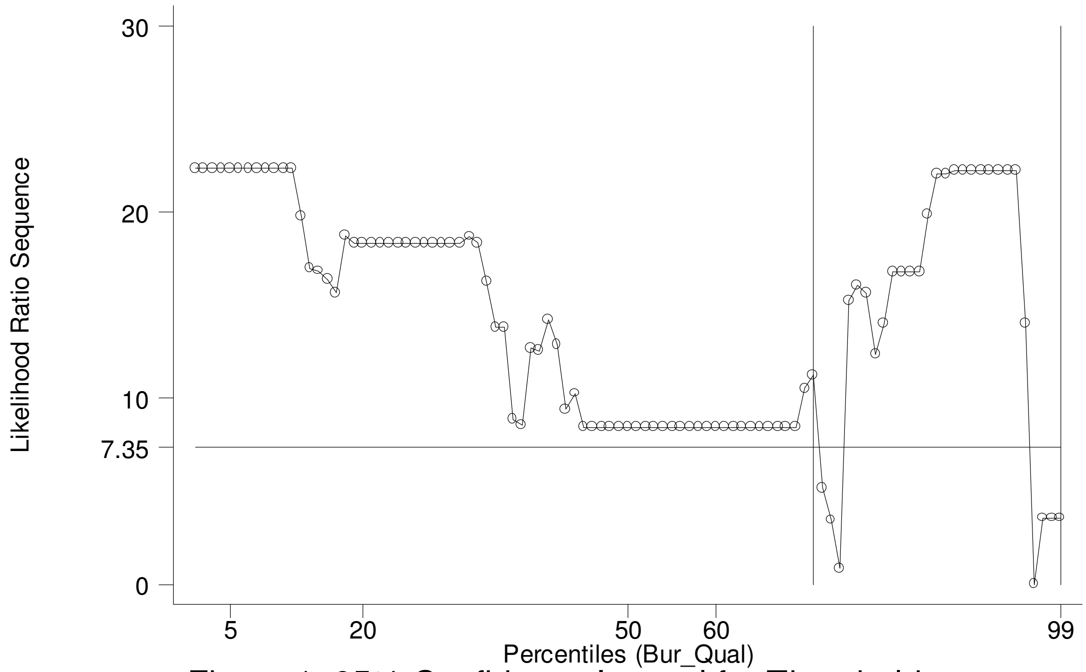


Figure 1: 99% Confidence Interval for Threshold



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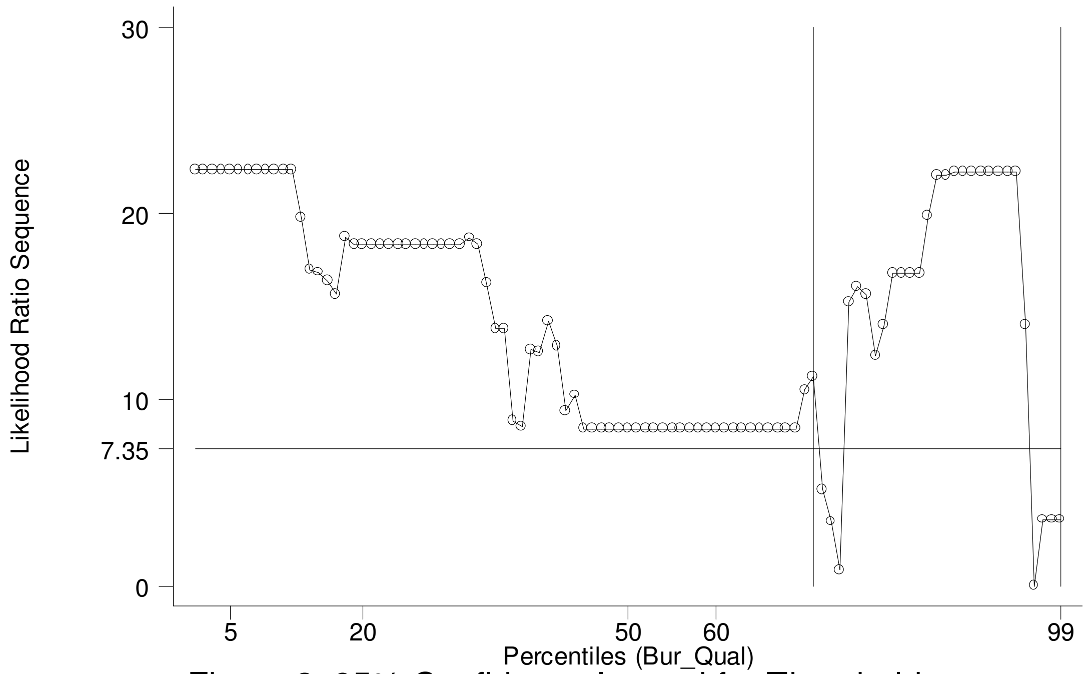

Figure 2: 95% Confidence Interval for Threshold

Table A1: Summary Statistics				
Variable	Mean	Std. Deviation	Minimum	Maximum
G_pcGDP	47.10011	160.8872	-195.5036	1124.728
y^0	7.895765	0.8363423	5.773635	10.29268
GAP	2.986612	1.285511	-1.971813	5.308823
Inv.	21.56386	1.719526	16.79326	26.35454
LSPR	4.525667	2.249861	0	10
Bur_Qual	1.709462	0.9916683	0	3.677083
H	1.111606	0.6614937	0-.9942523	2.311545
OPEN	0.3909287	0.4651112	0	1
POPGROWTH	817299	2410297	-112210	1.66e+07
Invt_Prof	5.611357	1.361356	2.25	10.83333
G_TWRD	0.0885489	0.1284418	-0.5711617	0.9309248
FDIWRD	-2.384414	0.6381988	-5.340099	-1.102932