EMPIRICAL ESSAYS ON TRADE OPENNESS, TOTAL FACTOR PRODUCTIVITY GROWTH AND EFFICIENCY

by
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Abstract

This thesis is concerned with understanding the factors responsible for the vast differences in per capita income levels and growth rates evident across countries. As part of this inquiry, it examines the role played by international trade both singly and in combination with geography, institutions and foreign R&D.

One line of inquiry revisits the contentious issue of the relationship between trade openness and growth. It examines this issue from two standpoints. First, the sensitivity of the.openness-growth nexus to alternative measures of TFP growth is considered. This approach departs from previous research on this subject which has focused mainly on the right hand side variables, namely the measures of openness and other growth determinants. Drawing on the current competing arguments over the performance of homogeneous versus heterogeneous estimators, three alternative sets of TFP growth estimates were generated; one for the each of the extremes of heterogeneity and homogeneity and an intermediate measure.

Despite being highly correlated amongst themselves and with alternative TFP estimates generated by other researchers, we find some of the measures used to proxy trade openness are sensitive to the measurement of TFP growth. Moreover, this sensitivity extends to other dimensions such as whether one performs cross-section or panel estimations and whether one assumes the openness indicators to be exogenous or endogenous. Our preference however, is for panel estimations with the alternative proxies for trade openness entered simultaneously instead of sequentially.

Second, the nature of the openness-growth relationship is examined by searching for contingent relationships between these two variables, linked to geography and institutional quality. Of the alternative methods employed for capturing contingent effects, we argue that the endogenous threshold model of Hansen (2000), best captures these effects. Using this methodology, we find evidence in support of contingent relationships between trade openness and natural barriers (institutional quality). More specifically, we find that there exists threshold level(s) of natural barriers and institutional quality above and below which the contribution to TFP growth from openness differs. However, support for the latter finding is weaker than that for the former.

A separate line of inquiry simultaneously examines the role of trade in the diffusion of foreign technology (embodied in capital goods) and its effect on technical efficiency levels. Using the methodology of stochastic frontier analysis which allows for such a dual consideration, we find evidence that trade and trade policy openness have contributed positively to both technology diffusion and raising efficiency levels in developing countries. Additionally, coinciding with improvements in the policy environment and trade liberalisation there is evidence of convergence in efficiency levels amongst developing countries.

CHAPTER 1

INTRODUCTION

1.1 CONTEXT AND BACKGROUND

Recent World Bank data show that average income levels in the world's richest and poorest nations differ by a factor of more than 100. Sierra Leone, with a per-capita GDP of $490 being the poorest, while Luxembourg with a per capita income of $50,061 is the richest (Rodrik, Subramanian and Trebbi, 2002).[1] Moreover, there has been a significant widening of the gap in average incomes between the richest and poorest countries over the last 40 years. Whereas in 1960, per capita GDP in the richest 20 countries was 18 times that of the poorest 20 countries, by 1995 it had risen to 37 times that of the latter group of countries (World Development Report 2000/1). This widening gap between rich and the poor countries has resulted in a situation whereby a U.S. citizen who is in the bottom 10% of the U.S. income distribution is better off than two thirds of the world population (Milanovic, 2002).

In terms of quality of life indicators, of the 191 countries ranked by the World Health Organisation (WHO), average healthy life expectancy at birth ranges from 25.9 years in Sierra Leone to 73.5 years in Japan (WHO Report, 2001). Given that as recently as two centuries ago per capita incomes were more or less the same across countries, then the current vast differences in the living standards between the richest and poorest countries in the world reflect sustained differences in growth rates of per capita income over a relatively short period. There has been divergence big time (see

Pritchett, 1997).[2] The aggregate figures however, mask a diverse pattern of economic growth experiences of some countries and regions, particularly since 1960. Some countries (and regions) have enjoyed sustained economic growth over many decades, while in other countries (and regions) economic growth has stagnated and per capita income has even declined. For example, the East and Southeast Asian regions (excluding China) experienced per capita GDP growth of 4.4% for the period 1960-2000. This period of sustained growth was sufficient that South Korea, Thailand and Malaysia ended the last century with productivity levels close to those experienced in the advanced countries. In contrast, both Latin America and Sub-Saharan Africa after experiencing robust growth up to the late 1970s, witnessed dramatic collapses in both GDP and productivity growth thereafter (see Rodrik, 2003a). Table 1.1 shows average annual growth rates of GDP per worker for these growth miracles and growth disasters over the period 1960-1990.

Understandably, these vast differences in the level and growth rate of per capita income across countries have generated great research interest in establishing their cause. Traditional neo-classical growth theory suggests that the answer lies in differences in capital accumulation (physical and human). In contrast, newer endogenous growth models focus on technological change (productivity differences): idea gaps rather than object gaps (Romer, 1993). Empirical support for the first view is provided by amongst others Mankiw, Romer and Weil (hereafter, MRW 1992), Barro and Sala-i-Martin (1995) and Young (1994, 1995). In MRW (1992) the authors augmented the Solow (1956) growth model to include human capital and

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[1] The figures are for 2000 and are expressed in current "international" dollars for purchasing power parity (PPP) differences.

[2] As late as 1820, per capita incomes were quite similar around the world ranging from around $500 in China and South Asia to $1000-$1,500 in the richest countries of Europe (World Development Report, 2000/1). Also see Maddison (1991).

find they are able to explain 78% of the cross-country variance of output per capita in 1985. This finding formed the basis for Mankiw's claim that "Put simply, most international differences in living standards can be explained by differences in accumulation of both human and physical capital" (1995, p.295). The findings of Young (1994, 1995) that the East Asian growth miracles were driven more by factor accumulation than by productivity change point to a similar conclusion.

TABLE 1.1

GROWTH MIRACLES AND DISASTERS, 1960-90

ANNUAL GROWTH RATES OF OUTPUT PER WORKER

Miracles	Growth	Disasters	Growth
Korea	6.1	Ghana	-0.3
Botswana	5.9	Venezuela	-0.5
Hong Kong	5.8	Mozambique	-0.7
Taiwan	5.8	Nicaragua	-0.7
Singapore	5.4	Mauritania	-0.8
Japan	5.2	Zambia	-0.8
Malta	4.8	Mali	-1.0
Cyprus	4.4	Madagascar	-1.3
Seychelles	4.4	Chad	-1.7
Lesotho	4.4	Guyana	-2.7

Source: Temple (1999), Table 2

Note: Figure for Botswana and Malta based on 1960-89.

More recently, this factor input view of income differences has been challenged by Klenow and Rodriguez-Clare (1997), Prescott (1998), Hall and Jones (1999) and Easterly and Levine (2001). While acknowledging the importance of capital accumulation in explaining per capita income differences, this literature argues that differences in the level of TFP account for most of the cross-country differences in the level and growth rate of GDP per capita. For example, in explaining the 35-fold difference in output per worker between the U.S. and Niger, Hall and Jones (1999) find that differences in capital intensities between the two countries contribute a factor of 1.5, differences in levels of educational attainment contribute a factor of 3.1 while the remaining difference, a factor of 7.7, is due to productivity. Thus the Solow assumption of identical productivity across countries appears not to hold (Romer, 2001).

Further, in responding to what they saw as a 'Neo-classical Revival' in growth economics, Klenow and Rodriguez-Clare (1997) demonstrate that the MRW (1992) results are not robust to certain modifications. First, they updated and modified the human capital data of MRW by adding data on primary and tertiary schooling. Klenow and Rodriguez-Clare argue that since there is less variation in primary school enrolment rates across countries compared to the secondary school rates, the ability of human capital stock to account for cross-country income differences will be lower than in MRW(1992). By focusing only on secondary schooling, the percentage variation in human capital across countries and its covariance with output per worker is overstated. Klenow and Rodriguez-Clare also took objection to the nature of the accumulation technology used by MRW (1992). Consequently they incorporated evidence suggesting that the production function of human capital is more labour, and less (physical) capital, intensive than is the production of other goods. With these modifications to the MRW framework, TFP is shown to explain the majority of the cross-country variation in output per worker.

Whilst recognising that partitioning income differences into the relative contributions from factor inputs and productivity is important, it is argued that the debate should be deepened somewhat to one about why some countries accumulate inputs faster than others and why some countries are more productive than others (Hall and Jones, 1999; Rodrik, Subramanian and Trebbi, 2002). For the latter authors, the answer lies in "deeper" or more fundamental sources of growth; factor accumulation and TFP change are at best proximate sources. Whilst the list of factors characterised as either "proximate" or "deeper" determinants of long-run growth differs between researchers, Rodrik et al. (2002) argue that from the extensive literature on the subject three factors stand out: openness to international trade (integration), institutions and geography.[3] It is on these three factors that this thesis mainly focuses.

1.2 AIMS, OBJECTIVE AND STRUCTURE OF THESIS

The broad research objective of this thesis is to deepen our understanding of the role played by international trade, geography and institutions in promoting long-run growth and development. It seeks to do so by empirically examining the relationship between openness to international trade, the level of GDP, TFP growth and efficiency levels for a broad cross-section of developed and developing countries. As part of this inquiry, it also considers the role played by other fundamental and proximate factors, both singly and in combination with trade openness, in explaining cross-national income, productivity and efficiency differences. These are institutional quality, geography and foreign R&D. The specific aims are to fill the gaps (identified below) in the existing empirical trade and growth literature, and to distil the implications for policy and future research based on the research findings.

[3] See Maddison (2001) for a discussion on the causal influences of global productivity performance from 1820-1992 and Sala-i-Martin (1997) for a list of the most significant factors explaining differences in cross-national growth rates between 1960-1990.

1.2.1 TFP Measurement

Although academic researchers and policy makers agree upon the importance of TFP to the process of economic development, there is less consensus among the former group on its theoretical conceptions and measurement (see Easterly and Levine, 2001; Felipe, 1999; Van Biesebroeck, 2003). Chapter 2 focuses on the latter issue. Specifically, it critically reviews the various methods (both stochastic and non-stochastic) used by empirical researchers for measuring TFP at the economy-wide level. Primarily because growth accounting is the most frequently used methodological framework for measuring TFP at the national level, most of the survey focuses on this methodology.

Placing emphasis on the measurement of TFP growth seems justified for three main reasons. First, until recently there has been an intense debate within the narrower confines of the growth accounting productivity literature over the magnitude of economy-wide productivity growth rates estimated for some of the South East Asian countries (see Young, 1995; Nelson and Pack, 1999). The wide variations in the estimates produced by different researchers for the same countries, using the same data and for the same time period, lead Felipe (1999) to conclude that the resulting TFP growth estimates are largely conditioned on the assumptions made, estimation techniques employed and functional form specified. This debate centers primarily on the suitability of the non-stochastic growth accounting methodology for correctly separating out the contributions of the growth of factor inputs and TFP growth to the observed growth in total output, given the theoretical and methodological assumptions on which it is premised. The second reason lies in the fact that some of these theoretical and methodological assumptions have been convincingly questioned both by theoretical and empirical growth economists. Third, is the inability of the aggregate growth accounting method to deal with the issues of parameter heterogeneity and possible endogeneity of factor inputs. These two issues, particularly the former, are the subject of recent research by empirical growth economists (see Temple, 1999; Durlauf, et al., 2001; Masanjala and Papageorgiou, 2004).

After an extensive review of the literature, we derive three (3) alternative residual measures of TFP growth for a sample of 93 countries (developed and developing) based on the econometric estimation of an aggregate production function. Two of the measures are based on the polar assumptions of complete heterogeneity and complete homogeneity in the production parameters across countries. For the homogeneous measure, the parameter estimates are derived after controlling for the likelihood that the factor inputs are endogenous. The third, and most preferred of the three measures, is an intermediate measure that incorporates both the heterogeneity and homogeneity assumptions. This measure of TFP growth allows for heterogeneity in the production parameters across countries but homogeneity in the factor elasticities (used to estimate TFP growth) within regions. These assumptions reflect some of the competing arguments regarding econometric estimation of cross-country regressions in general, and the production function in particular. Additionally, the three measures of TFP growth are representative of those previously employed in the literature.

Incorporating the assumption of heterogeneity into TFP measurement at the country level, as well as controlling for econometric problems such as the likely endogeneity of the factor inputs, represent novel features of this chapter.

1.2.2 Robustness and Heterogeneity Issues

Of the factors identified as the fundamental determinants of long-run economic growth, the relationship between openness to international trade and economic growth has perhaps been both the most controversial and the most extensively researched.[4] While on balance much of the empirical evidence points to a positive relationship between greater trade openness and economic performance, there are those who remain unconvinced (see Harrison and Hanson, 1999; Rodriguez and Rodrik, 2000).

Three main issues appear to lie at the heart of the current disagreement. The first relates to the measures used to proxy openness in empirical research (see Edwards, 1993; Rodrik, 1995). The second is the absence of good quality trade policy information with sufficiently broad country and time coverage to construct satisfactory measures of trade policy (Edwards, 1998; Baldwin, 2003). The third is the sensitivity of the relationship to the variables used to proxy openness, to country coverage and time period studied, and to the functional form used to estimate the relationship. This thesis focuses on the third of these points and ask the question: are the results sensitive to the way TFP is measured?

An early study that raised doubts over the robustness of the positive trade-growth association to alternative specifications is Levine and Renelt (1992). Using different measures of trade policies and Leamer's extreme-bounds analysis (EBA), they find no robust or consistently positive relationship between trade openness and long run growth. However, Sala-i-Martin (1997) argues that EBA is too stringent as a

[4] Edwards (1993) and Greenaway and Sapsford (1994) provide detailed surveys of the major studies undertaken up till the early 1990s while Rodriguez and Rodrik (2000) provides a critical review of some of the most recent studies in this literature.

robustness measure and rejects too many variables as non-robust. He thus proposes an alternative robustness test to EBA, which allows him to construct confidence levels for the entire distribution of coefficients for different long-run growth determinants (see Harrison and Hanson, 1999; Bleaney and Nishiyama, 2002). Using this test, Sala-i-Martin finds the Sachs-Warner (1995) openness measure to be the only openness measure that is robustly correlated with growth.

Edwards (1998) analysed the robustness of the openness-growth relationship by examining whether the positive and significant correlation between measures of trade policy and growth found in previous studies, are robust to alternative measures of trade policy. In this regard, Edwards employs nine alternative indicators of trade policy openness and a composite index constructed from five of the nine indicators. For the majority of the equations estimated (13 out of 18), the coefficient on the openness indicator has the expected sign and is statistically significant thus supporting the view that countries with more open (less distorted) trade policies experience faster TFP growth. Edwards argues that this finding is robust to the use of openness indicator, estimation technique and functional form.

More recently, Rodriguez and Rodrik (2000) demonstrated that the positive correlation between openness and growth found in five widely cited studies- Dollar (1992), Sachs and Warner (1995), Ben-David (1993), Edwards (1998) and Frankel and Romer (1999)- is not robust, either because of shortcomings in the openness measures used or a failure to control for other important growth determinants. Finally, in investigating another dimension of the robustness issue, Vamvakidis (2002) argues that the positive correlation between trade openness and growth is a recent phenomenon. Using historical data from 1870 to 1990, he finds no support for a positive correlation between these two variables prior to 1970. In fact, on the basis of cross-country growth regressions estimated for the period 1920-1940, the author finds the relationship to be negative.

The strength of these criticisms of the existing empirical research appears overwhelming. Yet, missing from the debate thus far is whether the relationship between trade openness and TFP growth is robust to alternative measures of TFP. In light of the concerns in the literature over the magnitude of estimates of TFP for some countries, then the natural question to ask is to what extent are the results from cross-country regressions on the trade openness-productivity relationship affected by how TFP growth is measured? Chapter 3 thus revisits the robustness debate relating to the nexus between openness and TFP growth. The main contribution of this chapter to the current debate is to examine the robustness of the trade openness-TFP growth relationship to alternative economy-wide measures of TFP growth. It uses the three alternative measures of TFP growth derived in Chapter 2 to undertake this sensitivity analysis. By shifting attention to the measurement of TFP growth, the thesis departs from focusing on the right hand side variables such as the measures used to proxy openness and other determinants of growth like other researchers that have investigated the subject.

Additionally, the chapter investigates robustness of the openness-growth relationship in other dimensions such as cross-section versus panel estimations, different time periods and to whether we assume the regressors to be exogenous or endogenous. This represents another departure from previous studies on this subject, which have generally focused on robustness in one dimension. For our cross-section analysis we test the robustness of Rodriguez and Rodrik's (2000) results, based on their critique of Edwards (1998), to alternative measures of TFP growth.

Our results indicate that some measures of openness are definitely sensitive to how TFP growth is measured. Further, some openness indicators are also sensitive to whether their relationship with TFP growth is examined on the basis of cross-section or panel estimations, or whether we assume them be exogenous or endogenous.

Chapter 4 further examines the relationship between openness and TFP growth. This time however, it also explores the role played by geography and institutional quality, both directly and in combination with trade openness. When used collectively in cross-country regressions the direct and indirect effects on income of these three factors are presently the subject of intense debate in the literature (see Rodrik et. al, 2002; Easterly and Levine, 2003; Sachs, 2003; Dollar and Kraay, 2003a). The debate centres around whether all the factors have a direct effect on income, and/or whether one factor explains variations in income through the other two factors. For example, Rodrik et al. (2002) argue that among the three factors "Institutions Rule". Based on instrumental variables two stage least squares (IV2SLS) regressions they find that once institutions are controlled for, integration (proxied by the ratio of trade to GDP) has no direct effect on income, while measures of geography have at best weak direct effects. Further, the measure of trade openness often enters the income regression with the "wrong" (i.e. negative) sign. In contrast, the measure of institutional quality (property rights and the rule of law) always enters with the correct sign and is highly statistically significant.

In terms of the links between the three determinants, Rodrik et al. (2002) find that institutional quality has a positive and significant effect on integration and vice versa. The latter result suggests that trade can have an indirect effect on incomes by improving institutional quality. The authors also find that geography (proxied by distance from the equator) exerts a significant effect on the quality of institutions. Easterly and Levine (2003) also obtained results qualitatively similar to Rodrik et al. (2002). They find that, while institutions have a direct effect on development, endowments (aspects of geography) do not; the latter only affecting country incomes indirectly through institutions. Further, policies (including trade policy openness) do not to have any effect on development once institutions are controlled for.

However, other studies have reached different conclusions to the two studies cited above. For example, Sachs (2003) finds that "Institutions Don't Rule". He demonstrates that malaria transmission, which he argues is strongly affected by ecological conditions, directly affects the level of per capita income after controlling for the quality of institutions. Additionally, Alcálá and Ciccone (2002) find that while trade is quite significant, the finding for institutional quality is mixed. It is occasionally, but not consistently, significant. Finally, Dollar and Kraay (2003a) argue that cross-country regressions of the log-level of per capita GDP on measures of trade and institutional quality are uninformative about the relative importance of trade and institutions in the long run because of the very high correlation between these two variables. Multicollinearity between the variables used to instrument trade and institutions respectively, making it nigh impossible to isolate the partial effects of the latter two variables. Regressing changes in decadal growth rates on instrumented changes in trade and changes in institutional quality, they find evidence of a strong effect of trade on growth, with a much smaller role for improvements in institutions. Dollar and Kraay conclude on the basis of these results that there is an important joint role for both trade and institutions in the very long run. However, there is a relatively larger role for trade over shorter horizons.

In light of the mixed results from this recent literature, in Chapter 4 we consider whether a simple linear specification is adequate to capture the interaction of trade policy with TFP growth or are there non-linearities in this relationship? And if there are non-linearities, are these generated by geography and institutions? Is the extent to which a country can integrate into the world economy and possibly reap growth benefits from so doing fashioned by the quality of its institutions and geography? For example, do countries have to reach some threshold level of institutional quality before they reap these benefits? We believe that these are questions upon which some light should be shed and this is therefore the aim of Chapter 4.

This chapter therefore explores the issue of heterogeneity in the openness-productivity growth relationship by looking for contingent relationships between natural barriers to trade and trade openness (distortions) on the one hand, and institutional quality and trade openness (distortions) on the other. Specifically, the chapter examines whether the productivity payoffs from openness or trade liberalisation are conditioned by the quality of a country's institutions and the extent of the natural barriers it faces in participating in international trade. It postulates that there exists some critical level of both institutional quality and transport costs (a proxy for natural barriers) above and below which the positive contribution of openness to TFP growth differs.

Chapter 4 makes two main contributions. First, the use of natural barriers and institutional quality as threshold or conditioning variables represents a novel contribution to the openness growth literature. Second, it places great emphasis on determining the form of the non-linearity that may characterise the openness-growth relationship and the model that best captures it. It thus compares the traditional methods for capturing threshold effects - exogenous sample splitting and the imposition of linear interaction effects – with the endogenous sample splitting methodology based on Hansen (2000), whereby a break or threshold is determined from the data itself rather than it being imposed. On the basis of econometric theory and the pattern of results obtained from the three approaches, we argue that the endogenous threshold regression model best captures the non-linearity in the openness-growth relationship.

Evidence is found to suggest that thresholds exist in the openness-TFP growth relationship for both natural barriers and institutional quality, above and below which the benefits of openness in terms of higher TFP growth differ. However, only in the case of natural barriers can a confidence interval at conventional levels be attached to this threshold value.

1.2.3 Technological Change as an Explanation for Income Differences

As indicated earlier, endogenous growth theorists view technological change (productivity differences) as the principal factor that explains the differences in incomes across countries. Central to much of the recent endogenous technological change literature is the view of technology as knowledge (Romer 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1992). The extension of this literature to incorporate open economy models (see Grossman and Helpman, 1991; Rivera-Batiz and Romer, 1991), has led to renewed interest in the relationship between international trade, technological change and growth. In these models, trade in both intermediate and final goods is shown to affect long-run growth. Technology is diffused by being embodied in intermediate inputs. The productivity of countries that import these intermediate inputs will therefore increase through the R&D efforts of its trade partner (see Keller, 2000).

The essential message from the work of Grossman and Helpman (1991) and Rivera-Batiz and Romer (1991) is that it is possible for technologically backward countries to close the technology gap by importing the knowledge embodied in intermediate manufactured products and capital equipment. Several recent empirical studies have used the theoretical models of Grossman and Helpman (1991) and Batiz and Romer (1991) as a base to demonstrate the importance of foreign R&D and imports to domestic productivity growth in both developed and developing countries. These include among others Coe and Helpman (1995); Coe, Helpman and Hoffmaister (1997); Xu and Wang (1999) and Keller (2002).

However, an implicit assumption in this literature is that countries use their stock of accessible technology efficiently. Having access to leading edge technologies through technology transfers may not of itself lead to productivity improvements if these technologies are not absorbed and utilised efficiently. Therefore, the absorptive capacity and technical efficiency of a country are critical factors in its ability to "catch up" with countries at the technological frontier. For developing countries this is even more of an imperative. Therefore, in examining the role of international trade as a channel for technological spillovers and the international diffusion of knowledge, Chapter 5 breaks with previous researchers and considers both channels simultaneously, rather than focusing on one or the other separately.

A methodology that permits one to explore jointly the determinants consistent with these 'two faces' of international trade is one-stage stochastic frontier analysis (SFA). We allow the transfer of (industrial country) foreign technology, through machinery imports, to determine the stock of R&D knowledge used in the production process, and for international trade to influence absorptive capacity and national efficiency levels in 57 developing countries. The consideration of this dual role for international trade together with the use of the SFA methodology to do so, represent a contribution to the literature on technology diffusion and spillovers. Additionally, by using SFA we are able to measure cross-country and temporal differences in efficiency levels and to explain these differences in terms of differences in trade and trade policy, geographical location, health and agricultural intensity. The results indicate significant convergence of efficiency levels among developing countries and an important influence of trade and trade policy in raising efficiency levels.

1.2.4 Summary and Conclusions

Chapter 6 summarises the main empirical findings of the thesis and considers the implications for policy based on these findings. It also highlights the limitations of the empirical techniques used, and presents areas for further research.

CHAPTER 2

AGGREGATE MEASURES OF TOTAL FACTOR PRODUCTIVITY: A CRITICAL REVIEW

2.1 INTRODUCTION

The importance of total factor productivity (TFP) to the process of economic growth and development has long been recognised by economists and policy makers. The only point of debate over its importance to the process is the extent of its contribution vis-à-vis other determinants of economic growth. For example, some assign a greater role to factor accumulation over TFP in explaining the vast differences in per capita growth and income levels across countries (Mankiw, Romer and Weil, 1992; Mankiw, 1995), others give the leading role to TFP (Klenow and Rodriguez-Clare, 1997; Easterly and Levine, 2001). There is even less consensus however on the conception and measurement of TFP. Different theories offer very different conceptions. As indicated by Easterly and Levine (2001), these range from changes in technology (Aghion and Howitt, 1998; Grossman and Helpman, 1991; Romer, 1990) to the role of externalities (Romer, 1986; Lucas, 1988), changes in the sector composition of production (Kongsamut, Rebelo and Xie, 1997) and the adoption of lower-cost production methods (Harberger, 1998).

In terms of its measurement, there exists an array of methodologies at both the micro and aggregate levels for calculating TFP. Methodologies differ based on their underlying assumptions, which imply very different calculations, each with its strengths and weaknesses. In terms of the techniques employed, they fall into two broad classes: stochastic and non-stochastic.[1]

In this chapter we derive three alternative stochastic measures of TFP growth at the economy-wide level for a sample of 93 developed and developing countries. The underlying methodology used for deriving these three sets of TFP growth estimates is a regression analogue of the growth accounting framework of Solow (1957) whereby TFP growth is measured as a residual. However, unlike the non-stochastic studies applying this methodology, the factor elasticities from the production function are estimated rather than imposed on the basis of the share of each factor payment in national accounts data. The factor elasticities are estimated on the basis of different assumptions made about the technology parameters of the aggregate production function, and also on the likelihood that the factor inputs are endogenous.

In order to gauge the relative importance of different assumptions, two of the measures of TFP growth are based on the polar assumptions of complete heterogeneity and complete homogeneity in the production parameters across countries. Additionally, the completely homogeneous measure corrects for the potential endogeneity of the factor inputs. The third, and most preferred of the three measures, is an intermediate measure that incorporates both the heterogeneity and homogeneity assumptions. That is, it allows for heterogeneity in the production parameters across countries but homogeneity in the factor elasticities (used to

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[1] The terms parametric and stochastic are frequently used interchangeably. However, the two terms are not strictly one and the same. The former refers to the explicit specification of some functional form (e.g. Cobb-Douglas and Translog) around which the measurement of TFP is organised, although the procedure for actually measuring TFP may be deterministic. That is, the process is non-random and as such is not associated with a set of probabilistic outcomes. In contrast, stochastic procedures involve the use of parametric functions that are characterised by random processes. In this chapter we adhere to the strict definition of the two terms.

estimate TFP growth) within regions. These assumptions are reflective of some of the competing arguments regarding econometric estimation of cross-country regressions in general, and the production function in particular.

To provide a complete analysis, these three benchmark measures are then compared with TFP growth rates generated on the basis of alternative methodologies by other researchers. The remainder of this chapter is organised as follows: Section 2.2 begins by defining and explaining the concept of productivity. It then outlines the non-parametric arithmetic and geometric index number approaches to measuring TFP employed by Kendrick (1961) and Solow (1957), and the refinements to the geometric index approach by Jorgenson and Griliches (1967) and Diewert (1976). Section 2.3 briefly reviews some empirical studies that have utilised the index number growth accounting framework. Another variant of the growth accounting methodology – parametric aggregate growth accounting- is discussed and critically appraised in Section 2.4. Section 2.5 discusses some of the theoretical and empirical criticisms levelled against the non-stochastic growth accounting methodology as a medium for computing TFP. As a means of overcoming some of the shortcomings and inherent limitations of the non-stochastic methods for measuring TFP growth, Section 2.6 advocates the use of econometrics as an alternative and reviews some studies that have utilised this methodology for measuring TFP for a large number of countries. Section 2.7 outlines the model, specifies the estimating equations and discusses the estimation methods employed to derive the parameters estimates required for deriving the three measures of TFP growth. It then presents the results from the estimation exercises. Section 2.8 analyses the TFP growth rates derived from the preferred intermediate measure and then compares these growth rates with those derived using alternative methods. Section 2.9 summarises the chapter and makes some concluding statements.

2.2 NON-STOCHASTIC AGGREGATE MEASURES OF TFP I : NON-PARAMETRIC INDEX NUMBER GROWTH ACCOUNTING

2.2.1 Definition And Concept Of Productivity

Productivity is a technical concept defined as a ratio of output to inputs. It is a yardstick for measuring how efficiently factor inputs are used in the production of output(s). Therefore, there are as many indices of productivity as there are factors of production (Nadiri, 1972). When a productivity index is computed on the basis of a single input, it is generally referred to as a partial or average productivity index. One of the most used partial productivity indices is the index of labour productivity. This is commonly expressed as:

$$A_L = \frac{Q}{L} \qquad \textbf{(2.1)}$$

where A_L is labour productivity, Q aggregate level of output and L aggregate level of labour.

At the national level, labour productivity (expressed as GDP per worker) is frequently used to gauge the economic progress of a nation. However, as noted by Rodrigo (2001), partial measures of productivity such as labour productivity provide little or no insight into the way this economic progress is realised; the role of capital accumulation (both physical and human) remains hidden from view. For a more meaningful measure of productivity one needs to go beyond labour productivity and correct for capital used in production. The measure most commonly used is total factor (or multi-factor) productivity.[2] Total factor productivity (TFP) is defined as the ratio of aggregate output to a combined (or composite) measure of the inputs used in production. This measure is intended to capture output differences that cannot be explained by input differences.[3] Assuming there are two factor of production – capital and labour – then TFP can be expressed as:

$$A = \frac{Q}{X} \tag{2.2}$$

where A is TFP, Q is output and X is a weighted average of labour and capital.

Whereas the concept of partial productivity is independent of theory in the sense that it does not depend on any model or assumption, the notion of TFP is to an extent theory dependent. Because the composite input measure is normally a weighted average of all the inputs used in production, the question of how to weight the inputs in the index immediately arises. The answer to this question is usually sought by a recourse to theory.

Researchers have long grappled with the notion and measurement of TFP. The main difference among them is the way that they have conceptualised it. Some researchers (for example Stigler, 1947; Kendrick, 1955; Abramovitz, 1956) conceptualised TFP

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[2] A discussion on the use and limitations of alternative productivity yardsticks is provided in Baumol et al. (1989, Ch. 11). They argue that TFP should not be taken to be a better alternative to labour productivity. The two measures of productivity should be seen as complementary measures of different aspects of economic growth.

[3] Rodrigo (2001) argues that one needs to distinguish between TFP and 'efficiency' per se. According to him, the latter is a technical concept used in production, where inputs and outputs are defined in purely physical terms. In contrast, TFP is an economic concept which involves the aggregation of inputs and outputs into common units using value or cost weights. Both are identical however, when there is only one input and one output.

(or the "residual") as an output-over-total-input index. One example is Kendrick's arithmetic measure of TFP growth (see Kendrick, 1961) based on a distribution equation derived from a homogenous production function and the Euler condition. That is:

$$\frac{dA}{A} = \frac{Q_1/Q_0}{(wL_1 + rK_1)/(wL_0 + rK_0)} - 1 \qquad \textbf{(2.3)}$$

where Q, L and K are as defined above, and *w* and *r* are the wage rate and the rate of return on capital respectively. Variables with the subscript 1 refer to the current period and those with the subscript 0 refer to the base period. In empirical estimates, the weights for calculating (2.3) are often permitted to change smoothly over time (see Nadiri, 1972).

Other researchers however, example Tinbergen (1942), Tintner (1944) and Solow (1957), conceptualised TFP change as a shift of the production function.[4] According to Griliches (1996), the first approach (index method) developed out of the national income measurement tradition based largely on the work of the National Bureau of Economic Research (NBER) and what later became the Bureau of Economic Affairs (BEA), while the second was influenced by Paul Douglas's work on production functions.

However, some researchers have incorporated both conceptualisations in a single measure. The geometric index number measure of Solow (1957) and Jorgenson and Griliches (1967) is one example. A more detailed discussion of this approach to measuring TFP is provided below, starting with the seminal study of Solow (1957).

2.2.2 The Solow Residual And The Method Of Growth Accounting

The residual measure of TFP and the associated procedure of growth accounting postulated by Robert Solow in his path breaking 1957 paper, *"Technical Change and the Aggregate Production Function"*, provides a convenient starting point for our review of conventional measures of productivity based on an aggregate production function. Solow's aim was to provide "an elementary way of segregating variations in output per head due to technical change from those due to changes in the availability of capital per head" (1957, p. 312). He defined technical change as "a shorthand for any kind of shift in the production function" (1957, p. 312). Although Solow (1957) was not the first to link a measure of productivity to the aggregate production function, nor the first to measure productivity as a residual, Solow was the first to establish a theoretical link between the aggregate production function and the index number approach to measuring TFP growth (Griliches, 1996; Hulten, 2000).[5]

According to Hulten (2000), whereas previous index number studies interpreted their results in light (emphasis Hulten's) of a production function, Solow started with the production function and deduced the consequences for (and restrictions on) the productivity index. Combined with the use of calculus, this had the effect of clarifying the meaning of hitherto arcane index number calculations and consequently brought the subject of productivity measurement from the "periphery of the field to the center" (Griliches, 1996, p. 1328). Further, Solow's paper

[4] Griliches (1996) credits Copeland (1937) with being the first to mention the output-over-input index and Stigler (1947) with the first empirical implementation of this index.

[5] Tinbergen (1942) is credited with linking productivity change with the aggregate production function. Additionally, prior to Solow (1957), other researchers such as Fabricant (1954), Kendrick (1955) and Abramovitz (1956) measured TFP as a residual. These authors however measured TFP based on an output over total-input index (see Nadiri, 1972; Nelson, 1981; Griliches, 1996).

connected indirectly to his earlier study on growth theory (Solow, 1956) and greatly influenced subsequent work in both macro and microeconomics.

2.2.2.1 Deriving The Solow Residual

Solow began with an aggregate production function with constant returns to scale and assumed to be continuous and twice differentiable. In its simplest form this can be written as:

$$Y_t = F(K_t, L_t, t) \qquad \textbf{(2.4)}$$

where Y_t represents output for a given time period, K_t and L_t represent capital and labour inputs (in "physical units") for a given time period respectively, and t is a shift factor which proxies for technical change. Assuming t to be Hicks neutral and separable from K and L then (2.4) can be written as:

$$Y_t = A_t F(K_t, L_t) \qquad \textbf{(2.5)}$$

where A_t- the Hicks neutral technical change parameter- captures shifts in the production function over time at given levels of capital and labour.[6] The goal is to calculate A_t. Solow achieved this by employing a non-parametric index number approach. This freed him of the need to impose a specific functional form on the production function. To solve for A_t, the total (logarithmic) differentiation of (2.5) with respect to time is taken and both sides of the equation divided by Y_t. This yields:

[6] Hicks neutral technical change refers to shifts in the production function that leave marginal rates of substitution unchanged but increase or decrease the output attainable from given inputs.

$$\frac{\dot{Y}_t}{Y_t} = \frac{\dot{A}_t}{A_t} + \frac{\partial Y}{\partial K}\frac{K_t}{Y_t}\frac{\dot{K}_t}{K_t} + \frac{\partial Y}{\partial L}\frac{L_t}{Y_t}\frac{\dot{L}_t}{L_t} \qquad \textbf{(2.6)}$$

Equation (2.6) shows that the growth of real output can be apportioned into the growth rates of capital and labour, both weighted by their respective output elasticities, and the growth rate of the Hicksian efficiency parameter. The former represent movements along the production function, while the latter represents a shift of the production function.

Solow then assumed that each input is paid the value of its marginal product, that is:

$$\frac{\partial Y}{\partial K} = \frac{r_t}{p_t}; \frac{\partial Y}{\partial L} = \frac{w_t}{p_t} \qquad \textbf{(2.7)}$$

where r is the rental rate on capital, w is the wage rate and p the output price. Relative prices can therefor be substituted for the corresponding marginal products thus converting the unobservable output elasticities in (2.6) into observable factor income shares, S^K and S^L. The total differential (2.6) then becomes:

$$R_t = \frac{\dot{A}_t}{A_t} = \frac{\dot{Y}_t}{Y_t} - S_t^K \frac{\dot{K}_t}{K_t} - S_t^L \frac{\dot{L}_t}{L_t} \qquad \textbf{(2.8)}$$

In equation (2.8), R_t is the Solow residual- the residual growth in output not accounted for by growth in inputs- and the procedure is known as growth accounting.[7] The objective of growth accounting is to break down the observed growth in aggregate output into contributions from the growth of its constituent parts

[7] Nelson (1981) and Maddison (1987) provide comprehensive surveys of this methodology.

i.e. growth in factor inputs and technical change (TFP growth). Under the assumption of competitive equilibrium and small changes in the quantity of inputs and outputs, (2.8) is equivalent to Kendrick's measure of TFP growth (2.3).

In its continuous time formulation, (2.8) is equivalent to a Divisia index of productivity growth. The Divisia index is a weighted sum of growth rates, where the weights - denoted S^K and S^L in the above expression- are the shares of each factor payment in total output. Since economic data do not come in continuous time form, Solow made the assumption that the time derivatives could be approximated by discrete-time changes, thus enabling the calculation of (2.8). With the national accounts and other statistical sources providing estimates of all the right hand side variables in (2.8), the rate of total factor productivity growth can be easily obtained as a residual category. This results in a non-parametric index of productivity growth. It is non-parametric because there is no parametric functional form to estimate, and it is an index number by reason of the fact that it can be computed directly from prices and quantities.

In this framework, TFP growth is taken as being synonymous with technical change (at least in theory). However, the pioneers of this literature have always steadfastly questioned the notion of equating the TFP residual with "pure" technical change (see Kendrick, 1956; Abramovitz, 1956; Griliches, 1996). In fact for Abramovitz (1956), the residual is " a measure of our ignorance". This ignorance, argues Hulten (2000), covers many components: some wanted (like the effects of technical and organisation innovation), others unwanted (measurement error, omitted variables, aggregation bias, model mis-specification). Additionally, there is an alternative literature that argues, on the basis of frontier analysis, that TFP growth comprises not only of technical change but also technical efficiency change. In Chapter 5, we employ one of the methodologies proposed in this alternative literature to examine the role played by international trade in transferring foreign technologies and improving efficiency levels in developing countries.

The early detailed growth accounting exercises of a few advanced industrialised countries by Solow (1957) and Denison (1962, 1967) found that the rate of capital accumulation per person accounted for between one eight and one quarter of GDP growth rates in the U.S. and other industrialised countries (Western Europe and Japan), whereas TFP growth accounted for more than half of GDP growth in many countries. However, the overwhelming contribution to output growth attributed to TFP growth for the U.S. was questioned by Jorgenson and Griliches (1967). This resulted in both authors attempting to 'squeeze down the residual'. Their contributions resulted in a tightening of the theoretical link between productivity theory and its measurement as established by Solow.

In the next section we briefly examine the contributions of Jorgenson and Griliches (1967) and Diewert (1976) to the strengthening of the link between productivity theory and measurement in particular, and the evolution of productivity theory in general.

2.2.3 Refinements To The Solow TFP Framework

In an influential paper titled "*The Explanation of Productivity Change*", Jorgenson and Griliches (1967) hypothesised that careful measurement of the inputs entered into the production function should result in the disappearance of the Solow residual. The suggestion here is that a sizeable estimate of TFP growth only appeared because factor inputs, particularly capital, were incorrectly measured. Therefore, careful measurement and correct model specification should rid the residual TFP measure of unwanted components and explain the wanted ones (Hulten, 2000). Consequently, Jorgenson and Griliches incorporated several measurement innovations based on the neo-classical theory of production in the Solow framework. These innovations led to the almost total disappearance of the contribution of TFP growth to output growth in the U.S. and thus contradicted the findings of the previous studies that TFP growth accounted for over half of U.S. output growth.[8]

One of the main innovations introduced by Jorgenson and Griliches is the incorporation of neo-classical investment theory, developed by Jorgenson (1963), into productivity analysis.[9] In this framework, the quantities of capital and new investment are connected by the perpetual inventory method, where the stock of capital comprises the sum of past investments adjusted for deterioration and retirement. Therefore, in contrast to the undeteriorated "gross" capital stock concept used in some studies, Jorgenson and Griliches defined capital net of deterioration. Additionally, to ensure conformation to the accounting system implied by the strict logic of production theory, they measured output gross of depreciation. This approach conflicted with both Solow and Denison. The former, despite using gross output in Solow (1957), prefers net output on the basis that it is a better measure of welfare improvements arising from technical progress, while the latter proposed a measure of output net of depreciation. However, based on the Production Function

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[8] Jorgenson and Griliches's conclusion was challenged by Denison (1972) who also found TFP growth accounting for a significant proportion of economic growth. The exchanges between Denison and Jorgenson and Griliches resulted in the latter two authors conceding that they exaggerated their initial explanation on the relative contributions of TFP growth and growth in factor inputs (see Maddison, 1987).

[9] Hulten (2000) provides a detailed explanation of the methodology applied by Jorgenson and Griliches (1967).

Theorem espoused in Hulten (1973), gross output is decisively shown to be the appropriate output measure.

Further, in keeping with their aim to adequately measure inputs to the production process, Jorgenson and Griliches disaggregated the factor inputs into quality classes. For instance, capital was disaggregated by type and vintage while labour was disaggregated according to skill levels. By first recognising that these factor inputs are largely heterogeneous and then disaggregating them, Jorgenson and Griliches avoided the aggregation bias associated with internal shifts in the composition of the inputs. For example, the compositional bias due to a shift from long-lived structures to shorter-lived equipment in the capital stock, and the bias due to a shift towards a more educated and healthy labour force. Failure to account for these quality improvements in both capital and labour will lead to them being assigned to the residual. This represented another significant advance in the measurement of TFP.

To arrive at Equation (2.8), the Divisia index method was first consistently applied to the aggregation of the individual types of capital and labour into the corresponding sub-aggregate, and then applied again to reach the final formulation. To compensate for the fact that data are not continuous over time but come in discrete-time units, Jorgenson and Girlishness introduced a discrete-time approximation to the Divisia index derived from the Törnqvist index. In the Törnqvist approximation, the continuous-time factor income shares in (2.8), are replaced by the average between-period shares. Continuous-time growth rates are also replaced by differences in the natural logarithm of the variable (see Appendix 2.1).

Jorgenson and Griliches (1967) is credited with tying data development, growth accounting and production theory firmly together and as a result, cementing the link between production theory and growth accounting. This link was further strengthened by Christensen and Jorgenson (1969, 1970) who developed an entire income, product and wealth accounting system. Further, Maddison (1997) contends that the great virtue of Jorgenson's approach is that it helps to identify the locus of technical progress by showing in detail how productivity has changed in different sectors and branches of the economy.

Following the contributions of Jorgenson and associates to the continuous-time theory of the Solow residual, Diewert (1976) further improved on the link between the theory of productivity analysis and its measurement. Prior to Diewert's contribution, the choice among competing discrete-time approximations required for the operationalisation of Solow's continuous-time productivity model was based largely on computational expediency.[10] This suggested that the discrete-time approximation did not evolve as part of the theory and thus weakened the link between theory and measurement.

Diewert (1976), however, showed that the Törnqvist discrete approximation of the Divisia index used by Jorgenson and Griliches (1967) is an exact index number if the production function in Equation (2.4) is a translog function (see Christensen, Jorgenson and Lau, 1973). Simply put, the Törnqvist index is not an approximation, it is exact under the right conditions. Additionally, because the translog function is generally regarded as a good second order approximation to an arbitrary linearly

[10] Because there are many ways to approximate the Divisia index using discrete data, the method does not yield unique estimates of total factor productivity when applied to discrete economic data. See Hulten (2000).

homogeneous function, it is deemed to be 'flexible'. What this means is that the discrete-time Törnqvist index is a good choice even if the underlying production function is not translog; the degree of exactness in the index depending on how close the translog production function is to the true production function. Diewert referred to this aspect of the index as "superlative". Thus, as a result of work done in the area of "exact" and "superlative" index numbers, it has been shown that there is a unique correspondence between the type of index used to aggregate over outputs and inputs and the structure of the underlying technology.[11]

It is argued that as a consequence of Diewert's (1976) study, the index number approach of Solow (1957) to measuring TFP is not completely non-parametric (in the strict definitional sense). This is because there is a parametric production function underlying the method of approximation if the discrete time index is to be an exact measure of Hicksian efficiency.

Another refinement to Solow (1957) came out of the recognition that sectoral reallocation of resources constitute a key factor in productivity growth. This is because part of the growth process involves transferring resources from low to high productivity sectors, particularly from agriculture to industry, where capital-labour ratios are higher (Massell, 1961). Thus an increase in total productivity in some industries is usually accompanied by some retardation of existing industries and the appearance and growth of new ones (Nadiri, 1970).

[11] For instance, the Laspeyres indexing procedure, used in many of the earlier productivity studies, has been shown to be exact for a linear production function in which all inputs are perfect substitutes in the production process. On the other hand, the geometric index implies an underlying Cobb-Douglas specification for the production function.

Thus with the major contributions of Dale Jorgenson, Zvi Griliches and Erwin Diewert among others, the Solow 'residual' and the associated method of growth accounting has undergone considerable developments. This has presently resulted in a production theoretical approach to productivity measurement that provides a consistent and well-founded method that integrates the theory of the firm, index number theory and national accounts (OECD, 2001).

In the section that follows we review some studies that have utilised the index number growth accounting procedure for measuring TFP at the aggregate level, as a basis for making international comparisons and 'sources of growth' analyses.

2.3 EMPIRICAL STUDIES BASED ON INDEX NUMBER GROWTH ACCOUNTING PROCEDURE

There is a large literature on studies that have utilised index number growth accounting for calculating TFP at the national level, both for a single country and for small groups of countries. Islam (1999) classifies this literature into two broad categories: time-series and cross-section.

2.3.1 Time-Series Growth Accounting

Studies that fall into this category focus on the time series dimension of the data. They consist of two types: absolute and relative. The first type provides TFP comparisons between countries only in terms of growth rates, while the second provides TFP comparisons in both levels and growth rates. In the absolute form, time-series data of individual countries are analysed independent of the data of other countries. Growth rates of TFP are obtained within individual countries and are then compared and analysed. Implementation of the absolute form, therefore, does not require time-series data of different countries to be converted to a common currency. Early studies utilising the absolute form of time-series growth include Denison (1962, 1967) among others.[12] The sample sizes for these studies were quite small (between 5 and 9 countries) and comprised OECD countries.[13] As indicated earlier, these researchers generally found that the residual (TFP growth) accounted for a greater share of output growth compared to the growth in factor inputs.

Based on the several innovations introduced into growth accounting in the context of a single country (the U.S.) by Jorgenson and Griliches (1967), the methodology was extended for the purpose of making international TFP comparisons by Jorgenson and associates as well as by other researchers. Christensen, Cummings and Jorgenson (1980) compared the growth rates of TFP for the U.S. and its eight major trading partners for the period 1947-73.[14] Dougherty (1991) undertakes the same exercise for the OECD countries covered in Christensen et al. (1980), except for the Netherlands, but this time for the period 1960-90. That is, including the post-1973 slow productivity growth period (Table 2.1).

[12] see Norsworthy (1984) for a more detailed review.

[13] For example, Denison (1967) presented a comparison of TFP growth rates among Belgium; Denmark; France; Germany; Italy; the Netherlands; Norway; the U.K.; and the U.S.A.

[14] These were Canada, France, Germany, Italy, Japan, Korea, the Netherlands, and the U.K.

Table 2.1 : Selected Growth Accounting Results for Individual Countries

	Share of Capital in National Output	GDP Growth (%)	Share (%) Contributed by Capital	Labour	TFP
OECD 1947-73					
Canada	0.44	5.17	49	17	34
France	0.40	5.40	41	4	55
Germany	0.39	6.61	41	3	56
Italy	0.39	5.30	34	2	64
Japan	0.39	9.50	35	23	42
Netherlands	0.45	5.36	46	8	46
UK	0.38	3.70	47	1	52
U.S.	0.40	4.00	43	24	33
OECD 1960-90					
Canada	0.45	4.10	56	33	11
France	0.42	3.50	58	1	41
Germany	0.40	3.20	59	-8	49
Italy	0.38	4.10	49	3	48
Japan	0.42	6.81	57	14	29
UK	0.39	2.49	52	-14	52
U.S.	0.41	3.10	45	42	13
Latin America 1940-80					
Argentina	0.54	3.60	43	26	31
Brazil	0.45	6.40	51	20	29
Chile	0.52	3.80	34	26	40
Mexico	0.69	6.30	40	23	37
Venezuela	0.55	5.20	57	34	9
East Asia 1966-90					
Hong Kong	0.37	7.20	42	28	30
Singapore	0.53	8.50	73	32	-5
South Korea	0.32	10.32	46	42	12
Taiwan	0.29	9.10	40	40	20

Source: Barro and Sala-i-Martin (1995),Table 10.8; Easterly and Levine (2001),Table 1. For OECD, Christensen, Cummings, and Jorgenson (1980) and Dougherty (1991); for Latin America, Elias (1990); for East Asia, Young (1995).

In terms of studies covering developing countries, Elias (1990) conducts a rigorous growth accounting exercise for seven Latin American countries, while Young (1995) does the same for the fast growing East Asian newly industrialised economies (NIEs). The results from these exercises show large cross-country variations in the fraction of growth accounted for by TFP growth, though some general patterns emerge. TFP growth accounts for about half of output growth for the OECD countries while for Latin American countries, where the variation is greater, the average is 30 percent. In the case of the East Asian NIEs, the average contribution of TFP growth is much lower and indicates that factor accumulation is the key component of the growth miracle for some of these economies, notably Singapore.

For the *relative* form of time series growth accounting, data from different countries are first converted to a common currency, using either official exchange rates or exchange rates based on purchasing power parity (PPP). The converted data are then analysed with reference to a benchmark country or the mean of the sample. Therefore, the relative form of time-series growth accounting can give not only TFP growth rates within each country but also relative TFP levels. For the purpose of making international TFP comparison, this aspect of time-series growth accounting was initiated by Jorgenson and Nishimizu (1978) for a sample of two countries: U.S. and Japan. The procedure was later utilised by Christensen, Cummings and Jorgenson (1981) for the same sample of countries used in their earlier 1980 study. The difference in TFP between any two countries, say country X and the U.S., is approximated by a translog multilateral index of differences in productivity. This index, based on Caves, Christensen and Diewert (1982a), is transitive and base-country invariant (see Appendix 2.2). Dougherty and Jorgenson (1996, 1998) have since updated Christensen et al. (1981) and presented relative TFP level indices for the G-7 countries for the period 1960-89.

Time-series growth accounting (both absolute and relative) has also been employed to examine the openness (trade and foreign direct investment)-productivity relationship both for a single country and a group of countries. Generally, researchers employ a two-step procedure that involves measuring TFP by the non-parametric index number procedure at the first stage. The TFP estimates are then regressed as part of a parameterised function against hypothesised determinants of TFP (which include a measure of openness) at the second stage.[15] These studies however, mainly use disaggregated data (firm, plant and industry) and are frequently limited to a particular sector (usually manufacturing) [see Cameron, Proudman and Redding 1999; Keller 2000, 2001].

As a result of data constraints, the more sophisticated form of the time series measure of TFP undertaken by Jorgenson and others have generally been limited to a small sample of advanced capitalist countries. The level of factor disaggregation required for the incorporation of changes in the quality of human and physical capital, for example the division of labour and capital into their various types and respective compensation, means that most developing countries will invariably be excluded from studies using this framework for some time yet (Islam, 1999). This is because in most instances their data collection procedures are not standardised and do not allow for that level of factor disaggregation.

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[15] When the study involves a group of countries, TFP is usually measured based on the superlative Törnqvist multilateral index of Caves, Christensen and Diewert (1982a).

Cross-section growth accounting represents one alternative to surmounting the sample size limitation of the time-series method since it can be applied to a large cross-section of countries. We now examine this method for calculating TFP for a large number of countries.

2.3.2 Cross-section Growth Accounting

Hall and Jones (1996, 1997) suggest a cross-section index number approach for comparing TFP levels across countries. Methodologically, this approach is similar to time-series growth accounting only that it is applied along a cross-section dimension.[16] Hall and Jones employ this procedure for a large sample of 133 countries.

There are definite advantages to the cross-section index number procedure employed by Hall and Jones (1996). First, it does not impose a specific form of aggregate production function; only constant returns to scale and differentiability are required to arrive at the standard growth accounting equation. Second, the technique allows factor income shares to differ across countries which means that econometric estimation is not required to obtain the share parameters.

However, there are also some inherent weaknesses in the procedure. First, it requires prior ordering of countries and as such the TFP indices may be sensitive to the ordering chosen. The issue of the ordering of countries arises in the cross-section index procedure adopted by Hall and Jones (1996) because whereas in Solow (1957) differentiation (in practice differencing) is conducted in the direction of time (*t*), for

[16] see Islam (1999) for a detailed exposition of the cross-section methodology employed in Hall and Jones (1996).

Hall and Jones conduct it in the cross-sectional direction (i). While in time-series growth accounting there is no ambiguity regarding the direction in which t moves, in the cross-sectional case movement of i depends on the particular way the countries are ordered (see Islam, 1999). Second, the index is sensitive to the inclusion/exclusion of countries. Third, computation of country specific values of the (physical) capital share parameter is undertaken assuming a uniform rate of return across countries. With respect to this last assumption, Islam (1999) argues that empirical studies suggest that the hypothesis of uncovered interest parity (UIP) does not hold.

2.4 NON-STOCHASTIC AGGREGATE MEASURES OF TFP II: PARAMETRIC AGGREGATE GROWTH ACCOUNTING

As a result of the limitations of both variants of the index number growth accounting procedure, a simpler form of the growth accounting methodology has emerged in the post-1990 period: aggregate growth accounting.[17] Facilitated by the emergence of several large international cross-country data sets, this new variant of the growth accounting methodology provides a simple and transparent method to calculate economy-wide estimates of TFP for a large cross-section of countries over an extended period (Collins and Bosworth, 1996). Unlike the non-parametric growth accounting procedure, which assumes the existence of an aggregate production function, in this framework a functional form characterising the production technology across countries is explicitly specified. The functional form most widely employed is the Cobb-Douglas aggregate production function. The output elasticities

[17] We follow Easterly and Levine (2001) in referring to this particular branch of the growth accounting methodology as aggregate growth accounting to distinguish it from the detailed growth accounting exercises undertaken on a few countries.

of the factors inputs are then imposed either based on the share of the respective factor payments in national income or on microeconomic evidence. The values assigned to the factor elasticities are assumed to be same for all countries, thus implying identical production technology for all countries, and are fixed over time.

An early study employing this method is Elias (1993) who use World Bank data to estimate TFP for 73 countries. Later, Fischer (1993) used the Summers and Heston income data to estimate TFP growth for 68 countries, while Nehru and Dhareshwar (1993) used World Bank data, including their then recently constructed data set on physical capital stocks, to estimate TFP growth for 80 high income and developing countries. Both studies employ a Cobb-Douglas aggregate production function and both impose factor shares of 0.4 for capital and 0.6 for labour, respectively.[18] Since then, several other studies have employed this methodology for measuring TFP (growth and levels) for large numbers of countries. Among the most well known of these studies are Collins and Bosworth (1996), Klenow and Rodriguez-Clare (1997) and Hall and Jones (1999).

Collins and Bosworth also utilise a Cobb-Douglas production function but include human capital as an input. However, unlike Fischer (1993), human capital is not entered as a separate input but as a labour augmenting variable. That is, a variable which is the product of human capital and labour. The authors assigned a value of 0.35 for the capital elasticity and 0.65 for the elasticity of the quality adjusted labour input. Like Young (1992, 1994), Collins and Bosworth conclude that TFP growth in

[18] Fischer (1993) estimated two other sets of TFP growth rates. The first, which he termed Bhalla residuals, was derived from a panel regression using GLS. The second, termed Mankiw-Romer-Weil residuals, was derived using the non-stochastic growth accounting approach with equals weights of 0..333 for physical capital, labour and human capital imposed on the basis of coefficients used in Mankiw, Romer and Weil (1992).

East Asia was not particularly high when compared to other regions and that factor accumulation was more important than TFP growth as a source of output growth.

The studies of Klenow and Rodriguez-Clare (1997) and Hall and Jones (1999) depart in a fundamental way from previous aggregate growth accounting exercises. Klenow and Rodriguez-Clare (1997) follow Mankiw, Romer and Weil (henceforth MRW, 1992) in specifying the production function as:

$$\frac{Q}{L} = A\left(\frac{K}{Q}\right)^{\frac{\alpha}{1-\alpha-\beta}}\left(\frac{H}{Q}\right)^{\frac{\beta}{1-\alpha-\beta}} \qquad \textbf{(2.9)}$$

where Q is output, K and H are stocks of physical and human capital, L the number of workers, α is the elasticity of physical capital and β the elasticity of human capital. Like MRW (1992) they also set the elasticities of physical and human capital to be 0.30 and 0.28 respectively.[19]

In (2.9), technical change (TFP) is conceived as being Harrod neutral instead of Hicks neutral as in previous growth accounting studies. In justifying this specification, Klenow and Rodriguez-Clare argue that it allows them to take into account the natural effect of higher TFP on the capital-labour ratio (which increases to keep the return on capital at its steady state equilibrium level) and therefore attribute the whole effect (i.e. higher TFP plus the resulting higher capital-labour ratio) to higher productivity. Based on this specification and additional data on educational attainment compared to the MRW study, they estimated very high TFP

[19] Klenow and Rodriguez-Clare admitted to being uncomfortable with a value of 0.28 for the elasticity of human capital but used this figure as well as the value of 0.30 for the elasticity of physical capital for purposes of comparison with the MRW (1992) study. They subsequently showed how the

growth rates for the East Asian economies, particularly Singapore, for the 1960-85 period.[20]

Hall and Jones (1999) also followed MRW (1992), and Klenow and Rodriguez-Clare in writing the decomposition of output per worker in terms of the capital-output ratio instead of the capital-labour ratio; albeit with a slightly different specification. They focus on TFP levels rather than growth and use cross-section data to undertake their analysis. Both Klenow and Rodriguez-Clare (1997), and Hall and Jones (1999) find productivity differences rather than differences in input intensities to be the main source of the large international dispersion in the levels and growth rates of output per worker.

While providing a simple and transparent framework for measuring TFP and decomposing output growth into its proximate sources, the aggregate growth accounting framework suffers from one major limitation. By imposing common parameters of the production function for all the countries, the method implicitly assumes that the production technology is identical across countries.[21] However, this parameter homogeneity assumption appears not to be supported by empirical evidence. For instance, despite imposing a common capital coefficient of 0.35 for their sample of countries, Collins and Bosworth (1996) indicate that there is considerable evidence that the capital elasticity is higher in developing economies than in industrial economies. Collins and Bosworth's claim thus suggest that

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contributions of the respective factor intensities and the technology parameter vary with higher values of the shares of the factor inputs.

[20] The authors also estimated the level of TFP in 1985 (relative to the U.S.) for the remaining 97 countries in their sample.

[21] Although the detailed growth accounting procedure employed by Jorgenson and his associates, and the cross-section growth accounting method employed in Hall and Jones (1996) allow factor shares to vary across countries, their limitations in other respects have already been stated.

previous studies employing the aggregate growth accounting approach may have overestimated TFP growth for developing countries by imposing too low a value for the output capital elasticity.

Further, recent evidence provided by growth econometricians has not supported the common parameter assumption in growth regressions. For instance, notwithstanding the use of different methodologies, Durlauf and Johnson (1995), Canova (1999), Durlauf et al. (2001) and Masanjala and Papageorgiou (2004) among others, find strong evidence of parameter heterogeneity across countries. As a result of these findings, the implicit assumption that countries with wide differences in social, political and institutional characteristics fall on a common surface and thus have the same Cobb-Douglas aggregate production function seems questionable.[22]

In addition to the specific shortcomings outlined above for each growth accounting method, some of the theoretical and methodological assumptions upon which non-stochastic (both non-parametric and parametric) growth accounting relies are increasingly questioned in the growth literature. We critically review these assumptions in the following section. Since our main interest in the growth accounting methodology is in terms of its suitability for measuring TFP growth for a large cross-section of countries, we limit our discussion to the factors that are likely to affect the measurement of TFP growth.[23]

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[22] Harberger (1987) had long asked "What do Thailand, the Dominican Republic, Zimbabwe, Greece, and Bolivia have in common that merits their being put in the same regression analysis?".
[23] For a more detailed critique of the growth accounting methodology see Nelson (1981) and Felipe (1999) and the references contained in both articles.

2.5 LIMITATIONS OF NON-STOCHASTIC GROWTH ACCOUNTING METHODOLOGY

Some of the key underlying assumptions of the non-stochastic growth accounting methodology for measuring economy-wide TFP have come under increasing scrutiny in both the theoretical and empirical growth literatures. For instance, when the values of the factor shares are determined on the basis of the remuneration of each factor as a share of total output, one typically assumes perfect competition, constant returns to scale and the absence of externalities. These assumptions have however been convincingly challenged by the 'new' growth theorists (Temple, 1999). Instead, 'new' growth theory proffers a framework in which markets are non-competitive, the production function exhibits increasing returns to scale, externalities among micro-units are important, and innovation is endogenous to the economic system.

Additionally, econometric studies have raised doubts over the plausibility of the assumptions of perfect competition (and thus marginal cost pricing) and constant returns to scale in the strict Solow (1957) model and the modified framework of Jorgenson et al. For instance, Hall (1988, 1990) find evidence of large mark-ups and significant increasing returns to scale in many U.S. industries.[24] The Solow residuals (TFP estimates) were also found to be pro-cyclical which negated the assumption of Hicks-neutral technical progress. Hall's findings demonstrate that in the presence of imperfect competition the residual leads to a biased estimate of the Hicksian shift parameter. Additionally, when the assumption of constant returns scale is not

[24] Caballero and Lyons (1990) also find strong evidence of increasing returns to scale in manufacturing for Germany, France, Britain and Belgium thus indicating strong externalities. However, the evidence at the economy-wide level is less clear (see Benhabib and Jovanovic, 1991).

satisfied, conventional indices of TFP include not only the effects of technical change but also the effects of non-constant returns to scale.[25]

If markets are not perfectly competitive, price will be greater than marginal cost and output elasticities will not equal their respective factor shares. Therefore, using the latter to weight the growth rates of factor inputs is questionable. This is particularly true when the sample involves a large number of developing countries where factor markets are usually highly distorted (see Balassa, 1988a). This view appears to be shared by Stiglitz who asks: "Does anyone who has studied wage setting in Singapore, for example, really believe that wages are set in a competitive process, so that the real wage equals the marginal product of labour as most of the studies assume?" (Stiglitz, 1997; p.16).

Another limitation of the non-stochastic growth accounting framework is its ability (or lack of it) to deal with problems posed by the possible endogeneity of factor inputs and TFP. Since factor inputs are decision variables, firms may respond to shocks by altering their use of some or all of their inputs. This suggests that causation may also run from output to inputs. Therefore, one cannot use the non-stochastic growth accounting methodology to elucidate a causal story (Easterly and Levine, 2001). Further, increases in TFP are likely to lead not only to output growth but also an induced growth in factor inputs, particularly physical capital (Barro and

[25] Hulten (2000) argues that the Solow model is not inextricably linked to the assumption of constant returns to scale. According to him, constant returns to scale is only needed for estimating the return to capital as a residual in the framework proposed by Jorgenson and Griliches (1967). Further, Caves, Christensen, and Diewert (1982a,b) argue that the Törnqvist index numbers are also superlative for some very general production structures including those which are non-homogeneous and exhibit non-constant returns to scale.

Sala-i-Martin, 1995). This makes it difficult to separate out the 'true' contributions of TFP growth and factor accumulation to output growth.

The seeming inability of the traditional growth accounting methodology to effectively separate out the contributions of the proximate determinants to observed output growth is one of the central issues in the debate on the factor(s) responsible for the phenomenal growth rates enjoyed by some East and South-East Asian countries in the post 1960 period (see Sarel, 1997; Felipe, 1999; Rodrigo, 2001). In response to the conclusion by Young (1992, 1995), Kim and Lau (1994) and Krugman (1994) that the spectacular growth rates enjoyed by these economies were driven mainly by capital accumulation and that the contribution of TFP growth was negligible, Nelson and Pack (1999), Hulten and Srinivasan (1999) and Hulten (2000) among others argue that the traditional growth accounting methodology employed in the above studies underestimates the true contribution of TFP growth to economic growth in East and South East Asia. They contend that the role played by TFP growth is actually larger and the savings/investment effect is proportionately smaller.

Hulten (2000) attributes the underestimation to the fact that the neo-classical growth models of Solow (1956), Cass (1965) and Koopmans (1965) produce a very different conclusion about the importance of technical change as a cause of economic growth to Solow's (1957) TFP model. He notes that whereas in the neo-classical growth models capital formation explains none of the long-run steady state growth in output because capital is itself endogenous and driven by technical change, the TFP model in contrast treats all capital formation as a wholly exogenous explanatory factor.[26]

[26] Hulten (2000) points to the fact that in the neo-classical growth models technical innovation causes output to increase, which increases investment, which results in an expansion in the stock of capital.

Consequently, the latter model tends to overstate the role of capital and understate the role of innovation in the growth process (see Hulten, 1975). Hulten argues that some part of the observed rate of capital accumulation is a TFP-induced effect and thus should be counted along with TFP in any assessment of the impact of innovation on economic growth. Therefore, only the fraction of capital accumulation arising from the underlying propensity to invest at a constant rate of TFP growth should be recorded as capital's independent contribution to output growth.

As an alternative, he proposes the use of the closely related Harrod-Rymes variant of the TFP residual instead of the conventional Hicksian approach. Whereas the latter measures the shift of the production function along a constant capital-labour ratio, the Harrodian concept of TFP measures the shift along a constant capital-output ratio. By holding the capital-output ratio constant when costless innovation occurs, the Harrodian measure attributes part of the observed growth rate of capital to the shift in the production function. In this framework, only capital accumulation in excess of the growth rate of output is counted as an independent impetus to output growth. The Harrodian approach thus allows for the induced-accumulation effect to be counted as part of TFP.[27]

Hulten and Srinivasan (1999) utilised this correction procedure for the same East Asian economies studied by Young based on the index number framework. They demonstrated that subtracting the contribution of the growth in the capital-labour ratio from growth in output per worker yielded an underestimate of the technological

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This induced capital accumulation is therefore a direct result of TFP growth and, in steady-state growth all capital accumulation and output growth is due to TFP.

[27] Hulten (1975) demonstrates that when the innovation is of the Harrod-neutral form, i.e. if the relative inputs shares remain unchanged for a given capital/output ratio, the accounting is exact. Otherwise the Harrodian correction is approximate.

change parameter. Whereas the conventional Hicksian TFP accounted for approximately one third of output growth in Hong Kong, South Korea, and Taiwan for the period 1966-1990/91, the Harrodian TFP measure accounted for nearly 50%. As indicated above, Klenow and Rodriguez-Clare (1997b) employed the Harrodian concept of technical change in measuring TFP growth for a large number of countries.

Finally, in the non-stochastic framework it is impossible to account for measurement errors or deal with outliers other than by an adhoc trimming of the data. In the section that follows we make a case for the econometric estimation of the parameters of the aggregate production function.

2.6 ECONOMETRIC ESTIMATION AS AN ALTERNATIVE METHODOLOGY

As a result of the limitations and/or weaknesses of the non-stochastic growth accounting methodology in general and individual measures in particular, we propose a stochastic approach to the measurement of TFP growth as an alternative. In this framework, the parameters of the aggregate production function are econometrically estimated rather than imposed. The estimated parameters are then used to estimate TFP growth as a Solow residual.

Direct estimation of the aggregate production function offers some advantages over the non-stochastic approach. First, by econometrically estimating the output factor elasticities instead of imposing them, we are not compelled to postulate a relationship between the output elasticities of the different factors and their income shares that may or may not exist in reality. For instance, there is no *a priori* requirement to assume competitive pricing behaviour on the part of economic agents or to assume constant returns to scale.[28] Further, econometric estimation offers the opportunity to directly test some of the assumptions made in the non-stochastic framework against alternative hypotheses.

Second, by directly estimating the production function we can allow for parameter heterogeneity and thus relax the assumption of identical technologies across countries, which one is constrained to adopt in the context of non-stochastic aggregate growth accounting.[29] When the parameter homogeneity assumption is not supported by the data, parameter estimates will be inconsistent.

According to Masanjala and Papageorgiou (2004), parameter heterogeneity in growth regressions has at least three possible interpretations: (a) Growth process nonlinearities i.e. in a cross-country growth regression, countries are characterised by different coefficient estimates. They cite the multiple steady state theoretical models of Azariadis and Drazen (1990); Durlauf (1993); and Galor and Zeira (1993) which suggest that parameters of a linear growth regression will not be constant across countries, as offering support for this interpretation. (b) The induction of nonlinearities which may result in multiple steady states and poverty traps when omitted growth determinants are introduced in the standard Solow model (see Durlauf and Quah, 1999). (c) Nonlinearity of the production function. The suggestion is that the identical Cobb-Douglas aggregate production function - a necessary condition for the linearity of the Solow growth model - may be

[28] At a more disaggregated level of analysis both non-competitive pricing and non-constant returns to scale can be incorporated into the measurement of TFP (see Harrison, 1994; Kim, 2000).

inappropriate and therefore, an alternative functional form may be able to explain parameter heterogeneity.

In this chapter we adopt the first interpretation. Various ways have been suggested in the literature for dealing with parameter heterogeneity. The suggestions fall within two broad classes: (a) the utilisation of estimators that allow for heterogeneity; (b) attempt to model the heterogeneity using information contained in other variables. Both suggestions will be taken up in this thesis. The first suggestion will be pursued in this chapter, while the second will be pursued in Chapter 4 where we attempt to model the nature of the heterogeneity in the openness-TFP growth relationship.

With respect to estimation techniques that allow for parameter heterogeneity, Pesaran and Smith (1995) advocate the use of separate group (individual) regressions once the time period is long enough to make it sensible, and the parameter of interest is the average effect of some exogenous variable on a dependent variable. They argue that in a static model, undertaking such a procedure (i.e. separate regressions for each group) and then averaging the coefficients over groups will yield consistent (and unbiased) estimates of the coefficient means as long as N and T tend to infinity.[30] They refer to this estimator as the mean group estimator. As will be explained later in this chapter, it is a variant of this estimator that we employ to derive our preferred measure of TFP growth.

Third, the implicit assumption of exogeneity of the factor inputs that underlies non-stochastic approaches to TFP measurement can be explicitly tested against the

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[29] Parameter heterogeneity may be a manifestation of measurement error and is also a special case of model misspecification (see Temple, 1998).

alternative assumption of endogeneity. As indicated earlier, because economic agents may vary their factor inputs in response to changes in output, then causality may run not only from the former to the latter but also vice versa. In examining the issue of endogeneity, Benhabib and Spiegel (1994) conclude that the coefficients of physical and human capital probably overestimate their effects while the coefficient of labour probably underestimate its effect. Through the use of instrumental variable (IV) estimation however, it is possible to control for this potential simultaneity problem and in the process derive consistent parameter estimates. It is a variant of this estimator we employ in this chapter.

Finally, for panel estimations one can use the cross-country and time-series variations in the data, as well as control for country and time specific effects, to determine the parameter estimates of the production function.

While being able to overcome some of the limitations inherent in the non-stochastic growth accounting approaches, direct estimation of the aggregate production function poses econometric challenges and potential pitfalls of its own. For example, unlike the non-parametric growth accounting measure of TFP, econometric estimation requires a specified functional form of the aggregate production function. However, it is possible that the functional form chosen may not be an appropriate representation of the underlying production technology thus leading to specification bias. This problem is more acute when the functional form specified is fairly restrictive, such as the Cobb-Douglas.

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[30] According to Pesaran and Smith (1995), the regressors must be strictly exogenous; the coefficients must differ randomly; and be distributed independently of the regressors across all groups.

Second, the use of IV estimation to address likely simultaneity bias due to possible endogenous factor inputs requires one to find suitable variables to instrument the suspected endogenous regressors. This is not always a straightforward task since there is generally a shortage of good instruments for factor inputs (see Griliches and Mairesse, 1995).

Third, there are challenges posed by measurement error introduced by data on some variables, particularly for developing countries, and "unrepresentative" observations that may act as influential outliers or leverage points. With regard to variables measured with error, the data on capital stock is frequently singled out in this regard. Since the investment series for many developing countries are not available before the late 1950s, the initial stock of physical capital, required for the computation of the capital stock series, is likely to be no more than an educated guess (see Temple, 1999).

These potential pitfalls and challenges notwithstanding, the benefits of econometrically estimating the parameters of the production function are, in our view, greater than the minuses. Additionally, the effects of problems such as measurement error in the data and outliers on the regression results can themselves be minimised through the use of econometric techniques. Moreover, the extent of the problem can be judged only by empirical analysis. Consequently, we choose this approach for measuring TFP growth instead of the non-stochastic methodology.

2.6.1 Review of Literature Using Econometrics to Measure Aggregate TFP

Here we briefly review some studies that undertake a direct estimation of an aggregate production function (or a steady-state equation) to generate economy wide measures of TFP either as part of a 'sources of growth' analysis, for making international TFP comparisons or for determining the factor (s) that explain cross-country differences in TFP.

To complement his earlier non-parametric growth accounting inquiry into the sources of growth in East Asia, Young (1994) uses cross-section data to estimate a Cobb-Douglas production function of the growth in output per worker on a constant and capital per worker for 118 countries for the period 1970-85. The residual for each country is taken as a measure of the growth of TFP (over and above the world average) in that economy. Consistent with his results in Young (1992), Young finds TFP growth in Hong Kong to be relatively high while in Singapore TFP growth was non-existent. His findings led him to conclude that TFP growth in other East and South East Asian countries had not been higher than in many other regions of the world.

In contrast, Kim and Lau (1994) use a regression procedure termed the meta-production function approach. A meta-production function is the common underlying production function that can be used to represent the input-output relationship of a given industry in all countries. The procedure amounts to estimating a pooled cross-section and time series regression for several countries. Kim and Lau (1994) pool data from the G-5 countries (U.S., Japan, Germany, France, and UK) and four East Asian newly industrialised economies (Singapore, Taiwan, South Korea, and Hong Kong) using data from the mid 1960s to 1990. They argue that in contrast to growth accounting, their method has the primary advantage of not depending on the assumptions of constant returns to scale; neutral technical progress; and profit maximisation with competitive output and input markets. They directly test these assumptions by fitting a translog production function and proxying technical efficiency by a time trend. Three of their main findings are: (i) all nine countries share the same aggregate meta-production function, with factor augmenting technical progress; (ii) the standard assumptions upon which growth accounting rests (as detailed above) were rejected and (iii) the hypothesis of zero technical progress is rejected for the G-5 countries but not the four East Asian NIEs. Based on the latter finding, Kim and Lau conclude that exogenous technological progress is unimportant as a source of growth for the four East Asian NIEs (see Felipe, 1999).

Islam (1995) uses panel data methods to estimate a steady state equation based on the Cobb-Douglas production function used in MRW (1992). Allowing for transitional dynamics, Islam then calculates relative TFP levels for the sample of 96 countries used in the latter study. He contends that the efficiency (TFP) index recovered from this exercise is very close to, though not exactly the same as, the conventional measure of TFP derived from growth accounting. In a later study (see Islam, 1999), Islam compares the TFP estimates obtained in Islam (1995) with those obtained in Hall and Jones (1996) and finds that both sets of TFP estimates are similar in terms of countries ranked at the bottom of the list than at the top. He attributed the differences to the fact that the two studies used different methodologies for estimating TFP. Whereas the TFP levels in Islam (1995) are generated on the basis of a panel regression for the period 1960-1985, the TFP levels in Hall and Jones (1996) are generated based on cross-section growth accounting for a single year - 1988.

With regard to the studies examining the openness-TFP nexus, researchers have used both panel and time-series estimation techniques to estimate the factor shares (elasticities) of the aggregate production function. In most of these studies, the estimates are then used to compute TFP as a residual in the manner of Solow (1957). The TFP estimates are then regressed against measures of trade openness and/or other socio-economic variables hypothesised as explaining cross-country variations in TFP.[31] For example, both Edwards (1998) and Miller and Upadhyay (2000) employ panel regression techniques to estimate the output factor elasticities of a Cobb-Douglas production function, which they later use to derive TFP estimates for large samples of countries. Both studies also control for country and time/period specific effects on output. However, whereas Edwards captures time invariant country-specific effects using a random effects model in growth rates, Miller and Upadhyay estimate a fixed effects model in levels. Additionally, in contrast to Edwards who assumes constant returns to scale, Miller and Upadhyay allow for non-constant returns to scale.

Although Miller and Upadhyay (2000) recognise the possibility that physical and human capital may be endogenous, since both factors are accumulated over time, both they and Edwards failed to address this possibility. Moreover, since the main focus of both studies is on the relationship between trade openness and TFP, the discussion and figures relating to individual country TFP estimates are quite limited.

In contrast to the panel estimations employed by Edwards (1998) and Miller and Upadhyay (2000), Senhadji (2000) estimates single country time-series OLS regressions for 66 countries. By adopting this method, he thus relaxes the parameter homogeneity and, by extension, the identical technology assumption implied by panel estimation. He assumes however that the production function is identical for

[31] Our review of these studies will focus mainly on issues pertaining to the measurement of TFP rather than the second stage analysis of the determinants of cross-country differences in TFP. The latter being the concern of subsequent chapters.

countries within the same region. Consequently, Senhadji divides the sample of countries into regions and uses the average of the individual country estimates for countries within a given region to obtain parameter estimates for that region. The regional parameter estimates (factor shares) are then used to derive estimates of TFP levels for countries within each region.

Senhadji employs a Cobb-Douglas production function with capital and skill-augmented labour (the product of an index of human capital and the labour force) as the inputs and assumes constant returns to scale. Given his preference for analysing the determinants of cross-country differences in TFP levels rather than growth rates, he first checks for nonstationarity of the data. Further, unlike the previous studies reviewed in this section, Senhadji controls for the possible endogeneity of the two factor inputs using the Fully Modified OLS estimator. He obtains values for the share of physical capital in output that are significantly higher (the average is 0.55) than the usual values of 0.33 to 0.40 employed in non-stochastic aggregate growth accounting exercises. Senhadji's other main findings include the convergence of TFP levels across countries, the low TFP performance of Africa, and evidence that the engine of growth in East Asia has been capital accumulation rather than TFP growth.

The final study reviewed in this section is that of Nehru and Dhareshwar (1994). Using World Bank data (the same data set used in this chapter), the authors derive alternative estimates of TFP growth for a large cross-section of countries on the basis of different estimation methods. Estimates of TFP growth derived from the estimation of an error correction model were chosen as the preferred estimates from among the alternatives. Specifically, Nehru and Dhareshwar estimate a Cobb-

Douglas production function in levels and apply the Engle-Granger cointegration test using a short run error correction model.

Among their main findings, the authors find that the lower the initial GDP per capita in 1960 (relative to the U.S.) the higher the variation in TFP growth performance between 1960-87. Second, in contradiction of previous results, TFP growth in the better performing high income countries is not much worse than the better performing low and middle income countries. The authors argue that once the more rapid growth in human capital in developing countries is taken into account, the difference in TFP growth with the developing world seems to diminish. Finally, countries that experienced the fastest per capita GDP growth over the period (Japan, Korea, Singapore and Thailand) appear to have achieved this more on the basis of rapid factor accumulation than TFP growth. Countries that maintained growth rates of around 3.5-4.5% tended to have the highest rates of TFP growth.

2.7 TFP GROWTH: MEASUREMENT AND ESTIMATION METHODOLOGY

2.7.1 Model Specification, Estimating Equations and Data

In this section we detail the estimation methodology, specify the estimating equations and describe the data (sources) for measuring TFP growth at the economy-wide level for a large cross-section of countries. Since we have data on capital stocks (see Nehru and Dhareshwar, 1993), our preferred approach is to directly estimate the production function rather than a model that approximates around the steady state like MRW (1992). There are two advantages to pursuing this approach. First, the absence of an unobservable initial efficiency term in the estimating equation from the beginning negates any possibility of spurious correlation resulting from its subsequent omission. Second, one can estimate a static rather than dynamic model thus obviating the need for more complex estimators (Temple, 1999).

To keep things simple, we follow previous studies in this literature and assume that the production technology for each country is captured by a Cobb-Douglas aggregate production function of the form:[32]

$$Y = AK^{\alpha}L^{\beta}, \quad 0 < \alpha < 1; 0 < \beta < 1 \qquad \textbf{(2.10)}$$

where Y is real GDP, K is physical capital stock, L is labour (proxied by the working age population between 15 and 64), A is a measure of total factor productivity, and α and β are output elasticities with respect to physical capital and labour respectively.

There are conflicting views over the role of human capital in economic growth. MRW (1992) advocate the inclusion of human capital as a separate term in the production function. On the other hand, Benhabib and Spiegel (1994), Islam (1995) and Pritchett (2001) argue that human capital influences growth indirectly through its effect on TFP. We empirically investigate these two competing arguments in this thesis. In this chapter we follow Griliches (1969) and MRW (1992) [see also Edwards, 1998; Miller and Upadhyay, 2000] and allow for possible complementarity between human and physical capital by including the former as a separate input in the production function. In the subsequent chapter, we examine the alternative claim

32 Mindful of the fact that questions have been raised by some researchers (e.g. Duffy and Papageorgiou, 2000; Massanjala and Papageorgiou, 2004) over the suitability of this functional form to explain cross-country growth regularities, we estimate the more flexible translog production function (Chapter 5) to determine the role of trade and trade policy openness in facilitating technological spillovers and efficiency improvements in developing countries.

by including human capital as one of the possible factors explaining cross-country differences in TFP growth.

When human capital stock (H), proxied by the average years of total schooling, is entered as a separate variable, the production function becomes:

$$Y = AK^{\alpha}L^{\beta}H^{\gamma}$$
$$0 < \alpha < 1; 0 < \beta < 1; 0 < \gamma < 1 \qquad \textbf{(2.11)}$$

Taking logs and totally differentiating (i.e. first differencing) both sides of equations (2.10) and (2.11) and adding an error term, yields our two estimating equations, (2.12) and (2.13), respectively.

$$d\log Y_{it} = d\log A_{it} + \alpha d\log K_{it} + \beta d\log L_{it} + \varepsilon_{it} \qquad \textbf{(2.12)}$$

$$d\log Y_{it} = d\log A_{it} + \alpha d\log K_{it} + \beta d\log L_{it} + \gamma d\log H_{it} + \varepsilon_{it} \qquad \textbf{(2.13)}$$

where the variables Y, K, L and H are now expressed as growth rates; i indexes countries; t indexes time; ε is the error term; α, β remain as defined above and γ is the elasticity of output with respect to human capital. We estimate (2.12) for a sample of 93 developed and developing countries (see appendix for the list) for the period 1960-1990, and (2.13) for a reduced sample of 83 countries for the period 1960-1987. All the data used in estimating the production functions are taken from the World Bank's STARS database (World Bank, 1993). This database contains data on GDP, physical and human capital stock, and the working age population for 93 developed and developing countries from 1950-1990.[33]

There is a suggestion (see Temple, 1999) that the unobservable TFP growth variable ($d\log A_{it}$) in the above equations should be replaced by some function of observables to avoid biasing the factor share estimates. Some researchers investigating the relationship between trade openness and growth have adopted this approach. Examples include Harrison (1996) and Söderbom and Teal (2001). In both of these studies the authors explicitly model the technology variable (TFP) as a function of trade policy openness. Miller and Upadhyay (2000) argue however that such studies treat all determinants of output growth as inputs, which may be conceptually inaccurate since many included determinants may only affect output indirectly. In their view, since these additional determinants affect the efficiency of real inputs such as capital and labour they are in effect direct determinants of TFP. They therefore adopted the two-step approach to calculating TFP. As stated previously, this is the approach adopted in this chapter. In Chapter 5, where the methodology employed explicitly recognises the two components of TFP change – technical change and efficiency change – we follow the approach adopted in Harrison (1996) and Söderbom and Teal (2001), albeit using a different estimation methodology.

Choosing a method of estimating (2.12) and (2.13) to obtain unbiased and consistent parameter estimates presents something of a dilemma. Should we ignore the empirical evidence of widespread parameter heterogeneity in cross-country growth regressions and employ panel data estimation methods that assume parameter homogeneity? Conversely, should we follow the recommendation of time series

[33] Data on human capital are provided for 83 countries from 1960-1987.

econometricians and estimate the parameters of the production function individually by running a separate time series regression for each country? Or still yet, should we employ a 'hybrid' procedure that combines both the heterogeneity and homogeneity assumptions? Our preference is for the third option.

The justification is that while we concede that the parameter homogeneity assumption seems implausible in the face of strong empirical evidence to the contrary (Pesaran and Smith, 1995; Mairesse and Griliches, 1990), we equally concede that in order to make comparisons between countries and draw inferences from them on the basis of cross-country regressions, then there must be something(s) in common among some of the economies (see Solow, 2001). We argue that the common factor is identical production technology parameters within regions. These parameters are however, assumed to be different between regions. Our assumption represents a middle ground between the extreme assumptions of complete heterogeneity and complete homogeneity of the production parameters. In other words, the world is neither completely heterogeneous nor completely homogeneous. This assumption has some support in the finding of Koop et al. (2000), that most of the variation in technical efficiency is between regional groupings rather than within them.

Maddala et al. (2001) recently expressed a similar sentiment in the context of the ongoing debate regarding the performance of homogeneous estimators versus their heterogeneous rivals (see Robertson and Symons, 1992; Pesaran and Smith, 1995; Baltagi et al. 2000). They argue that individual cross-section estimates imply that all cross-sectional units are different while pooled (panel) estimations suggest that they are all identical. However, in their view, the truth is perhaps somewhere in between these two extremes with the parameters having some common elements. As an alternative, Maddala et al. argue in favour of shrinkage estimators that shrink the individual country estimates towards the pooled mean estimates.[34]

Although the motivation is similar, the method that we employ is far simpler than the shrinkage Bayesian type estimators proposed by Maddala et al. (1997, 2001). In fact, it is based on the principle of the mean group estimator advocated by Pesaran and Smith (1995). However, instead of using the parameter estimates from the individual countries to calculate the overall average response of the capital and labour output elasticities as suggested by Pesaran and Smith, we calculate the mean output factor elasticities by region. The regional factor elasticities are then used to estimate TFP growth rates for the countries that comprise each of the six different World Bank regions (see Appendix 2.3 for country listings): Industrial countries (INDUS), East Asia (EASIA), South Asia (SASIA), Sub-Saharan Africa (SSA), Latin America and the Caribbean (LAC) and Middle East and North Africa (MENA).[35]

As indicated previously, Senhadji (2000) adopted a similar method in conducting a growth accounting exercise for 66 countries. However, although the method employed in this thesis is similar to that employed by Senhadji, there are some differences between the two studies. First, our focus is on TFP growth whereas Senhadji focuses on TFP levels. Second, the estimation procedures employed by Senhadji differ from those employed in this chapter. Finally, the specification of the Cobb-Douglas production function differs across the two studies. Whereas human

[34] Another intermediate estimator recently proposed in the literature is the pooled mean group estimator. This estimator constrains the long-run coefficients to be identical but permits the short-run coefficients and error variances to differ across groups (see Pesaran, Shin and Smith, 1999).
[35] These are the same six regions used in Collins and Bosworth (1996).

capital is entered as a separate variable in our estimating equations, it is entered as a labour augmenting variable in Senhadji's specification.

Notwithstanding our arguments in favour of the augmented mean group estimator for deriving cross-country estimates of TFP growth, we recognise that there are some researchers who have either found the performance of heterogeneous estimators less satisfactory when compared to rival homogeneous panel estimators based on different performance criteria (Baltagi and Griffin, 1997; Baltagi et al., 2002), or point to pitfalls associated with the single country time series regression option (Temple, 1999). For example, in terms of performance criteria, Baltagi and Griffin (1997) and Baltagi et al. (2002) find wide variability in the parameter estimates yielded by individual group regressions as well as theoretically implausible results for some groups based on the estimation of a dynamic demand function.[36] They argue that the efficiency gains from pooling are likely to more than offset the biases resulting from individual heterogeneity.

Temple (1999) also advocates the use of panel data methods to estimate (2.12) and (2.13) rather than single country regressions using annual data. He suggests that problems posed by data quality from developing countries and the likelihood of short-run business cycle effects driving apparent long-run correlations due to the limited time span of data make the arguments in favour of such an approach less than compelling. Additionally, despite their reservations of the coefficient homogeneity assumption, Pesaran and Smith argue that panel estimators will also yield consistent (and unbiased) estimates for a static model.

In light of the above arguments combined with our own arguments in favour of the augmented mean group measure for deriving TFP estimates, we employ two alternative approaches. First, in recognition of the potential pitfalls in estimating single country regressions identified by Temple (1999), we compare the plausibility of the TFP growth estimates derived from both unconstrained and constrained estimations of Equation (2.11) with estimates derived by other researchers. However, in doing so we make allowance for the fact that we are using a more unconventional method to estimate TFP growth. This approach may also help us to determine whether a balance needs to be struck between empirics on the one hand and economic theory on the other. In many ways the evaluation of the performance of heterogeneous type estimators is similar in spirit to Baltagi and Griffin (1997).

Second, we also employ panel data methods to estimate the parameters of the two estimating equations specified in this section. These estimates will also be used to derive alternative estimates of TFP growth for the sample of countries. These TFP estimates are therefore derived based on the extreme assumption of complete homogeneity in the production parameters across countries.

2.7.2 Estimation Results: Heterogeneous Estimators

In this section we present the results from the individual country time series regressions for both the unconstrained and constrained models. To control for the possible endogeneity of the factor inputs, we first employed instrumental variable two stage least squares (IV2SLS) time series estimation for each country and then

[36] Both studies also examined the forecast performance of various heterogeneous and homogeneous estimators over one, five and ten year horizons.

tested for the exogeneity of the regressors using a Wu-Hausman F-test.[37] For the unconstrained estimation of the production function, the null hypothesis of exogeneity of the regressors could not be rejected for most of the countries (72 out of 93). Therefore, we take the regressors to be exogenous and regard OLS as both a consistent and efficient estimator of the single country production function parameters.[38]

Table A2.1 of Appendix 2.4 shows the results for each country separately based on time-series OLS estimations of an unrestricted form of equations 2.12 and 2.13 respectively.[39] Focussing on the results without human capital as input into the production function, it is evident from the table that there is widespread heterogeneity in the parameter estimates across countries. Additionally, for some countries (both developed and developing) the estimations yield some theoretically implausible results: capital and labour output elasticities that are negatively signed and with large values. Examples of countries with factor elasticities exhibiting these characteristics include Australia, Austria, Belgium and Canada from the group of developed countries, and Colombia, India, Nigeria and Pakistan from among the developing group. This finding is consistent with that of Knowles and Owen (2000), who replicated the single country estimation exercise of Senhadji (1999) and also obtained theoretically implausible results for the capital coefficient for a number of developing countries (e.g. Senegal, Peru, China, Guyana, Haiti, Kenya).[40]

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[37] We use the Wu-Hausman F-test instead of the Durbin-Wu-Hausman chi-square test since the sample period is not infinitely long.
[38] There is no systematic pattern to the countries whose factor inputs were found to be endogenous. For example, they are not limited to one type of country (e.g. developed) or regional grouping.
[39] Because our TFP growth rates were not generated from the instrumental variable estimations, we do not present the results from that estimation exercise.
[40] Like us, Senhadji used data on physical capital stocks from Nehru and Dhareshwar (1993) which are a part of the World Bank STARS database.

They also note that the countries for which such a finding was obtained featured heavily in the list of 22 countries that Senhadji dropped from his original sample of 88 countries. We also cross check the results of our OLS estimations by re-estimating the equations using data from Duffy and Papageorgiou (2000) for a sample of 82 countries. The results were virtually the same for the 82 countries common to both data sets.[41] It is possible that the economically implausible results may be due to the use of an inappropriate functional form, measurement error and the use of annual data. We explore the last possibility in greater detail below.

Table 2.2 presents summary statistics of the factor estimates for the single country estimations based on (2.12) for all countries taken together, and the six regions into which the sample of countries is divided. Across the entire sample of countries, the table shows a wide range of variability for both factor elasticities, with the range being larger for the output labour elasticity : -20.97 to 10.60. This fact is also evident from the standard deviation of both parameter estimates. The mean group output elasticity of physical capital is approximately 0.33 while that of labour is 0.13. The magnitude of the former falls within the range of values commonly employed in the traditional non-stochastic growth accounting literature for physical capital based on national accounts data. In contrast, the mean group output elasticity of labour is much lower than that employed by previous researchers using that methodology. Finally, there is evidence of decreasing returns to scale in the factor inputs for the sample of countries as a whole.

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[41] This finding is not surprising since Duffy and Papageorgiou (2000) obtained their data from the World Bank STARS database. The only transformation they made to the data is to convert it from constant end of period 1987 local currency units, to constant end of period 1987 U.S. dollars.

However, the above results conceal the widespread heterogeneity of the parameter estimates across regions. For example, the mean elasticity of physical capital ranges from -0.04 in South Asia to 0.55 in Latin America and the Caribbean. The spread is far greater for average labour elasticity, which ranges from –2.94 in South Asia (SASIA) to 2.02 in East Asia (EASIA). The average values of the physical capital elasticity for Sub-Saharan Africa (SSA) and the industrial countries (INDUS) are however, within the range commonly employed in the non-stochastic growth accounting literature. To a large extent, the widespread variability in the results is driven by the estimates obtained for countries that comprise the Middle East and North Africa, and South Asia groups. This is further reflected by the size of the standard deviation for both parameter estimates in the latter two regions.

Table 2.2: Summary Statistics of Capital and Labour Output Elasticities by Region (Unconstrained Model)

	SSA	MENA	LAC	EASIA	SASIA	INDUS	ALL COUN.
Mean							
α	0.328	0.097	0.555	0.146	-0.036	0.369	**0.327**
β	-0.057	-2.502	1.010	2.021	-2.942	0.752	**0.134**
Median							
α	0.355	0.235	0.550	0.115	0.140	0.440	**0.360**
β	-0.335	0.135	0.590	2.685	-4.120	0.310	**0.080**
Std. Dev.							
α	0.476	0.936	0.480	0.155	0.739	0.578	**0.594**
β	3.358	8.471	3.198	1.689	2.943	2.567	**4.218**
Min.							
α	-0.360	-2.200	-0.340	-0.090	-1.290	-1.400	**-2.200**
β	-5.260	-20.970	-4.080	-0.600	-6.480	-3.070	**-20.97**
Max.							
α	1.260	1.140	1.580	0.370	0.760	1.100	**1.580**
β	9.200	10.600	7.980	3.690	0.330	8.590	**10.600**
N	22	12	22	8	5	24	**93**

Note: Table 1 provides OLS estimates of the output elasticities of capital (α) and labour (β) for the following Cobb-Douglas production function: $Y_t = A_t K_t^{\alpha} L_t^{\beta}$, where Y is real GDP, K is physical capital stock, L is labour, A is a measure of total factor productivity and t a time index.

SSA: Sub-Saharan Africa; MENA: Middle East & North Africa; LAC: Latin America & the Caribbean; EASIA: East Asia; SASIA: South Asia; INDUS: Industrial Countries; ALL COUN.: All Countries.

The mean output capital and labour elasticities for each region from the above table were then used to derive estimates of TFP growth. For two regions however, Middle East and North Africa (MENA) and South Asia (SASIA), we use the median values of the output factor elasticities. This is due to the fact that some countries in these two regions - Cyprus, Iraq and Libya (MENA) and Myanmar, India and Pakistan (SASIA)– have coefficients with large negative values, particularly for the labour input. Given the relatively small size of these two groupings, this will undoubtedly affect the mean. As indicated previously, this augmented mean group measure of TFP growth which we denote TFPG-AMG, combines elements of the two polar assumptions of complete heterogeneity and complete homogeneity of the parameters of the production function.

The TFP growth estimates derived from this unconstrained model are clearly highly implausible in terms of the magnitude of the growth rates estimated for some countries and regions. This is true even allowing for the fact that different methodologies and the different assumptions on which they rely, produce different TFP estimates for the same country over generally the same time period. Table 2.3 presents some summary figures by regions.

The table shows that among the six regions, South Asia (SASIA) had the highest average TFP growth rate between 1960-90, with 8.22% per annum. Among the countries that comprise this region, Pakistan had the highest TFP growth over the period with 10.6 % and Myanmar the lowest with 7.1%. In contrast, Latin America and the Caribbean (LAC) had the lowest average TFP growth (-2.17%) during the sample period; Uruguay being the country with the highest annual rate of TFP growth (0.11%) and Nicaragua the country with the lowest (-4.70%). These results, both in terms of the magnitudes of the TFP growth rates (particularly for SASIA) and the rankings of the regions, differ with those obtained by other researchers either for the same or a similar time period (see Collins and Bosworth, 1996; Nehru and Dhareshwar, 1994; Senhadji, 2000).

The magnitudes of the TFP growth rates for South Asia (and the countries therein) are extremely high compared to those obtained by other researchers. Further, in terms of regional rankings, the three studies cited above all find that East Asia had the highest annual rate of TFP growth among the six regions, while Sub-Saharan Africa (SSA) had the lowest. In some instances, the differences are quite marked even allowing for the fact that those studies assumed constant returns to scale and parameter homogeneity of the production function.

Table 2.3: Average TFP Growth (TFPG-AMG) 1960-90 (%)

Region	#countries	Regional Mean	Maximum Country	Maximum Rate	Minimum Country	Minimum Rate
SSA	22	1.67	Kenya	4.67	Uganda	-0.37
EASIA	8	1.72	China	9.61	Philippines	-2.03
SASIA	5	8.22	Pakistan	10.60	Myanmar	7.10
MENA	12	2.69	Malta	5.83	Kuwait	-2.07
LAC	22	-2.17	Uruguay	0.11	Nicaragua	-4.70
INDUS	24	1.15	Portugal	1.89	New Zealand	-0.04

NOTE: Regions are as defined in Table 2.2.

We next estimate (2.12) assuming constant returns to scale.[42] The individual country parameter estimates are shown in Table A2.2 of Appendix 2.4. Although there are still some theoretically implausible results in terms of our priors for the parameter estimates for some countries (e.g. Canada, Colombia, Cyprus and Malta amongst others) these cases are fewer in number compared to when we assumed variable

[42]In this instance we chose to estimate the production without human capital as input.

returns to scale. Summary statistics for the capital and labour output elasticities are shown in Table 2.4. There is still evidence of widespread heterogeneity in the mean factor elasticities across regions, with that for physical capital ranging from 0.66 in Latin America and the Caribbean (LAC) to 0.09 in Middle East and North Africa (MENA). This finding, plus the estimates of the capital elasticity for the LAC, EASIA and SASIA regions are consistent with those found previously (see Senhadji, 2000).

Table 2.4: Summary Statistics of Capital and Labour Output Elasticities by Region (Constrained Model)

	SSA	MENA	LAC	EASIA	SASIA	INDUS	ALL COUN.
Mean							
α	0.38	0.09	0.66	0.29	0.38	0.51	**0.43**
β	0.62	0.91	0.34	0.71	0.62	0.49	**0.57**
Median							
α	0.42	0.19	0.64	0.20	0.21	0.62	**0.51**
β	0.58	0.81	0.36	0.80	0.79	0.38	**0.49**
Std. Dev.							
α	0.468	0.805	0.447	0.310	0.356	0.451	**0.518**
β	0.468	0.805	0.447	0.310	0.356	0.451	**0.518**
Min.							
α	-0.75	-1.42	-0.332	-0.03	0.00	-0.78	**-1.42**
β	-0.38	-0.28	-0.56	-0.03	0.23	-0.16	**-0.56**
Max.							
α	1.38	1.28	1.56	0.97	0.77	1.16	**1.56**
β	1.75	2.42	1.32	0.97	1.00	1.78	**2.42**
N	22	12	22	8	5	24	93

Note: Table 1 provides OLS estimates of the output elasticities of capital (α) and labour (β) for the following Cobb-Douglas production function: $Y_t = A_t K_t^{\alpha} L_t^{\beta}$, where Y is real GDP, K is physical capital stock, L is labour, A is a measure of total factor productivity and t a time index.

Summary data on the TFP growth estimates for the six regions derived using the mean factor elasticities from the constrained model is shown in Table 2.5. This measure is denoted TFPG-AMG2. The table shows that among the regions, East Asia (EASIA) had the highest average TFP growth rate between 1960-90, with

1.71% per annum. Among the countries that comprise this region, Korea had the highest TFP growth over the period with 2.70 % and Philippines the lowest with -0.02%. In contrast, Latin America and the Caribbean (LAC) had the lowest average TFP growth (-0.65%) during the sample period; Ecuador being the country with the highest annual rate of TFP growth (0.73%) and Nicaragua the country with the lowest (-2.74%).

The above results, both in terms of the magnitudes of the TFP growth rates and the rankings of the regions, are generally consistent with those obtained by other researchers either for the same or a similar time period (see Collins and Bosworth, 1996; Nehru and Dhareshwar, 1994; Senhadji, 2000). For example, based on a fixed effects estimation of a constrained aggregate production function without human capital as an input, Nehru and Dhareshwar (1994) find East Asia had the highest average annual rate of TFP growth (1.48%) while Sub-Saharan Africa had the lowest (-0.37%) for the same period as this study.[43] Of some interest is the fact that unlike this study, the latter authors' estimates of TFP growth are not derived as a residual. Similarly, Collins and Bosworth (1996) estimated the average annual rate of TFP growth for East and South Asia to be 1.1% and 0.8 % respectively, for the period 1960-94. Recall, Collins and Bosworth use the non-stochastic aggregate growth accounting method and included human capital as augmenting the skill of the labour force.

[43] Based on their preferred estimates of TFP growth derived from an error correction model, Nehru and Dhareshwar obtained even larger negative average rates of TFP growth for both Sub-Saharan Africa and Latin America.

Table 2.5: Average TFP Growth (TFPG-AMG2) 1960-90 (%)						
Region	**#countries**	**Regional Mean**	**Maximum Country**	**Rate**	**Minimum Country**	**Rate**
SSA	22	-0.35	Mauritius	2.30	Uganda	-2.47
EASIA	8	1.71	Korea	2.70	Philippines	-0.02
SASIA	5	0.87	Pakistan	1.49	Myanmar	0.13
MENA	12	1.54	Malta	5.98	Kuwait	-6.00
LAC	22	-0.65	Ecuador	0.73	Nicaragua	-2.74
INDUS	24	0.75	Luxembourg.	1.31	Switzerland	-0.18

Based on the comparisons of the estimates of TFP growth derived from both the unconstrained and constrained models, we choose the estimates from the latter model as the preferred ones. Finally, a second set of alternative TFP estimates from this model is derived by using the estimated elasticities from the time series regression for each country to calculate TFP growth rates for that country. These estimates are referred to as TFPG-HET to reflect the fact that they are derived on the assumption of complete heterogeneity of the parameters of the production function across countries.

2.7.3 Estimation Results: Homogeneous Estimators

In this section we present results from panel regressions based on the estimating equations (2.12) and (2.13), respectively. In estimating these equations, we rule out using estimators with time invariant country specific fixed or random effects which are commonly used as a means of addressing unobserved heterogeneity across countries. Our rationale for doing so is informed by the fact that the issue of heterogeneity across countries has already been addressed by our utilisation of two heterogeneous estimators above. Time dummies are however included in order to capture temporal shocks over the sample period.

Table 2.6 shows pooled (panel) estimates of equations (2.12) and (2.13). From this table, the OLS regressions (regressions 1 and 4), which assume exogeneity of the regressors, have higher physical capital and lower labour coefficients than the estimations that control for the possibility of the regressors being endogenous (IV2SLS and GMM-IV). In contrast to the findings for the individual country regressions, where the factor inputs were generally found to be exogenous and the residuals homoscedastic, the opposite is true for the pooled data. Based on the Durbin-Wu-Hausman (D-W-H) test for exogeneity of the regressors and the Pagan-Hall test for homoscedasticity of the disturbance term, we are able to reject (at a 1% significance level) both assumptions for the two pooled OLS regressions.[44] This suggests that there is non-orthogonality between the regressors (factor inputs) and the error term and consequently, OLS is an inconsistent estimator of the parameters of the production function. It may therefore be argued that failure to deal with endogeneity biases the physical capital coefficient upwards and the labour coefficient downwards (Benhabib and Spiegel, 1994).

The standard approach in the empirical literature for addressing the problem of endogenous covariates is to first instrument them and then undertake IV estimation. We employ this procedure by using the conventional IV estimator (regressions 2 and 5) and a Generalised Method of Moments (GMM) IV estimator (regressions 3 and 6). In addition to addressing the endogeneity issue, both estimators also help in

[44] We use the Durbin-Wu-Hausman (D-W-H) test as an alternative to the Hausman test because whereas the latter requires that the model first be estimated via OLS and then IV, the former (i.e. D-W-H test), in contrast, requires only an IV estimation to evaluate the exogeneity of the regressors in the OLS estimation. Additionally when heteroscedasticity is present, the Hausman test often generates negative test statistics and may miscalculate the degrees of freedom of the test (see Baum et al., 2003). This claim has indeed been confirmed by our findings.

minimising the effects of measurement error which is known to characterise data emanating from most developing countries.[45]

Table 2.6 : Panel Estimates of Production Function (1960-90) Annual Data Dependent Variable: GDP Growth						
	OLS (1)	**IV 2SLS (2)**	**GMM- IV (Rob. s.e.) (3)**	**OLS (4)**	**IV 2SLS (5)**	**GMM- IV (Rob. s.e.) (6)**
D log K	0.483*** (11.34)	0.245*** (6.54)	0.240*** (3.86)	0.441*** (9.66)	0.177*** (4.29)	0.183*** (2.75)
D log L	-0.071 (-1.17)	0.242*** (3.37)	0.209* (1.95)	0.046 (1.03)	0.355*** (4.43)	0.361** (2.30)
D log H				-0.030 (-0.59)	-0.022 (-0.46)	-0.025 (-0.42)
Inputs Endogenous	NO	YES	YES	NO	YES	YES
# Observations	2760	2571	2571	2228	2060	2060
# Countries	93	93	93	83	83	83
R^2	0.10	0.12	0.13	0.08	0.10	0.10
Instrument Validity Test						
Sargan χ^2 (p-value)		0.203			0.686 (0.876)	
Hansen J χ^2 (p-value)			1.682 (0.431)			0.178 (0.915)
Endogeneity Test						
Durbin-Wu-Hausman Test χ^2 (p-value)		151.000 (0.000)			159.064 (0.000)	
Heteroscedasticity Tests						
White/Koenker Test (OLS) χ^2 (p-value)	12.932 (0.002)					
Pagan-Hall Test (IV) χ^2 (p-value)		20.393 (0.000)			23.768 (0.000)	

NOTES: The numbers in parentheses for the estimates of the factor inputs are z (t) statistics. For the various diagnostic tests they are p-values. *** means significant at 1%;** means significant at 5%;* means significant at 10%. The instruments in the IV and GMM-IV regressions are the growth rates of GDP, the stock of capital and labour (lagged two periods), and time dummies. All regressions include time dummies.

From among the regressions that control for endogeneity, the estimates obtained using the feasible efficient two-step GMM estimator are the preferred ones. This

[45] We use lagged (two period) first differences of output, physical capital, human capital, labour and the product of physical capital and labour as instruments in our estimations. Unlike the lagged levels,

estimator, introduced by L. Hansen (1982), is robust to heteroscedasticity of unknown form. If heteroscedasticity is present, which the Pagan-Hall test statistic shows to be the case, then the conventional IV estimator although consistent, is inefficient.[46] This inefficiency arises because the estimates of the standard errors are inconsistent and thus prevents valid inferences being made. Additionally, the usual forms of the diagnostic tests for endogeneity and overidentifying restrictions are invalid in the presence of heteroscedasticity. It should also be noted that the problems posed by heteroscedasticity for the traditional IV estimator can only be partially resolved through the use of heteroscedasticity-consistent or "robust" standard errors and statistics (Baum, Schaffer and Stillman, 2003).[47]

In contrast to the conventional IV estimator, the GMM estimator makes use of the orthogonality conditions to allow for efficient estimation in the presence of heteroscedasticity of unknown form. Moreover, even if heteroscedasticity is not present, the GMM estimator is no worse asymptotically than the IV estimator. The use of the efficient GMM estimator however is not costless. Hayashi (2000) argues that because the optimal weighting matrix at the core of the efficient GMM estimator is a function of fourth moments, obtaining reasonable estimates of these moments may require very large sample sizes. Consequently, the efficient GMM estimator can have poor small sample properties. We take some comfort however in the relatively large size of our sample compared to previous studies in the literature that have also

the lagged first differences were highly correlated to the current growth rates.

[46] Given that the sample comprises countries of vastly differing sizes, then seeking to minimise the effects of heteroscedasticity seems a plausible objective.

[47] This point is confirmed by the fact that despite using robust standard errors, the Pagan-Hall test statistic still convincingly rejected the null hypothesis of homoscedasticity of the disturbance term. In fact, the test statistic and corresponding p-value remained unchanged for the two conventional IV estimations.

utilised the GMM estimator. Therefore, we are reasonably confident about the properties of this estimator for our estimation exercises.

For the GMM-IV estimation that excludes human capital, the coefficient for physical capital is estimated to be 0.24 while that for labour is approximately 0.21. Both coefficients are positively signed and are significant at the 1 and 10% levels, respectively. The magnitude of the coefficients however is smaller than that found by similar studies at the economy wide level. However, as indicated above, these studies fail to address the problem of endogeneity among the factor inputs. When human capital is added as an input, the size of the physical capital coefficient falls to 0.18 while that of labour rises to 0.36. Again both coefficients are positively signed and are significantly different from zero at conventional levels (1 and 5%, respectively). However, the coefficient on human capital is not significant. This is consistent with the findings of Benhabib and Spiegel (1994) and Islam (1995) that human capital does not contribute directly to output growth. The role of human capital in economic growth is an issue that will be subjected to further empirical scrutiny later in this thesis.

Additionally, despite using a different estimation method to Harrison (1996), Miller and Upadhyay (2000) and Söderbom and Teal (2001) among others, we, like these authors, also find evidence of decreasing returns to scale in production; albeit to a greater degree than the cited studies immediately above.

Having decided that the results obtained using the efficient two-step GMM-IV estimator are the preferred results among the set of homogeneous estimators, the next task is to determine whether this estimator passes the necessary diagnostic tests. This is necessary to establish the validity of the model estimated. Specifically, it must be established that the variables used to instrument the endogenous regressors are "good instruments". "Good instruments" are instruments that are both relevant and valid. This means that they should be highly correlated with the endogenous regressors and simultaneously orthogonal to (uncorrelated with) the errors. One can assess the first requirement by examining the significance of the excluded instruments in the first stage regressions. This is shown for the two GMM-IV regressions in Table 2.7. For the regression without human capital, the table shows that the coefficients on the excluded instruments are highly correlated with the endogenous factor inputs of physical capital and labour (regressions 1 and 3, Table 2.7); the Partial-R^2 being 0.78 and 0.82, respectively. Additionally, the F-test statistic permits a rejection - at a 1% level of significance - of the null hypothesis that the excluded instruments are collectively not significantly different from zero. The pattern of results (regressions 2, 4 and 6) remains unchanged for the GMM-IV regression that includes human capital as an input.

The second requirement, that the instruments be orthogonal to the errors, can be evaluated based on Hansen's diagnostic test of overidentifying restrictions. Only if the equation is overidentified (when the number of excluded instruments exceed the number of included endogenous regressors), can one test whether the instruments are uncorrelated with the error process. The diagnostic test is really one that tests the joint hypotheses of correct model specification and the orthogonality conditions. Therefore, a rejection may call into question either or both hypotheses. Based on the chi-square values obtained for Hansen's J statistic for the GMM-IV regressions shown in Table 2.6, the null hypothesis that the instruments are uncorrelated with the error process cannot be rejected for both regressions. This finding thus provides evidence of the validity of the instruments as well as their independence from the error process.

Table 2.7 : First Stage Regressions of Endogenous Variables (1960-1990) Annual					
Dependent Variable	**D log K (1)**	**(2)**	**D log L (3)**	**(4)**	**D log H (5)**
Excluded Instruments					
D log GDP_2	0.078*** (13.43)	0.084*** (12.68)	-0.016*** (-6.06)	-0.018*** (-6.38)	-0.002 (-0.88)
D log K_2	0.692*** (64.74)	0.720*** (60.57)	-0.173*** (-34.79)	-0.175*** (-34.67)	-0.013*** (-2.68)
D log L_2	-0.029 (-1.57)	0.004 (0.18)	0.173*** (19.85)	0.132*** (15.01)	0.031*** (3.63)
D log (K*L)_2	3.800*** (18.92)	3.230*** (14.60)	9.074*** (97.10)	9.653*** (102.72)	0.924*** (163.93)
D log H_2		0.016 (1.19)		0.0409* (7.14)	-0.073 (-0.79)
Adj. R^2	0.81	0.79	0.82	0.85	0.93
Partial R^2 of Excluded Instruments	0.78	0.77	0.82	0.85	0.93
F-test of Excluded Instruments (p-value)	2302.56 (0.000)	1371.91 (0.000)	2888.94 (0.000)	2403.23 (0.000)	5733.39 (0.000)
# Observations	2571	2060	2571	2060	2060
# Countries	93	83	93	83	83

NOTES: The numbers in parentheses for the estimates of the factor inputs are t- statistics. For the diagnostic test they are p-values.*** means significant at 1%.
All regressions include a constant and time dummies.

2.7.3.1 Annual Data Versus Period Averages

It has been argued (see Fajnzylber and Lederman, 1999; Temple, 1999) that in using annual data to estimate growth equations, one runs the risk of mistakenly attributing short-term business cycle effects as the true determinants of long-run growth rates. This has implications for measured TFP growth rates. Fajnzylber and Lederman (1999) argue, for example, that short-run or business cycle fluctuations may disguise changes in capacity utilisation as changes in TFP. They note that during recessions firms might be forced to operate sub-optimally with low levels of capacity utilisation. The result can be changes in measured TFP that do not reflect movements of the production frontier. Fajnzylber and Lederman suggest that if the primary objective of the study is to capture the effects of trade and other economic reforms on long-run growth, then one should purge the measured change in TFP from the effects of recessions and other short-term fluctuations.

The norm in the empirical literature for minimising the influence of short-term fluctuations is to use data in five-year averages rather than annually.[48] However, as Temple (1999) notes, the issue of using data in five or ten year averages instead of annually is not completely settled. He argues that while care must be taken in modelling the short-run dynamics when using annual data, the use of period averages means that one is left with little time series variation in the data. The consequence of the lack of complete agreement on the issue has resulted in some researchers using annual data (e.g. Nehru and Dhareshwar, 1994; Edwards, 1998; Senhadji, 2000) while others (e.g. Islam, 1995; Miller and Upadhyay, 2000) use five-year averages.

In light of the concerns raised over the use of annual data to measure changes TFP and the fact that the *raison d'être* of this thesis is to indeed capture the effects of trade and other economic reforms on economic performance, we alternatively estimate the aggregate production function using data in five-year averages. Table 2.8 presents estimates of the parameters of the production function based on these averages.

[48] In some instances, the motivation for using data in 5-year averages is not so much to control for short-run business cycle effects but simply a reflection of the fact that some of the key variables

Table 2.8: Panel Estimates of Production Function (1960-1990) 5-Year Averages Dependent Variable: GDP Growth						
	OLS (1)	**IV 2SLS (2)**	**GMM- IV (3)**	**OLS (4)**	**IV 2SLS (5)**	**GMM- IV (6)**
D log K	0.531*** (14.22)	0.254*** (3.83)	0.306*** (4.36)	0.487*** (13.04)	0.241*** (3.71)	0.275*** (3.69)
D log L	-0.136 (-1.45)	0.388** (2.34)	0.354** (2.27)	0.124 (1.25)	0.704*** (4.08)	0.460** (2.50)
D log H				-0.054 (-1.17)	-0.143** (-2.24)	-0.091 (-1.17)
Inputs Endogenous ?	NO	YES	YES	NO	YES	YES
# Observations	557	557	415	498	415	415
# Countries	93	93	83	83	83	83
R^2	0.35	0.27	0.32	0.34	0.27	0.31
Instrument Validity Test						
Sargan χ^2 (p-value)		15.492 (8.3e-05)			10.686 (0.001)	
Hansen J χ^2 (p-value)			4.240 (0.237)			2.711 (0.44)
Endogeneity Test						
Durbin-Wu-Hausman Test χ^2 (p-value)		40.216 (0.000)			42.874 (0.000)	
Heteroscedasticity Tests						
White/Koenker Test (OLS) χ^2 (p-value)	25.873 (0.000)			13.709 (0.003)		
Pagan-Hall Test (IV) χ^2 (p-value)		12.846 (0.002)			8.128 (0.043)	

NOTES: The numbers in parentheses for the estimates of the factor inputs are z (t) statistics. For the various diagnostic tests they are p-values. *** means significant at 1%;** means significant at 5%;* means significant at 10%.

The instruments in the IV and GMM-IV regressions are the growth rates of GDP, the stocks of physical and human capital, labour and the product of human capital and labour (all lagged one period), and period dummies. All regressions include period dummies.

Generally, the results in Table 2.8 mirror those obtained when annual data were used. However, the estimated coefficients are larger (in absolute terms) compared to those obtained using annual data. The results obtained from the GMM-IV estimations are

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required for the empirical analysis (e.g. human capital or institutional quality) are only available in 5-yearly periods.

once again the preferred results.[49] The criteria for relevance and validity of the instruments are also once again met. The first stage regressions for this estimator are shown in Table 2.9.

Having chosen the results from the GMM-IV regressions as the preferred results when parameter homogeneity is assumed across countries, we next use the factor elasticities to derive TFP growth rates for the sample of countries on the basis of both annual and 5-year data. However, we only utilise the factor elasticities from the specification of the production function that excludes human capital. The latter variable being either negative and/or statistically insignificant in all the estimation exercises. We refer to these measures of TFP growth as TFPG-GMM.

[49] Two alternative instrumental variable panel data estimators employed in empirical growth studies using five-yearly data are the first differenced GMM estimator proposed by Holtz-Eakin, Newey and Rosen (1988) and Arellano and Bond (1991) [see Caseli et al., 1996], and the system GMM estimator developed by Blundell and Bond (1998) [see also Blundell and Bond, 2000]. Our estimation of a static rather than dynamic model rules out use of the first estimator while in the case of the second we choose not to adopt the more complex error components approach of Blundell and Bond. Instead we opt for a simpler variant of the GMM estimator.

Table 2.9 : First Stage Regressions of Endogenous Variables (1960-1990) 5-Year Averages					
Dependent Variable	**D log K (1)**	**(2)**	**D log L (3)**	**(4)**	**D log H (5)**
Excluded Instruments					
D log GDP_1	0.223*** (6.67)	0.222*** (6.64)	-0.065*** (-4.87)	-0.064*** (-4.82)	-0.027 (-1.55)
D log K_1	0.370*** (11.44)	0.367*** (11.27)	-0.086*** (-6.60)	-0.079*** (-6.16)	-0.016 (-0.92)
D log L_1	-0.0112 (-1.27)	-0.150 (-1.38)	0.317*** (8.97)	0.421*** (9.80)	0.142** (2.47)
D log (K*L)_1	10.149*** (13.53)	10.241*** (13.37)	8.318*** (27.53)	8.070*** (26.69)	-0.255 (-0.63)
D log (L*H)_1	0.845 (0.63)	2.772*** (0.80)	0.291 (0.54)	-4.905*** (-3.58)	-1.619 (-0.88)
D log H_1		-0.051 (-0.60)		0.136*** (4.11)	0.874*** (19.73)
Adj. R^2	0.73	0.74	0.72	0.74	0.87
Partial R^2 of Excluded Instruments	0.70	0.70	0.73	0.74	0.87
F-test of Excluded Instruments (p-value)	192.80 (0.000)	160.48 (0.000)	216.31 (0.000)	190.14 (0.000)	470.95 (0.000)
# Observations	415	415	415	415	415
# Countries	83	83	83	83	83

Notes: The numbers in parentheses for the estimates of the factor inputs are t- statistics. For the diagnostic test they are p-values. *** means significant at 1%; ** means significant at 5%.

All regressions include a constant and time dummies.

2.8 ANALYSIS OF TFP ESTIMATES

In this section, we compare the estimates of TFP growth derived on the basis of the augmented mean group estimator (TFPG-AMG2) with those derived from the two alternative stochastic TFP growth measures (TFPG-HET and TFPG-GMM), as well as with estimates of TFP growth based on alternative stochastic and non-stochastic approaches employed in the literature. Table 2.10 presents mean annual TFP growth rates by region for the three stochastic measures: TFPG-AMG2, TFPG-HET and TFPG-GMM along with a 'representative' non-stochastic growth accounting measure derived using the method employed in Fischer (1993) and the actual estimates derived by Nehru and Dhareshwar (1994).[50]

As the table shows, with the exception of one region – MENA- the estimates of TFP growth derived on the basis of the augmented mean group estimator (TFPG-AMG2) are reasonably close to those obtained by Nehru and Dhareshwar (1994) across the different regions. To a lesser extent, this is also true for the estimates obtained when we employ the non-stochastic method used in Fischer (1993). However, there are also some marked differences notably for MENA, as mentioned above, and to a lesser extent, the LAC and INDUS regions. These differences once again highlight the differences in methods and assumptions of the measures.

Across all measures, the completely heterogeneous measure (TFPG-HET) consistently yields the highest mean annual TFP growth rate for each of the six regions. This therefore suggests that that not allowing for heterogeneity biases the TFP estimates downwards. However, a contributing factor to this result may be the negative coefficients obtained for some of the countries. The TFP growth estimates derived from the estimator that corrects for possible endogeneity (TFPG-GMM), are larger than those obtained from the other measures shown in the table except the completely heterogeneous measure. This is explained by the low values of the capital and labour output elasticities obtained when we used the GMM-IV estimator.

[50] We derive non-stochastic growth accounting measure by imposing a capital elasticity of 0.4 and labour elasticity of 0.6 based on a Cobb-Douglas production function without human capital (see Fischer, 1993). The TFP growth estimates taken from Nehru and Dhareshwar (1994) are derived from a fixed effects estimation of a restricted Cobb-Douglas production function. Unlike the other TFP measures considered in this section, it is not a residual measure of TFP growth (see Section).

Therefore, as expected, correcting for endogeneity results in a bigger share of observed output growth being assigned to TFP. This finding is interesting in the context of the recent debate concerning the ability of the non-stochastic growth accounting framework to correctly assign the relative contributions of factor inputs and TFP to output growth. The endogeneity issue underlies much of this debate (see Hulten and Srinivasan, 1999).

Table 2.10 : Mean TFP Growth by Region and Measure 1960-1990 (%)

	TFPG-AMG2	TFPG-HET	TFPG-GMM	TFPG-FIS	TFPG-ND
SSA	-0.35	2.94	1.34	-0.22	-0.37
EASIA	1.72	6.76	3.90	1.97	1.48
SASIA	0.87	4.09	2.36	0.84	0.64
MENA	1.54	4.78	2.43	0.59	0.11
LAC	-0.65	3.27	1.61	0.05	-0.12
INDUS	0.75	3.69	2.32	1.54	1.20

NOTES: TFPG-FIS: non-stochastic growth accounting residual measure of TFP growth calculated by imposing a capital elasticity of 0.4 and labour elasticity of 0.6 on a Cobb-Douglas production function; TFPG-ND: non-residual measure of TFP growth from Nehru and Dhareshwar (1994), calculated from a fixed effects estimation of a restricted Cobb-Douglas production function. TFPG-HET and TFPG-GMM are defined in the text.

The correlation between the alternative measures are shown in Table 2.11. As is evident from the table, the three stochastic residual measures of TFP growth derived in this chapter are highly correlated with each other and with alternative measures used by other researchers; differences in methodologies and assumptions notwithstanding. This finding is generally consistent with Van Biesebroeck (2003) for Colombian plant level data and Fischer (1993) based on cross-country data. Interestingly, the completely heterogeneous measure (TFPG-HET) which assumes constant returns to scale has a higher correlation coefficient with the GMM measure (TFPG-GMM) that assumes variable returns to scale than with the augmented mean group measure which also admits constant returns to scale. Further, the correlation between TFPG-HET and the other measures that assume constant returns to scale is lower than with TFPG-GMM, suggesting than heterogeneity becomes less of an issue once endogeneity is controlled for.

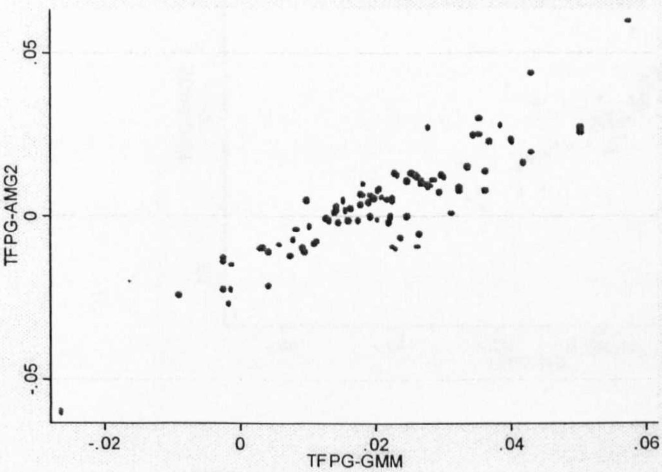
Table 2.11 : Correlation Matrix of Alternative TFP Growth Estimates

	TFPG-AMG2	TFPG-HET	TFPG-GMM	TFPG-FIS	TFPG-ND
TFPG-AMG	1.00				
TFPG-HET	0.72	1.00			
TFPG-GMM	0.89	0.91	1.00		
TFPG-FIS	0.91	0.71	0.92	1.00	
TFPG-ND	0.89	0.66	0.90	0.99	1.00

NOTES: TFPG-HET: residual measure of TFP growth calculated using the factor elasticities from single country estimations of a Cobb-Douglas production function; TFPG-AMG2: residual measure of TFP growth calculated using the mean factor elasticities by region from single country estimations of a Cobb-Douglas production function; TFPG-GMM: residual measure of TFP growth calculated using the factor elasticities from pooled GMM-IV estimation of a Cobb-Douglas production function. TFPG-FIS: residual measure of TFP growth calculated by imposing a capital elasticity of 0.4 and labour elasticity of 0.6 on a Cobb-Douglas production function as in Fischer (1993); TFPG-ND: non-residual measure of TFP growth from Nehru and Dhareshwar (1994), calculated from a fixed effects estimation of a restricted Cobb-Douglas production function.

On the strength of our arguments in favour of econometrically estimating the production function rather than employing the non-stochastic aggregate growth accounting methodology, we compare more closely the distribution of the TFP growth estimates for the preferred measure, TFPG-AMG2, with that of TFPG-GMM. The choice of the latter measure rather than the completely heterogeneous measure, TFPG-HET, is based largely on our view that the world is not characterised by complete heterogeneity of the technology parameters of the production function. Additionally as indicated earlier, there are strong arguments in favour of estimating the production function by panel methods coupled with the fact that this estimation procedure is the one most frequently used in cross-country regression analysis. Figures 2.1 and 2.2 plot the TFP estimates derived from the augmented mean group measure against those derived from the GMM based measure and estimates from Nehru and Dhareshwar (1994) respectively. Both figures confirm the high correlation among the estimates noted above.

Figure 2.1: TFP Growth Comparison with TFPG-GMM

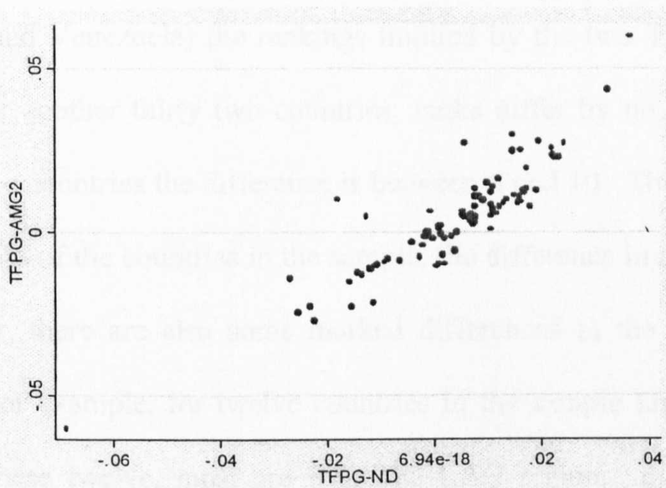


TFPG-AMG2: TFP Growth This Study

TFPG-GMM: Alternative TFP Growth Estimates from This Study

Table A2.3 of Appendix 2.5 presents estimates of annual TFP growth rates for the 93 countries in the sample for the period 1960-90, for the two selected TFP measures. It also shows the rankings of countries implied by the two measures. Thus comparisons between the two measures can be made in these two dimensions: cardinal (actual TFP estimates) and ordinal (rankings). In the first dimension, as suggested by the Table 2.10 which shows the mean annual TFP growth rates by region, the estimates produced by the GMM measure are generally much higher than the estimates produced by the augmented mean group measure. Only for a few countries (Kuwait, Cyprus, Nicaragua, Malta) are estimates derived from the latter measure greater than those produced by the former. So in the cardinal dimension, there are differences in the estimates implied by the two measures.

Figure 2.2: TFP Growth Comparison with Estimates from Nehru and Dhareshwar (1994)



TFPG-AMG2: TFP Growth This Study

TFPG-ND: TFP Growth from Nehru and Dhareshwar (1994)

In the ordinal dimension however, the rank ordering of countries produced by the two measures are very close. For example, both measures have Malta as the highest ranked country in terms of average annual rate of TFP growth over the sample period. Further, of the ten countries listed as having the highest annual rate of TFP growth by the intermediate and GMM measures respectively, six countries (Malta, Cyprus, Korea, Taiwan, China and Israel) are common to both lists. This is also true at the other extreme, i.e. the ten countries with the lowest annual TFP growth rates. Here the six countries common to both lists include Mozambique, Iraq, Haiti, Nicaragua, Sudan and Kuwait. Careful inspection of the rankings reveals that countries from East Asia (EASIA), and Middle East and North (MENA) are at the top of the rankings while countries from Latin America and the Caribbean (LAC) and Sub-Saharan African (SSA) are at the bottom.

Further comparisons show that for eight countries (Bolivia, Canada, Ethiopia, Malta, Mozambique, Peru and Venezuela) the rankings implied by the two TFP measures coincide exactly. For another thirty two countries, ranks differ by no more than 5 while for twenty three countries the difference is between 6 and 10. This means that for approximately 66% of the countries in the sample, the difference in rank does not exceed 10. However, there are also some marked differences in the rankings for specific countries. For example, for twelve countries in the sample ranks differ by more than 20. Of these twelve, most are from the LAC region. In the case of Paraguay, the difference in rank is as high as 44. This can possibly be explained by the fact that, whereas a number of countries in this region is shown as having negative or very low rates of TFP growth over the period by the augmented mean group measure, these countries are shown as having positive and significant (in some instances) TFP growth by the GMM measure.

As indicated at the start of this chapter, each method for measuring TFP has its strengths and its limitations. Moreover, as noted by Miller and Upadhyay (2000), all measures of TFP produce anomalous results (see also Fischer, 1993). All of these attributes (both positive and negative) apply to our preferred augmented mean group measure of TFP growth. In terms of the deficiencies however, we believe that they are no worse than, and in many respects far less than, the deficiencies associated with other aggregate TFP measures employed in the literature.

2.9 SUMMARY AND CONCLUSIONS

This chapter critically reviewed the alternative methodologies commonly used to calculate cross-country TFP estimates, particularly the method of growth accounting. It highlighted the limitations and/or weaknesses of the non-stochastic (both parametric and non-parametric) variant of this method for deriving TFP estimates for a large cross-section of countries. For example, we noted that due to the level of factor disaggregation required for incorporating changes in the quality of human and physical capital, the sophisticated non-parametric index number approach of Jorgenson and others is generally limited in its applicability only to small groups of developed countries. Additionally, the cross-section time series variant proposed by Hall and Jones is sensitive to the inclusion/exclusion of countries.

On the other hand, the non-stochastic aggregate cross-country growth accounting method used in Fischer (1993) and Collins and Bosworth (1996), while offering a simple and transparent method for deriving TFP estimates for a large number of countries over time, relies on assumptions that have been questioned by both theoretical and empirical growth economists. Further, the method seems incapable of adequately addressing the issues of cross-country heterogeneity in the parameters of the production function and of possible simultaneity bias due to endogenous factor inputs: two issues that have been the subject of recent empirical scrutiny (see Pesaran and Smith, 1995; Caselli et al., 1996; Durlauf and Quah, 1998).

As a result of these limitations and the strength of the arguments in favour of addressing them, we argue for directly estimating the parameters of the production function rather than imposing them on the basis of their respective shares in national income. In this regard, we derive three alternative sets of TFP growth estimates using the estimated parameters from the aggregate production function. Since the estimates of TFP growth were computed as residuals, the method can be described as an econometric analogue to the conventional measure based on Solow (1957). The parameters were estimated on the basis of assumptions that reflect the current debate regarding the performance of heterogeneous type estimators vis-à-vis their homogeneous counterparts, and also the issue of the suspected endogeneity of the factor inputs. Two of the measures of TFP growth were derived on the polar assumptions of complete heterogeneity and complete homogeneity of the factor inputs, while the third combines elements of the two polar assumptions to yield an intermediate measure. Additionally, the completely homogeneous measure which also reflects the parameter homogeneity assumption, is derived from an estimator (GMM-IV) that controls for possible endogeneity bias resulting from the factor inputs.

Among our main findings are first, the estimates of TFP growth derived from the three estimators are highly correlated among themselves and with estimates derived by other researchers using different methodologies (stochastic and non-stochastic). This finding is generally consistent with Van Biesebrock (2003) at the micro level and to a lesser extent Fischer (1993) at the macro level. Second, on cardinal grounds our preferred set of TFP estimates, derived using an augmented mean group estimator from a constrained production function, compares reasonably well with estimates of TFP growth generated by other researchers using completely different methods. For some randomly chosen countries, the estimates are quite close (see Nehru and Dhareshwar, 1994; Collins and Bosworth, 1996). Third, when compared with the TFP estimates derived from the econometric method most commonly adopted in the literature i.e. panel data estimation, the ordinal ranking of countries implied by both sets of estimates is strikingly close. However, there are differences on cardinal grounds with the estimates of TFP growth generated by the panel GMM-IV estimator, with estimates from the latter group generally giving higher TFP growth than those produced by the intermediate augmented mean group estimator. This result is not inconsistent with previous findings, where correcting for endogeneity results in a bigger share of observed output growth being assigned to TFP while, in contrast, allowing for heterogeneity on the basis of single country regressions produces the opposite effect (Senhadji, 2000; Van Biesebrock , 2003).

Our final important finding and one with implications for future research is that while parameter heterogeneity is clearly an important issue in cross-country empirical work as shown in the recent study of Durlauf et. al (2001), the approach to capturing it suggested by time series econometricians (single country regressions) may be a bit premature in the cross-country context. This may be due to the quality of the data, particularly for developing countries whose data collection procedures are generally not uniform , and the limited current time span of the existing data (Temple, 1999). This conclusion is arrived at on the basis of implausible TFP growth estimates for some countries and regions when we run individual country regressions assuming variable returns to scale. This appears to be due to the theoretically implausible parameter estimates obtained for some countries when the production function is estimated. Plausible estimates of TFP growth were only obtained when we assumed constant returns to scale. That is, by putting some constraint on the parameters of the production function across countries. In making this concession, some balance is struck between economic theoretic and the empirical literatures. Moreover, in using the plausibility of the estimates of TFP growth vis-à-vis those found by other researchers as a criterion for evaluating the performance of heterogeneous type estimators, our approach is similar in spirit to Baltagi and Griffin (1997).

CHAPTER 3

ON THE ROBUSTNESS OF TFP MEASURES: EVIDENCE FROM CROSS-COUNTRY REGRESSIONS

3.1 INTRODUCTION

Having, in the previous chapter, constructed three alternative residual measures of TFP growth, we now use these measures to consider one of the most debated and contentious issues in all of economics: the relationship between trade openness and growth. On the one hand, advocates of free trade and outward oriented trade policies have advanced both theoretical and empirical evidence demonstrating that the adoption of these policies result in better long-run economic performance, measured either in terms of higher per capita GDP or TFP growth (or levels). On the other hand, there are some researchers who remain sceptical in the face of this evidence. Ironically, despite the large number of multi-country studies utilising comparable analytical frameworks, numerous econometric studies using large-cross country data sets, theoretical advances concerning the interaction of trade and economic growth and the unprecedented wave of trade and economic liberalisation undertaken by several countries over the last two decades, this debate still persists till this day (Baldwin, 2003; Dixon, 1998).[1]

[1] Dixon (1998) estimates that around 100 countries in all parts of the globe have undertaken unilateral trade reforms of one form or another. One can argue however, that in the majority of cases the shift in policy orientation from inward to more outward-oriented policies has been driven by the policy conditionalities of the International Monetary Fund (IMF) and the World Bank in response to the host of macroeconomic problems faced by many of these countries.

This issue is no less contentious at the microeconomic level than it is at the macro level. Notwithstanding the use of more sophisticated econometric techniques and detailed micro data for individual countries to examine the relationship between productivity and openness to trade, micro level studies have yielded results that are ambiguous (see Pack, 1988; Bhagwhati, 1988; Tybout, 1992). Tybout (1992) concludes that "...in view of the diverse, ambiguous theoretical literature on the link between trade and productivity, it is not surprising that stable, predictable correlations have not emerged" (p. 207). Our focus in this thesis however, is on the relationship between trade openness and TFP growth at the national or economy-wide level.

Two main issues lie at the heart of the considerable disagreements concerning the relationship between trade policies and macroeconomic performance. The first, relates to the suitability of the indices commonly used in empirical trade and growth studies to proxy a country's trade regime (Edwards, 1993; Rodrik, 1995; Rodriguez and Rodrik, 2000). For example, Rodrik (1995) argues that in most studies of openness and growth, "the trade regime indicator is typically measured very badly" and "openness in the sense of lack of trade restrictions is often confused with macroeconomic aspects of the policy regime" (p. 2941). Additionally, Pritchett (1996) finds that the commonly used trade policy measures are uncorrelated among themselves.

The second, which has a direct bearing on the first, is the lack of good quality trade policy information with broad country and time coverage, particularly for developing countries, to construct satisfactory measures of trade policy (Edwards, 1998; Harrison and Hanson, 1999; Baldwin, 2003). Other concerns relate to the econometric models employed and the fragility of the results to alternative specifications and sensitivity checks (Levine and Renelt, 1992; Edwards, 1998; Rodriguez and Rodrik, 2000; Wacziarg, 2001); the time period and country coverage (Wacziarg, 2001; Vamvakadis, 2002); the direction of causality between trade and growth (Harrison, 1996) and, preceding the latter half of the 1980s, the absence of a convincing theoretical framework linking commercial policy and trade orientation to growth (Edwards, 1993, 1998).

However, missing from the debate over the relationship between trade openness and economic performance, in terms of its effect on TFP, is a concern with whether the way the latter is measured, has an important bearing on the empirical findings. Yet, until recently, there has been an intense debate within the narrower confines of the TFP literature over the magnitude of economy-wide TFP growth rates estimated for some of the South East Asian countries (see Young, 1995; Kim and Lau, 1994; Nelson and Pack, 1999; Hulten and Srinivasan, 1999). The wide variations in the TFP estimates produced by different researchers for the same countries, using the same data and for the same time period, leading Felipe (1999) to conclude that the resulting TFP estimates are largely conditioned on the assumptions made, estimation techniques employed and functional form specified. According to him, authors then regress the growth rate of TFP on variables such as openness, inflation, and government expenditures. Felipe argues that, "since the dependent variable is measured with error, and most likely so are the right hand side variables, the ordinary least squares estimates are biased and inconsistent" (p. 29). In light of Felipe's claims, the natural question to ask is, to what extent are the results from these regressions affected by variations in the estimates of TFP growth? More specifically, in relation to openness, is the relationship between this variable and TFP growth robust to alternative measures of the latter?

This chapter seeks to answer this question and in the process fill the existing void in the literature with regard to this particular issue. It therefore shifts attention away from concerns over the measures used to proxy trade openness to a concern over whether the effect of the openness measures on TFP growth is sensitive to how TFP growth is measured. The remainder of the chapter is organised as follows: Section 3.2 presents a brief overview of the post-war thinking on trade policy and economic development. Sections 3.3 and 3.4 briefly review the voluminous empirical trade and growth literature from 1970 to the present. The review in Section 3.3 covers mainly (though not solely) those empirical studies that preceded the endogenous growth literature, while Section 3.4 reviews those that follow the emergence of this literature. We revisit the empirical trade and growth literature in Section 3.5. That section first discusses some measurement issues relating to the variables that are employed in the empirical analysis. It next details the empirical methodology, specifies the estimating equations and presents the estimation results for both cross-section and panel estimations. Conclusions are presented in Section 3.6.

3.2 THE ROLE OF INTERNATIONAL TRADE IN ECONOMIC DEVELOPMENT

3.2.1 A Marginal Role for Trade: 1945-1980

Following the end of the 2nd World War, many newly independent developing countries employed restrictive trade policies in pursuit of an import-substituting industrialisation (ISI) strategy as a means of achieving long-term economic development.[2] This strategy was in keeping with the widespread view prevailing among economists and policy makers at that time, that the stimulation of industrialisation through import-substituting policies was the best way for these countries to develop more rapidly. The economic reasoning seems to be that since there was an existing domestic demand for imported manufactured goods, then by restricting the imports of these goods, this demand would then be shifted to domestic producers. This in turn would permit the country's primary-product export earnings to be used for importing the capital goods needed for industrialisation. It was a strategy that also resonated with the political leaders of the newly independent nations some of whom saw the achievement of industrial status as an opportunity to realise not only economic objectives, but also broad political ambitions (see Sachs and Warner 1995; Rodrigo, 2001; Baldwin, 2003).

The ISI model originated in the ideas of Raul Prebisch (1950) and Hans Singer (1950).[3] Both based their policy prescriptions on what they saw as a secular decline in the prices of primary products (the exports of developing countries) vis-à-vis the prices of manufactured goods (the exports of the developed industrialised countries).[4] In their view, this decline in the terms of trade coupled with the low elasticity of demand for primary products made the expansion of production of these products an unattractive proposition. They further argued that while productivity advances in the industrial 'centre' translate into higher wages, advances in the developing 'periphery'

[2] As pointed out by Krueger (1997), Latin America and a few other countries (including China, Thailand, and Turkey), then regarded as "underdeveloped", were not formally colonies prior to the Second World War. However, they were regarded as being "economically dependent".

[3] Prebisch was at the time the Secretary General of the United Nations Economic Commission for Latin America (ECLA). He later founded and became the Secretary General of the United Nations Conference on Trade and Development (UNCTAD). As pointed out by Greenaway and Milner (1993), Prebisch's ideas on development in general and trade policy in particular, belonged to a body of analysis known as structuralism.

[4] Commonly referred to as the Singer-Prebisch thesis.

merely led to lower export prices. Therefore, free trade would lead to a widening gap between rich and poor countries. The fear was that free trade would lock in comparative advantage towards continued specialisation in the production and export of primary products based on low-skilled labour. Manufactures would continue to be imported from metropolitan countries, much as before, and domestic industry would never take off (Rodrigo, 2001, Ch. 5; see also Greenaway and Milner, 1993, Ch. 3; Krueger, 1997).

It is these "structural obstacles" in the 'periphery' which provided the justification for widespread intervention to regulate trade, finance, production and distribution (Greenaway and Milner, 1993). With regard to trade policy, protection was seen as necessary for a limited period during which industrial skills could be accumulated by producing for the domestic market. In the absence of protection, it made little sense for private investment (or even public investment) to go into areas dominated by established producers abroad though such industries could become viable in the long run through dynamic effects. Therefore, industrialisation, buttressed by an inward oriented strategy, was seen as the key to structural transformation.

The theoretical and intellectual support for the inward oriented development strategy advocated by Prebisch and Singer rested on the infant industry argument advanced by Alexander Hamilton (1751) and Friedrich List (1856) for the USA and Germany in their respective episodes of early industrial emergence.[5] The infant industry argument was accepted by many classical and neo-classical economists as a

[5] Advocates of the ISI model argued that the infant industry argument, premised on the basis of a single industry, was applicable to the entire manufacturing sector and not only to a single industry (Baldwin, 2003). Greenaway and Milner (1993) provide a detailed economic analysis of this and other influential arguments for inward orientation that revolve around the structuralists belief that developing countries are characterised by widespread market imperfections.

theoretically valid exception to the case for worldwide free trade (Baldwin, 2003). For example, John Stuart Mill, credited with first formulating the argument in economic terms, argued that it takes time for new producers in a country to become "educated to the level of those with whom the processes are traditional". During the temporary period, when domestic costs in the nascent industry are above the product's import price, a tariff is seen as a socially desirable method of financing the investment in human resources needed to compete successfully with foreign producers.

The widespread acceptance of the premises underlying ISI policies for almost three decades after the 2nd World War by academics, policy makers and institutions was noted by Edwards (1993) and Krueger (1997) among others. According to Edwards, from the 1950s to the 1970s, a large number of development economists embraced the inward-oriented ISI programme and devoted considerable energy towards the design of planning models for its implementation. Krueger on the other hand, points to the developing country exceptions that were incorporated into the General Agreement on Tariffs and Trade (GATT) Articles. Article XVIII explicitly protecting the developing countries from the "obligations" of industrialised countries and permitting them to adopt tariffs and quantitative restrictions.

It is generally agreed that initially, ISI policies worked quite well (see Baldwin, 2003; Rodrik, 1999). The high prices of imported non-essential manufactured goods, resulting from the high levels of implicit protection, shifted domestic demand for these goods from foreign to domestic producers. This in turn led to significant increases in the output of simple manufactured goods, facilitated by the provision of foreign exchange by governments to domestic producers for the importation of key intermediate inputs and capital goods. Since many of the manufacturing activities were quite simple and consisted largely of assembling products manufactured abroad, for example cars, they intensively utilised the abundant unskilled labour present in the newly industrialising nations. At this stage, the growth effects of the ISI policies were enough to offset the simultaneous adverse effects on economic efficiency resulting from their implementation. Additionally, the overvalued domestic currencies resulting from the tight exchange controls and expansionary production policies not only kept the import prices of the needed capital goods and intermediate prices low but appeared not to reduce earnings from the exports of primary-products.

After two decades of post-war upswing, inward-oriented ISI policies appeared unsustainable in the face of the economic slowdown and external shocks visited upon the global economy in the decade 1973-1983. Growth rates in a number of developing countries in Latin America, the Middle East and Sub-Saharan Africa collapsed. This was accompanied by both macroeconomic and balance-of-payments crises that worsened with the debt crisis of 1982. There are however, conflicting views over the factor(s) responsible for the parlous economic state many developing found themselves in after 1975. The predominant view held by many economists and policy-makers is that the inefficiencies of ISI built up steadily to the point where developing countries could not withstand the post-1973 shocks. Baldwin (2003), argues that the extension of ISI policies to cover more and more intermediate inputs and capital goods imposed hardships on the export sector which then began to have adverse growth effects. For example, an overvalued currency resulted in the number of units of foreign exchange received by exporters remaining low while, simultaneously, these producers were forced to purchase increasing amounts of intermediate inputs and capital goods domestically at high prices. The resulting squeeze on profit margins forced them to curtail export production.

Additionally, the higher skill and technology requirements for the more complex intermediates and capital goods and the absence of large domestic markets needed to achieve efficient levels of production of these goods, further worsened the profit outlook for domestic producers. This situation was made worse by the simultaneous pursuit of aggressive expansionary activities by governments and private businesses which fuelled greater inflationary pressures. This commonly resulted in large government budget deficits and balance-of-payments deficits which were invariably met with tighter controls over exchange rates and imports and greater government intervention (see also Krueger, 1998). The net outcome was a general slowing of the growth rate compared to the early period of ISI.

Krueger (1998) argues that ISI inflicted both static and dynamic losses on the countries that adopted it. With respect to the former, this arises as a result of resource misallocation, while in the case of the latter it is a consequence of rising incremental capital/labour ratios, small domestic markets, rising corruption and reduced access to ideas and knowledge capital from abroad. According to Krueger, after the 'easy' ISI opportunities have been exploited, the new activities induced by protection lie further away from a country's comparative advantage. For developing countries with a relative abundance of unskilled labour, this results in more human and physical capital intensive activities. This in turn means rising incremental capital-labour ratios which, for a given savings and investment rate, implies a declining rate of economic growth.

However, there are those who challenge this view and instead argue that the economic crises faced by most developing countries in the decade after 1975 had their genesis in factors that were generally unrelated to ISI as a development strategy. Rodrik (1997, 1999) believes that the transition from rising economic and productivity growth in the two decades preceding 1973 to economic crisis in the decade immediately after was more abrupt and complex. He argues that not only did ISI resulted in unprecedented economic growth to scores of countries in Latin America, the Middle East and North Africa and some countries in Sub-Saharan Africa for about two decades, TFP growth was also high and did not discriminate unambiguously between the ISI majority and those later found to have followed outward-oriented policies.

However, as growth rates in the industrial countries declined sharply following the 1973 oil shock, both per capita GDP and TFP growth collapsed in Latin America, the Middle East and Sub-Saharan Africa. A number of countries in these three groups experienced negative TFP growth while both budget and trade deficits widened dramatically as their governments persisted with expansionary policies. This resulted in widespread macroeconomic instability that was finally precipitated by the world debt crisis in 1982, and eventually led to many of these countries signing on to IMF and World Bank programs that induced a policy change. In contrast, East Asia was not significantly affected while South Asia, which had rigidly followed ISI policies, marginally improved its performance without effecting a qualitative change in its long-term growth rate (Rodrik, 1996; Rodrigo, 2001).

Rodrik posits that the proximate reason for the growth collapses in many developing countries in the period 1975-90 was their inability to adjust macroeconomic policies to the series of external shocks they experienced from 1973. These episodes led to inflation, rising trade and budget imbalances, debt crises and foreign exchange problems. He further argues that the countries that successfully withstood these shocks were those whose governments undertook the appropriate macroeconomic adjustments (in the areas of fiscal, monetary and exchange-rate policy) rapidly and decisively.

More fundamentally however, the success in adopting these macroeconomic adjustments was linked to deeper social determinants, namely, the ability to manage the domestic social conflicts triggered by the turbulence of the world economy during the 1970s. It is this that made the difference between continued growth and economic collapse. According to Rodrik (1997), "countries with deeper social divisions and weaker institutions of conflict management experienced greater economic deterioration in response to the external shocks of the 1970s" (p.3). Thus while South Korea succeeded in overcoming the crisis quickly, Turkey and Brazil did not. Moreover, India experienced no crisis of a similar magnitude despite adhering rigidly to ISI policies. This, Rodrik argues, is because India's links with the global economy were relatively weaker.

If we leave aside the debate over the factors truly responsible for the economic crises faced by most of the developing world (at the start of the 1980s) that adhered to ISI policies, then it is hard to escape the conclusion that some of structuralist arguments upon which the case for ISI is made, are not fully supported by the evidence. Taking the most pervasive and probably most influential of the arguments for inward orientation– infant industry protection – there is conclusive evidence which shows that most infant industries never grew-up (see Bell, Ross-Larson and Westphal, 1984). Additionally, because protection provides the infant with access to rents then politically it becomes problematic to remove the shelter (Greenaway and Milner, 1993). Consequently, inefficient production takes place behind protective barriers. Greenaway and Milner argue that this may not be a feature of infant industry protection per se but rather the form of the support given, namely a protected environment with direct controls. They note however that certain types of policies are definitely more conducive to rent-seeking than others. This claim is also reflected in the writings of Rodrik (see Rodrik, 1995).[6]

This then raises the question about the optimal intervention strategy or more correctly the appropriate instruments for dealing with the distortions identified. The issue of optimal policy intervention is central to neo-classical economists response to the existence of market distortions. In their view, appropriate instruments have a chance of efficiently correcting the distortion while inappropriate instruments may make the situation worse. See Greenaway and Milner (1993) and Baldwin (1969, 2003) for a discussion on possible alternative instruments to protection as a means of dealing with the distortions identified by proponents of the inward-oriented development strategy.

It is to an overview of the trade and development strategy widely regarded as representative of the views of mainstream neo-classical economists that the thesis now turns.

[6] To be fair to Rodrik and one of the main advocates of ISI – Raul Prebisch – they both recognised the limitations of trade restrictions as a means of bringing about sustained economic growth. This is clearly evident in their writings. In Rodriguez and Rodrik (2000), the authors state that they know of no credible evidence – at least for the post-1945 period – that suggests that trade restrictions are systematically associated with higher growth rates. Similarly, Prebisch (1959) noted that, "... protection by itself does not increase productivity. On the contrary, if excessive, it tends to weaken the incentive to produce" (p.259).

3.2.2 A Central Role for Trade: The Period 1980-Present

As the decade of the 1980s approached, neo-classical economists were unanimous in their condemnation of ISI as a strategy for economic development. It was a verdict to which policy-makers over much of the developing world had converged a decade or so later. The philosophy of an 'outward-oriented' approach to development was now displacing the previously followed 'inward-oriented' approach. What was responsible for this sea change in thinking regarding the role of trade policy in fostering economic development?[7] A confluence and interaction of several factors led to this paradigm shift.

First, there was a pronounced change in the intellectual climate in industrialised countries towards 'new conservatism' (Greenaway and Milner, 1993); second, the juxtaposition of the extraordinary success of the strongly export-oriented East Asian newly industrialised economies (NIEs) with the poor economic performance of most of the inward-oriented developing countries (World Development Report (1987); Greenaway and Nam, 1988); third, growing evidence on and greater exposure to the costs of protection contained in the multi-country case studies on trade and industrialisation policies undertaken by NBER, OECD, IBRD (Greenaway and Milner, 1993; Baldwin, 2003); fourth, increasing evidence from fieldwork studies which suggest that agents in LDCs mostly behaved as rational optimising agents (Stern, 1989); and finally, 'enforced' liberalisation as part of the policy conditionalities for World Bank Structural Adjustment Loans (SALs).[8]

[7] The radical change in ideas with regard to trade policy and economic development was noted by Anne Krueger in her 1997 presidential address to the American Economics Association (see Krueger, 1997).

[8] Greenaway and Milner (1993) argue that the major multilateral lending agencies, especially the World Bank, were willing sponsors to the ideas of 'new conservatism' in general and neo-classicism

This new development paradigm, a reflection of the neo-liberal, free-market ideas on trade and development, came to the fore in the World Bank's World Development Report of 1987 (hereafter, WDR, 1987).[9] Using the East Asian NIEs as its reference point, it argued that an undistorted price system and minimal government intervention through tariffs, subsidies and taxes targeted on specific sectors offers the best possible conditions for rapid growth. As a consequence, it advocated an outward-orientation that is neutral between export and import-competing production and which establishes a liberal trading regime.[10] While outer-oriented is not be construed as more incentives for producing for export than the domestic market, it does however imply a growth and industrialisation strategy that relies on the rapid growth of exports (see Krueger, 1998).

The theoretical rationale is that with rough parity in the effective exchange rates for imports and exports, the market mechanism would shift resources away from heavily protected (inefficient) import substituting sectors towards export sectors, in harmony with comparative advantage, thereby raising allocative efficiency in production. The implication here is that trade liberalisation (or movements towards openness) reduces static inefficiencies arising from resource misallocation and waste. These short-run (allocative efficiency) gains from the reallocation of resources can temporarily increase the rate of growth in the transition that follows a trade liberalisation episode.

in particular. With regard to the World Bank, the authors cited the agency's open endorsement of these ideas and also the fact that they found clear expression in the policy reform packages introduced by a wide range of developing countries. Indeed one can argue that it is the IMF and World Bank's endorsement of these ideas that contributed to the expression the "Washington consensus".

[9] Rodrigo (2001) asserts that WDR (1987) is an expression of the views of Anne Krueger who was the World Bank's Chief Economist at the time.

[10] It should be noted that outward-orientation is not synonymous with *laissez-faire* free trade. It describes a 'neutral' trade regime that provides fairly uniform incentives for both import-competing and exporting activities primarily through the main mechanism of the effective exchange rate (see Krueger, 1997; 1998; Srinivasan and Bhagwati, 1999).

These are however, static gains from trade since they result from once and for all reallocation of resources.

In addition to the static gains that arise from a more outward-oriented trade strategy, proponents of this strategy point to dynamic gains that are also likely to accrue. Rodrik (1995) argues that while both types of gains are highlighted in making the case for a switch to the more market-oriented outward trade regime, greater emphasis is placed on the latter. He argues that is because the benefits that accrue from static gains, basically some Harberger triangles, are quantitatively minor compared to the benefits from dynamic gains, which usually are sizeable rectangles. The latter gains can arise through various avenues. Two of the more discussed routes are the gains arising from cost-cutting and those arising from technical change on account of a more rapid diffusion of technology.

The former refers essentially to benefits resulting from pro-competitive effects due to the wider scale of market interactions brought on by trade openness. For example, with liberalisation of trade, imports as well as the number of foreign firms operating in the liberalising country increases. This in turn leads to greater competitive pressures on domestic firms. Faced with this increased competition, domestic firms are forced to either improve their efficiency and productivity (e.g. by eliminating management slack and overmanning) in order to survive or, failing to do so, exit the industry. The resulting gains are termed X-efficiency gains. In contrast, it is argued that protection results in inefficient production. This is because domestic firms operating in such an environment have a greater inclination to succumb to the 'quiet life' as protection increases their market power. In short, through competitive pressures brought on by trade policy openness, demand-side factors of production or producer behaviour can be influenced (see Urata, 1994).

In terms of the benefit from technical change, this is more likely in developing countries to arise from the supply-side impact of trade liberalisation. Here, the stated view is that firms are able to use high-quality parts, components, and machinery at lower prices which result in improved productivity. Moreover, since many technical improvements are 'embodied' in goods, increased trade or even enhanced contact with foreigners which trade creates, can stimulate innovative activity or new ideas through 'reverse engineering', imitation or copying. The contrasting argument is that the protection of firms producing intermediate and capital goods forces other firms using them to use low quality but high-priced products. In an effort to offset the disadvantage, these firms in turn ask for protection. Consequently, protection tends to proliferate thus bringing on a vicious cycle of low efficiency and increasing protection. Additionally, firms have no incentive to innovative.

Moreover, by increasing the size of the market, trade openness allows economies to better capture the potential benefits arising from scale economies. A representative statement on the dynamic gains from an outward-oriented strategy is that of Balassa (1988):

> It has often been observed that [monopolies and oligopolies] prefer a "quiet life" to innovative activity, which entails risk and uncertainty. In turn, the carrot and stick of competition give inducement for technological change. For one thing, in creating competition for domestic products in home markets, imports provide incentives for firms to improve their operations. For another thing, in response to competition in foreign markets, exporting firms try to

keep up with modern technology in order to improve their market position (p. 45).

Another major argument advanced in favour of outward-orientation and hence export promoting trade policies is that the institutional setting under which ISI policies operate are more likely to trigger directly unproductive profit-seeking (DUP) activities (Bhagwati, 1982). These activities, of which rent-seeking (Krueger, 1974) are the most well known and perhaps most important, divert resources from productive use into unproductive but profitable lobbying aimed at either changing policies, evading them or seeking the revenues and rents they generate (Srinivasan and Bhagwati, 1999). These activities are therefore growth inhibiting rather than growth enhancing.

However, the theoretical and empirical evidence advanced in support of an outward looking approach to trade policy and economic development, have been fiercely challenged by many researchers. In terms of the former, challenges have been mounted by Rodrik (1988, 1992), and Ocampo and Taylor (1998). With respect to the literature that implies a positive relationship between trade reforms and TFP growth, Rodrik (1992) argues that many of the arguments in favour of such a relationship lack coherence. He singles out the argument relating to static gains from allocative efficiency as the only one to be solidly grounded in accepted economic theory. According to him, indiscriminate protection of nascent industries yields few productivity gains and the benefits of the IS strategy are unlikely to offset its costs in terms of resource misallocation.

Of the other arguments, Rodrik considers the argument for trade liberalisation based on the contention that liberalisation may foster the rationalisation of industry structure by forcing inefficient firms to exit the industry to be one of the most appealing. This argument however, relies crucially on two features of the industry concerned: (a) economies of scale, and (b) free entry and exit. According to him, if they are present then there is a good case for trade liberalisation on the grounds of productivity. However, if increasing returns to scale activities are to be found predominantly among import competing (i.e. protected) sectors, as they often tend to be, one cannot take for granted that liberalisation will work to expand such activities. Whether scale effects add or subtract from the resource allocation gains depends on a variety of factors with no clear-cut presumption either way (see Rodrik, 1988). This conclusion is consistent with that of Ocampo and Taylor (1998) who argued that microeconomically, the case for liberalisation is dubious under increasing returns to scale and when firms can invest directly in productivity enhancement.

In terms of the empirical evidence, the source of contention revolves around the ascription of the spectacular economic performance of the East Asian NIEs mainly to the pursuit of an outward looking export-oriented strategy. For example, arguing that it was to escape slowing growth rates and economic crisis that made many inward-oriented developing countries eventually liberalise trade, Krueger (1998) noted that, "by contrast, by the early 1960s a few then-developing countries – most notably Korea, Taiwan, Hong-Kong and Singapore – had abandoned import substitution and adopted outer-oriented trade strategies. The results were spectacularly rapid growth" (p. 1514). Krueger's hypothesis about the causal factor (s) for the superior economic performance of the East Asian NIEs vis-à-vis the majority of developing countries that persisted with ISI, is consistent with the thinking of the 'Washington

Consensus'. It is a view that guided IMF and World Bank policy towards developing countries, particularly in the formulation of stabilisation and structural adjustment programs in the decade of the 1980s.

However, the notion that the East Asian success derived primarily from pursuing neo-liberal, free-market outer-oriented trade strategies has been vigorously challenged. Most, if not all, critics point to strong state intervention in Korea, Taiwan, Singapore, and indeed Japan itself, which is seen as establishing the original blueprint for export-oriented growth. It is argued that with the exception of Hong Kong, where state intervention was limited to the fundamentals, the state intervened decisively in the other East Asian NIEs to promote manufactured exports and to create the necessary institutional conditions for export-led growth (Wade, 1990; Rodrik, 1995; Rodrigo, 2001). The wide extent and scope of state intervention in East Asian economies were in fact clearly admitted in the World Bank's (1993) landmark *East Asian Miracle* study.[11] As the Bank noted, the state in all of these economies intervened either functionally or selectively in imports, export promotion, credit allocation, technology flows, firm growth, foreign investment and public ownership.

However, while lauding the *East Asian Miracle* study for conceding on the issue of state intervention, Lall (1994) argues that it failed to seriously confront the most important problem. That is, technological learning at the micro-level or the acquisition of technological capability. Lall shows that the industrial strategies adopted by each country involved costly learning trajectories, stretched out over

[11] Lall (1994) argues that the World Bank East Asian Miracle study was commissioned to bridge the chasm between the Bank's neoclassical conceptions and the reality of successful state interventions in East Asia. He also addresses in some detail what he considers to be major failings of that study.

decades and successive technologies (see also Rodrigo, 2001). Consistent with Lall's perspectives is the recent dissent from Joseph Stiglitz (see Stiglitz 1996, 1998), former Chief Economist of the World Bank. Stiglitz argues that the fundamental weakness of the Washington consensus is that it sees development as a technical-economic problem. That is, if governments get the fundamentals right and then withdraw, market forces would spring into action and automatically generate rapid growth. He notes that many countries which implemented policies of liberalisation, stabilisation and privatisation, central premises of the Washington consensus, failed to grow satisfactorily.

Additionally, Smith (1991) argues that many of the major export manufacturing East Asian NIEs simultaneously protect some infant industries while intervening to actively promote exports in others. He further argues that periods of significant export expansion are almost always preceded by periods of strong import substitution (also see Chenery et al., 1986). For instance, both Korea and Taiwan had brief phases of ISI with high levels of protection and outright bans on the imports of some goods (Bruton, 1989; Frank et al., 1975). However, as noted by Pack and Westphal (1986), these countries did limit the period of protection and managed a relatively expeditious transition to exports.

Finally, Evans (1991) questioned the theoretical and empirical evidence favouring an outward oriented development strategy over an ISI strategy. He argued this evidence and the attribution of market liberalisation as the key policy instrument, is often wildly overstated. With regard to the empirical evidence, he argues that it is based on case studies covering a relatively small number of countries (see Section 3.3.1

below). In reference to these case studies - compiled by Balassa, Krueger, Bhagwati and others - Bruton (1989) argues that though the evidence is impressive, they cannot be considered conclusive.

In concluding our discussion on the evolution of post-war thinking on trade policy and economic development, we note that despite continued differences in thinking on this subject, sometimes based on ideology rather than economics, there has been a considerable narrowing of contentious issues between those who subscribe to the neoclassical paradigm and those who hold more heterodox views. This is clearly evident in the views of the multilateral institutions as reflected in their programs and documents. In terms of the latter, moderation of positions (e.g. regarding the role of the state) advocated in the World Development Report of 1987 in the later reports of 1989 and 1991 respectively, bears testimony to this view. There is now a greater recognition of the roles played by the state and institutions in promoting growth (see World Development Report, 1991). This rethink can possibly be attributed to the varied and largely disappointing experience of stabilisation and structural adjustment programs in many developing countries in the decade of the 1980s.

This convergence of views on the role of trade policy in economic development is also evident among academic researchers. For instance, Rodrik though critical of the view that places trade policy openness at the centre of all development strategy, is not advocating a system of indiscriminate protection as a viable trade and development strategy (see Rodrik, 1999; Rodriguez and Rodrik, 2000). In his view, trade policy reform should be accompanied by sound macroeconomic policies and an institutional environment that can withstand the external shocks associated with greater integration into the world economy. Similarly, most advocates of an outward oriented trade policy also call for other policy changes aimed at eliminating large government deficits, maintaining market oriented exchange rates, increasing competition among domestic firms, reducing government corruption and strengthening the legal system among others, for trade liberalisation to be effective in the long run (see Baldwin, 2003).

3.3 REVIEW OF EMPIRICAL LITERATURE

On balance, most of the empirical studies investigating the link between trade and growth find that greater trade openness leads to faster growth. However, this finding, whether based on multi-country case studies or cross-country regression analyses has been questioned by various researchers. These include, among others, Levine and Renelt (1992) and Edwards (1993) for studies over the period 1970 through to 1992. Studies in the post 1992 period include Rodriguez and Rodrik (2000), and Harrison and Hanson (1999). As indicated previously, the main reasons for the scepticism over the finding of a positive relationship between trade and growth relationship relate to the difficulties associated in constructing satisfactory measures of trade openness, data problems and econometric techniques employed.

Most of the empirical work examining the effects of trade policy on economic performance at the economy-wide level undertaken over the last three decades can be classified into two broad and distinctive groups. The first group comprises large-scale multi-country studies that have investigated in some detail, the experiences of a group of countries with trade policy reform. Studies in this group represent the early attempts by researchers to link trade policies with economic performance. Most of these early studies found a consistently positive relationship between trade and growth. The second consists of econometric studies that have investigated, on the basis of aggregate cross-country data, the relationship between export growth and output growth as well as the impact of trade reforms on exports and economic growth.

Baldwin (2003) argues that the change in conventional thinking by economists and policymakers about the best policy approach to promote growth in developing countries was significantly influenced by the studies from these two groups, as well as by new theoretical modelling of the interactions between trade and growth. We now briefly review some of the studies from both groups in the following sections. More detailed reviews can be found in Edwards (1993), Greenaway and Sapford (1994), Rodriguez and Rodrik (2000) and Baldwin (2003).

3.3.1 Multi-Country Case Studies

Among the studies in this group, the two studies of commercial policies in developing countries directed by Little, Scitovsky and Scott (1970) and Balassa (1971) are regarded as the pioneers of modern multi-country investigations on trade orientation and economic performance in developing countries. Both projects undertook detailed analyses of the commercial policies in a number of developing countries with the aim of determining the effects of these policies on the overall economic structure of these countries.[12] They utilised the then newly formalised

[12] The Little et al project covered Argentina, Brazil, Mexico, India, Pakistan, the Philippines and Taiwan, while the Balassa project investigated Chile, Brazil, Mexico, Malaysia, Pakistan, the Philippines and the developed country of Norway for comparison.

concept of the effective rate of protection (ERP) as a means of comparing import substitution policies across countries.[13]

Both the Little et al. and Balassa studies found an extraordinarily high average rate of protection of value-added in manufacturing in most of the developing countries examined. In several of the countries, the ERP in manufacturing was almost double the nominal rate and frequently exceeded 100 percent. There was also great variability among industries and broad sectors which in many cases seemed to make little economic sense.[14] Further, exports of agricultural and mineral products were heavily discriminated against, with Pakistan having negative rates of protection in agriculture and Malaysia in mining and energy. The fundamental policy recommendations of these studies were that developing countries should significantly reduce their average levels of effective protection and reduce the discrimination against exports.

Later studies directed by Krueger (1978) and Bhagwati (1978) on behalf of the National Bureau of Economic Research (NBER), as well as by Papageorgiou, Michaely and Choski (hereafter PMC, 1991) on behalf of the World Bank, were broader both in terms of scope and focus than the two pioneering studies cited above. These projects investigated particular episodes of inward and outward-looking policy actions by considering not only changes in levels of import protection and export subsidisation, like the two pioneering studies mentioned above, but the array of

[13] The notion of the effective rate of protection was pioneered by Bela Balassa (1965), Harry Johnson (1965) and Max Corden (1966). It measures protection on a value-added basis rather than on the basis of the final price of a product. It thus takes into account the rate of protection on intermediate inputs as well as the final product (see Edwards, 1993; Baldwin, 2003).

[14] In an extreme example, in 1961 Chile was reported to have had an effective rate of protection on processed foods of 2,884 percent compared to 300 percent for non-durable consumer goods (see Baldwin, 2003; Balassa, 1971, p. 54).

macroeconomic policies (e.g. monetary, fiscal and exchange rate policies) employed by governments to promote import substitution or deal with its consequences.

Additionally, the Krueger-Bhagwati project is regarded as providing the first systematic attempt at formally classifying trade regimes.[15] Trade orientation was measured by the degree to which the protective (and incentives) structure in a country was biased against exports while trade liberalisation was defined as "any policy that reduces the degree of anti-export bias". A formal index of the degree of bias, computed as the ratio of the effective exchange rate paid by importers to the effective exchange rate paid by exporters, was constructed.[16] If this ratio exceeded the value of one, then the country's trade regime is regarded as being biased against exports and following import-substituting policies. If the ratio is less than one, the country is said to be following some variant of an outward-oriented strategy (e.g. an export promotion strategy). A unitary value means that the country has a neutral trade regime.

To evaluate the effect of trade policies, Bhagwati and Krueger combined the concepts of premium and bias with the definition of five phases in the evolution of trade regimes.[17] The policy conclusion of both Bhagwati (1978) and Krueger (1978) was that import-substitution policies generally do not result in sustainable increases in long-run growth rates and that outward-oriented policies are more appropriate for achieving this goal. The authors also provided detailed discussions on the process of

[15] The project included nine individual country studies: Turkey, Ghana, Israel, Egypt, the Philippines, India, Korea, Chile, and Columbia. Although Brazil and Pakistan were also included in the project, there were no published volumes on these countries.

[16] The effective exchange rate is the nominal rate for imports and exports corrected for various export subsidies and for import tariffs and non-tariff barriers.

[17] Phases I and II characterise illiberal and highly protective trade regimes while Phases III –V represent different stages in the movement towards free trade (see Bhagwati 1978 and Krueger 1978 for a fuller discussion on these Phases as well as the movements of countries between Phases).

moving from inward to outward-looking policies, the sequencing of trade and exchange rate liberalisation and other necessary accompanying policies such as fiscal, monetary and competition policies.

The World Bank commissioned study of PMC (1991), went further than the Krueger-Bhagwati project and investigated the most appropriate ways of actually implementing a liberalisation policy. Consequently, issues relating to sequencing, speed, and transitional costs were analysed and compared across countries. Additionally, motivated by the difficulties encountered by previous researchers in measuring the importance of quantitative restrictions, the individual country researchers constructed an annual index of trade liberalisation. The authors defined trade liberalisation as:

> ... any change which leads a country's trade system toward neutrality in the sense of bringing its economy closer to the situation which would prevail if there was no governmental interference....(Papageorgiou, Michaely, and Choski, 1991, vol. 7, p. xx).

An analysis of the evolution of this liberalisation index through time, together with the behaviour of other variables, meant that the authors were able to identify episodes of significant changes in trade policy. They found the impact of liberalisation on both exports and growth to be very significant. The average growth of real exports for the three years prior to liberalisation is estimated at 4.4%, whilst the figure for the three years after liberalisation is given as 10.5%. With respect for the rate of output growth, the average rate of growth for the three years prior to liberalisation is estimated at 4.45% and the three years after 5.51 % (see Greenaway and Sapsford, 1994).

Notwithstanding the efforts made by the PMC (1991) study to surmount the difficulties posed by measuring trade orientation, their liberalisation index is regarded as being subjective and reflective of the personal perception of the individual country author. Consequently, the index is not comparable across countries; a point conceded by the authors of the study. This deficiency precluded the authors from using the indices as indicators of trade orientation in their cross-country econometric analysis.

In a comprehensive review of most of the early studies that attempted to link a country's trade regime to its economic performance, Edwards (1993) was largely sceptical of their findings. The two main reasons for his scepticism were first, the difficulties encountered by the researchers in computing satisfactory indices of protection and trade orientation and second, the absence, in his view, of a fully convincing theoretical framework that links commercial policy, trade orientation, and growth.

Despite praising the studies of Little et al (1970) and Balassa (1971) for the wealth of information they provided on commercial practices in developing countries and their then highly innovative perspective on trade policy, Edwards noted that these two studies faced some serious measurement difficulties. He argues that no attempt was made in any of the specific country studies to calculate the evolution of the ERPs through time. According to him, the provision of one or at most two snap shots of protection in specific countries meant that no serious effort was made at analysing liberalisation episodes. Second, Edwards notes that in some instances the two studies generated important differences in ERP calculations in the same country for the same years.[18] Additionally, neither Little et al. (1970) nor Balassa (1971) sought to analyse how specific countries evolved from one trade regime to another, nor did they investigate empirically and in detail how alternative policies had affected growth in particular historical settings.

Thus while these studies have been insightful with respect to the nature of the development process and its relationship with trade, one is reluctant to draw broad generalisations from them because of their specificity and the subjectivity that the personal viewpoint of the authors may introduce into the analysis.

3.3.2 Cross- Country-Econometric Studies

In addition to the multi-country case studies that investigated the relationship between trade policies and economic performance, cross-country econometric studies were also undertaken during this period to test the relationship between trade and GDP growth. Most of these studies focused on the relationship between exports (levels and growth) and economic growth though a few also focused on the impact of trade liberalisation on economic growth. Generally, these studies have found that growth in exports as well as strong liberalisation episodes are associated with faster economic growth. Additionally, some have found evidence of a difference in the effect of exports on GDP growth on countries above or below some critical or threshold level of some variable. Greenaway and Sapsford (1994) refer to this critical

[18] Using the Corden (1966) method to compute the ERP for the manufacturing sector in the Philippines in 1965, Little et al (1970) got a figure of 49 per cent while Balassa computed an ERP of 61 per cent (see Edwards 1993).

level as the "threshold effect".[19] We now undertake a brief survey of this literature. See Edwards (1993), Greenaway and Sapsford (1994) and Jung and Marshall (1985) for more detailed reviews.

The studies that examined the export-growth hypothesis have generally utilised either rank correlation (mainly the early studies) or OLS estimation of an aggregate production function as their estimating methodology.[20] An example of a study that utilised the first approach is Michaely (1977). Based on a sample of 41 developing countries, Michaely finds growth in the share of exports in GDP to be positively and significantly associated with per capita GNP growth. The production function approach, on the other hand, originated in the work of Michalopoulos and Jay (1973) and was subsequently used by among others, Balassa (1978; 1985); Tyler (1981); Kavoussi (1984) and Moschos (1989). In all these studies, the growth rate of either GNP or GDP is regressed upon the growth rate of exports and a set of additional explanatory variables, usually related to the labour force and investment (Greenaway and Sapsford, 1994). For example, Belassa (1978) regressed the growth rate of exports on the growth of GNP, both including and excluding exports from the measure of output. He found the strongest positive relationship between the two variables when exports are included as part of output. However, Balassa also found a generally positive relationship when exports are excluded from GNP.

Krueger (1978, Ch. 11) also used the data from the individual country studies she directed to examine the relationship between liberalisation and exports, and liberalisation and economic growth. She econometrically tested two hypotheses: (1)

[19] We will explore the issue of the existence or non-existence of threshold effects in the openness-growth relationship in the next chapter.

more liberalised regimes result in higher rates of growth of exports; and (2) a more liberalised trade sector has a positive effect on aggregate growth. For the latter hypothesis, Krueger identified two sets of effects through which openness positively affects growth. The first, are direct effects that operate via "dynamic advantages"- including higher capacity utilisation and more efficient investment projects- and the second are indirect effects that work through exports: more liberalised economies have faster growth of exports which in turn result in more rapidly growing GNP.

Krueger finds strong support for the first hypothesis as a more depreciated real effective exchange rate for exports was shown to impact positively on non-traditional exports. Traditional exports however, did not appear to be sensitive to real exchange rate changes. Additionally, despite finding that higher growth of exports is associated with higher GNP growth, Krueger did not find evidence in support of her second hypothesis: a direct effect of liberalisation on growth. In contrast, Kessides (1991), using data based on the indices of liberalisation from the PMC (1991) study, finds that strong liberalisation episodes are associated with higher increases in the rate of GDP growth than weaker episodes. Further, countries with sustained liberalisation episodes were found to have larger increases in their rates of GDP growth relative to countries with failed liberalisation episodes.

However, on the basis of time series analysis for a sample of 19 countries used in the PMC (1991) study, Greenaway and Sapsford (1994) find little support for a positive association between exports and growth, and also between trade liberalisation and growth through the medium of exports. Their findings are consistent with previous

[20] Some researchers (e.g. Balassa,1978 and Kavoussi, 1984) have employed both approaches in the same study.

time series results in this literature which have been less conclusive about a close and robust relationship between exports and growth compare to cross-section analyses.

One major criticism levelled against studies examining the relationship between exports and economic growth is that the results of most of these studies are based on bivariate models or loosely specified production functions. Additionally, concerns have also been raised about the direction of causality. Does an increase in the growth rate of exports cause an increase in the rate of growth of GDP, or is the causality in the reverse? The tendency by most of the researchers who have investigated the export-growth hypothesis has been to ignore the issue and proceed on the basis that an increase in the growth rate of exports leads to an increase in the rate of growth of GDP. [21] Those studies that have sought to investigate the existence of reverse causality going from GDP growth to exports growth have relied mainly on time series techniques. Generally the results have been mixed with no overwhelming evidence that causality runs from export growth to GDP growth. For example, Jung and Marshall (1985) find, on the basis of Granger causality tests for 37 countries, that only in four countries (Indonesia, Egypt, Costa Rica and Ecuador) that export growth caused GDP growth. Additionally, Hutchinson and Singh (1987), also using Granger causality tests (for 34 countries), find that in only ten countries exports growth "caused" GDP growth. In three other cases GDP growth caused export growth. However, for 18 of the countries, it was not possible to establish one-way causality. In a more recent study, Harrison (1996) suggests that causality runs in both directions.

[21] The rank correlation analyses can of course only show covariation, while the OLS studies based on cross-sectional data are incapable of showing causation.

Many of the criticisms levelled against the early cross-country statistical/econometric studies that sought to investigate the relationship between trade (liberalisation) and economic growth are reflected in the following statement from Edwards (1993). According to him:

> [M]uch of the cross-country regression based studies have been plagued by empirical and conceptual shortcomings. The theoretical frameworks used have been increasingly simplistic, failing to address important questions such as the exact mechanism through which export expansion affects GDP growth, and ignoring important determinants of growth such as educational attainment. Also, many papers have been characterized by a lack of care in dealing with issues related to endogeneity and measurement errors. All of this has resulted, in many cases, in unconvincing results whose fragility has been exposed by subsequent work (Edwards, 1993; p. 1389).

Edwards (1993) cites the new endogenous growth theories as providing the modified framework necessary to handle policy effects on growth. We now turn to an examination of these theories.

3.4 TRADE OPENNESS IN THE CONTEXT OF 'NEW' GROWTH THEORY

Endogenous growth theory is widely seen as providing the theoretical link between trade openness and long-run growth that is missing in the standard neo-classical exogenous growth model. As Edwards (1998) argues, prior to the studies of Romer (1986), Lucas (1988) and Grosman and Helpman (1991) theoretical models had been unable to firmly link trade policy to faster equilibrium growth. Within the framework of the neo-classical growth model, trade and other policies will affect the equilibrium level of aggregate output but not its steady-state rate of growth (see Srinivasan and Bhagwati, 1999 for a dissenting view). Endogenous growth models however, demonstrate how international openness can affect growth rates through its effect on technological progress (TFP growth).

For example, Grossman and Helpman (1991) [see also Rivera-Batiz and Romer, 1991] consider open-economy growth models through both increasing variety (following Romer, 1990) and rising product quality (following Aghion and Howitt, 1992).[22] In this framework, skilled labour may either be employed in the production of current output or research. The rate of output growth is determined by the rate of introduction of the new designs for goods discovered in the research sector. Moreover, the pace of innovation is itself a function of the flow of skilled labour employed in research and the productivity of research (see Redding, 1998). International openness will affect an economy's rate of growth, in-so-far as barriers to the free movement of goods, ideas and factors of production affect incentives to innovate, the underlying productivity of that innovation or the dissemination of research discoveries across national boundaries.[23]

Grossman and Helpman (1991) identify a number of ways in which international flows of ideas and international trade in goods may affect long-run economic growth. One example is through technological spillovers and the international transmission of knowledge which they demonstrated in a model with trade in both intermediate and final goods. Technology is diffused by being embodied in intermediate inputs: if research and development (R&D) expenditures create new intermediate goods that are different (horizontally differentiated inputs model) or better (the quality ladder

[22] According to Grossman and Helpman, the effects of international openness are, to a large degree, independent of whether technological change is modelled in terms of increasing variety (increasing specialisation) or increasing quality (Redding, 1998).

model) and if these goods are exported to other economies, then the importing country's productivity will increase through the R&D efforts of its trade partner (see Keller, 2000). Therefore, to the extent that countries that are open to trade can either learn more quickly how to produce these new inputs or can import them, openness will be positively related to TFP.

Recently, a number of studies (e.g. Coe and Helpman, 1995; Coe, Helpman and Hoffmaister, 1997; Xu and Wang, 1999; Keller, 2000) 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). The role of capital goods imports as a conduit for technology transfer and in explaining differences in national efficiency in developing countries will be empirically examined in Chapter 5.

However, international trade in either intermediate or final goods may have an ambiguous effect on an economy's rate of growth (see Grossman and Helpman, 1991, Ch. 6). Whether or not a country gains from trade depends on a number of factors, including its comparative advantage vis-à-vis the rest of the world. For example, if the exploitation of comparative advantage leads a country that is technological backward to specialise in traditional goods (or sectors) that exhibit little potential for further growth, then that country may experience a reduction in its long-run rate of growth (see Feenstra, 1990 and Matsuyama, 1992).

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[23] Quah (1996a,b) suggests that the distinction between ideas and goods is somewhat artificial. He argues that an increasing proportion of value-added is embedded in logical units 'bits and bytes of memory' whether computer, biological or chemical rather than in physical or material form.

It is this ambiguity provided by some endogenous growth models that contributes to the continuing debate over whether these models have indeed provided the hitherto missing theoretical link between openness and long-run growth. For some (e.g. Edwards, 1998; Miller and Upadhyay, 2000), the studies of Romer (1992), Grossman and Helpman (1991, Ch. 9) and Barro and Sala-i-Martin (1995, Ch. 8) among others, provide persuasive intellectual support for the proposition that openness impacts positively on long-run growth. Countries that are more open to the rest of the world have a greater ability to absorb technological advances generated in the leading nations which spurs long-run growth. For Rodriguez and Rodrik (2000) however, there is no determinate theoretical link between trade protection and growth once real-world phenomena such as learning, technological change and market imperfections are taken into account. They further argue that the models of Feenstra (1990), Grossman and Helpman (1991), and Matsuyama (1992) are "formalisations of some very old arguments about infant industries and about the need for temporary protection to catch up with more advanced countries" (p. 10).

Against the background of the developments in growth theory, we once more return to the empirical literature.

3.5 EMPIRICAL STUDIES IN POST 'NEW' GROWTH THEORY ERA

As a result of developments in the 'new' endogenous growth literature, the criticisms of earlier statistical analyses and the availability of more comprehensive multi-country data sets (for example, Maddison, 1992; Nehru and Dhareshwar, 1993; Summers and Heston, 1988, 1991, 1995), there has been a proliferation of cross-country studies in the post 1990 period that continue to examine the relationship between trade liberalisation and growth. These cross-country econometric analyses have employed various measures of "openness" or "outwardness" and, in some cases, sophisticated econometric techniques to understand their association with the growth rates of GDP or total factor productivity (TFP). Once again, most of these studies have found a strong positive relationship between outward-looking policies and growth.

However, in an early and frequently cited study, Levine and Renelt (1992) find evidence which raises doubts about the robustness of some of these results to alternative specifications. Using six different measures of trade policies (along with other explanatory variables typically used in growth models) and the extreme-bounds analysis of Leamer (1985), they found no robust or consistently positive relationship between trade openness and long run growth.[24] The authors did find however, a robust, positive relationship between investment and trade shares, and also between investment and the Leamer index. The correlation between investment and trade led them to conclude that the beneficial effects of trade reform may operate through improved resource accumulation rather than through improved resource allocation.

Five of the best known and probably most widely cited and influential of the recent studies that have found a positive relationship between trade openness and growth - Dollar (1992), Sachs and Warner (1995), Ben-David (1993), Edwards (1998) and Frankel and Romer (1999)- have been extensively reviewed by Rodriguez and Rodrik (2000) and Baldwin (2003). Using the actual data sets from the five cited studies, Rodriguez and Rodrik demonstrated that the positive correlation between openness and growth found by the above cited studies is not robust, either because of shortcomings in the openness measures used or because of a failure to control for other important growth determinants. Consequently, with the exception of Edwards (1998) which forms part of our empirical analysis, these studies will not be the subject of a further detailed review in this thesis. Instead we briefly survey other recent papers on the subject some of which have attempted to address econometric problems posed by the possible endogeneity of trade indicators as well as unobserved country specific effects. These include, among others, the studies of Dollar and Kraay (2001), Greenaway et al. (1998, 2002) and Wacziarg (2001). Most of the recent studies once again find that trade or trade reforms are associated with either higher income levels or growth.

To examine the relationship between trade and growth, Dollar and Kraay (2001) use the within-country (rather than cross-country) variation in the data to identify the effects of trade on the latter. Specifically, they examined whether changes in decadal average growth rates can be explained by changes in trade volumes, which the authors regard "as an imperfect proxy for changes in trade policy". Dollar and Kraay argue that by using this approach, their results are not driven by geography-induced differences in trade (as in Frankel and Romer, 1999) or other unobserved country characteristics that influence growth but vary little over time, such as institutional conditions. They also include period dummies to control for shocks common to all countries, such as global demand shocks or reductions in transport costs. Their data set consists of 187 observations on growth in the 1990s and growth in the 1980s, for roughly 100 countries.

[24] The measures of trade used by Levine and Renelt include the black market premium, David Dollar's real exchange rate of protection, trade volumes, and two indices compiled by Leamer.

Dollar and Kraay (2001) find a strong and significantly positive relationship between the effects of changes in trade volumes on changes in growth for their IV regressions. Moreover, when they include a variable that proxies for institutional quality, and other omitted political and macroeconomic measures that affect growth and are correlated with increases in trade (e.g. changes in the share of government expenditure in GDP, changes in the rate of inflation and changes in the number of revolutions), the high level of statistical significance of changes in the volume of trade remains unchanged.[25] However, if these additional variables are assumed endogenous, the coefficient on the changes in the trade volume measure lose statistical significance. This finding leads the authors to conclude, "that the available data on trade, growth and other policies may not be sufficiently informative to enable us to isolate the precise partial effect of trade on growth, since our instruments are not sufficiently informative".[26]

Recently, Greenaway et al. (2002) investigated the impact of trade liberalisation on per capita GDP growth for a large sample of developing countries over varying time periods between 1975-1993. The novel features of this study are the authors' use of a dynamic panel framework based on GMM (and GMM-IV) estimations (see Arellano and Bond, 1991) and three different indicators of liberalisation, to analyse the empirical relationship between the latter variable and growth. The authors find evidence to suggest that liberalisation does in fact impact positively and significantly on growth. However, this impact does not appear to be immediate but with a lag thus

[25] Dollar and Kraay use a measure of the willingness of individuals to hold liquid assets via financial intermediaries as a proxy for a country's institutional quality.
[26] See Rodrik (2000) for a critique of the criteria used by Dollar and Kraay to distinguish the list of globalisers from non-globalisers and what he argues are other methodological flaws.

pointing to a J curve type effect. This evidence is consistent with their findings in an earlier paper (Greenaway et al., 1998).

The final study we review is Wacziarg (2001). This paper takes a completely different approach to investigating the empirical relationship between trade openness and growth to the studies reviewed earlier. Arguing that theory points to a number of costs and benefits to trade openness, which are generally not mutually exclusive, the author attempts to establish whether the dynamic gains from trade outweigh the dynamic costs. To this end, he employs a system of simultaneous equations which capture different theoretical arguments on the potential costs and benefits of trade policy openness. First, various channel variables are included in a growth regression. Then in order to identify the effect of trade policy on growth through a particular channel, Wacziarg multiplies the effects of trade policy on that channel and the effect of the channel on growth.

Using a new measure of trade openness which he constructed based on a weighted average of several indicators (tariff revenues, NTBs, and an indicator of overall outward orientation), Wacziarg finds that openness impacts on growth positively for a sample of 57 countries (developed and developing) for the period 1970-1989. Of the total effect of openness on growth, accelerated accumulation of physical capital accounts for more than half of the total, with enhanced technology transmission and improvements in macroeconomic policy accounting for smaller amounts.

Recently, Srinivasan and Bhagwati (1999) have sharply criticised cross-country regression analyses as the basis for determining the relationships between trade openness and growth. They argue that due to the weak theoretical foundations of most of these studies, the poor quality of the data bases they must use and inappropriate econometric techniques utilised in many instances, the best evidence in support of the openness-growth link is that " nuanced, in-depth analyses of country experiences in major OECD, NBER, and IBRD projects during the 1960s and 1970s have shown plausibly, taking into account numerous country-specific factors, that trade does seem to create, even sustain growth" (p.6).[27] Srinivasan and Bhagwati do however concede that such regressions can contain useful information and can be valuable aids in thinking about the issue. Additionally, with respect to the issue of the possible endogeneity of the right hand side variables included in typical growth regressions, they admit to the fact that some researchers (as was indicated above) have attempted to address this particular issue by using two stage least squares or IV estimations.

Notwithstanding Srinivasan and Bhagwati's critique, we seek in this thesis to examine the empirical relationship between trade openness, TFP growth and efficiency at the cross-national level. Additionally, consistent with recent empirical studies on the subject, we also control (where practicable) for possible simultaneity bias due to the likelihood of some regressors being endogenous. Before doing so, we revisit the empirical evidence.

[27] See Rodrik's website for response to Srinivasan and Bhagwati's (1999) claim that the detailed country studies based on the OECD, NBER and IBRD projects establish more clearly a positive

3.6 OPENNESS, TRADE ORIENTATION AND TFP GROWTH : REVISITING THE EMPIRICAL EVIDENCE

In this section, we use the three alternative residual estimates of TFP growth constructed in the previous chapter to test the sensitivity of various measures of trade openness to these alternative estimates. To do so, we employ both cross-section and panel data estimations. This approach is largely informed by the fact that some of the more frequently cited and influential empirical papers (in academic and policy making circles) linking openness to growth on the basis of macroeconomic data, generally fall into either one or the other category.[28] For example, the often-cited studies of Dollar (1992), Sachs and Warner (1995) and Edwards (1992, 1998) are of the cross-section type while in terms of panel estimations, the studies by Miller and Upadhyay (2000) and, to a lesser extent, Dollar and Kraay (2001) are examples.

For the cross-section analysis, we use data from Rodriguez and Rodrik (2000) to specifically test the robustness of their findings in relation to their critique of Edwards (1998).[29] Doubts, however, have been expressed over results which find a positive association between greater openness and economic growth on the basis of studies which use cross-sectional averages or starting values for time series data (see Harrison, 1996). Harrison argues that the use of cross-section data make it impossible to control for unobserved country-specific effects, possibly biasing the results. She further argues that long-run averages or initial values for trade policy variables- particularly in developing countries- ignore the important changes which have occurred over time for the *same* country. Additionally, Söderbom and Teal

relationship between openness and growth compared to cross-national regressions.

[28] One exception is Harrison (1996) who employs both cross-section and panel estimations.

[29] We thank Professor Dani Rodrik for making the data used in Edwards (1998) as well as Rodriguez and Rodrik (2000) available to us.

(2001) argue that cross-section estimations while informative of the correlations that can be established from the data, are uninformative as to the determinants unless convincing instruments can be found. On the issue of instrument validity, they pointed to Rodriguez and Rodrik's finding that the instruments used by Edwards (1998) were generally not valid. In light of these arguments, we utilise pooled cross-section, time-series data to broaden our investigation of the robustness of measures of openness to alternative measures of TFP growth.

Summary statistics for all variables used in the cross-section and panel estimations are shown in Appendix 3.2 for this chapter.

3.6.1 Measurement Issues, Data and Estimation

3.6.1.1 TFP Growth

As a result of the different methodologies, estimation techniques and data employed by researchers in estimating TFP at the national level, obtaining comparative data on TFP across a large number of countries is quite difficult. In fact, this absence of high quality comparative data on TFP has been cited by Edwards (1998) as one of the contributory factors to the impairment of the connection between openness and productivity growth. In light of this, and to a large extent to test Edwards' claim, we use three alternative residual measures of TFP growth constructed using the estimated factor elasticities from an aggregate Cobb-Douglas production function. These three measures are representative of the existing residual TFP measures at the country level, generated on the basis of an econometric estimation of an aggregate production function. Two of the measures of TFP growth are based on the polar assumptions of complete heterogeneity and homogeneity respectively, in the production parameters across countries. The third, is an intermediate measure in that it incorporates elements of both heterogeneity and homogeneity. That is, we allow for heterogeneity in the production parameters across countries but homogeneity in the factor elasticities (used to estimate TFP growth) within regions. The measure is based on the principle of the mean group estimator of Pesaran and Smith (1995).

The data for constructing these TFP growth estimates were obtained from the World Bank STARS database.

3.6.1.2 Measures of Openness and Trade Orientation

As indicated earlier, one of the main factors in the disagreements over the empirical relationship between trade openness and growth is the difficulties involved in constructing satisfactory measures of openness. Proudman, Redding and Bianchi (1997) argue that this is due to the fact that openness is neither directly observable nor has an accepted definition derived from theory. Consequently, a large literature has evolved proposing and evaluating alternative measures to capture the concept of openness.[30] Essentially, three strands have been identified in the literature (Baldwin,1989b; Pritchett, 1996; Cameron et al., 1998). The first links economic growth to *ex post* measures of openness such as export or trade shares. As indicated in our earlier review of the empirical literature, the early cross-country studies linking exports to economic growth (e.g. Balassa, 1982, Feder, 1983; Jung and Marshall, 1985) employed measures of export performance.

The second strand seeks to evaluate openness using an outcome-based approach. This approach assesses the deviation of the actual outcome from what the outcome would have been without the trade barriers (i.e. the predicted outcome). Outcome-based measures can be either trade flow based or price based. The former, generated as the residuals from a trade intensity regression, indicates the amount by which a country's actual trade intensity differs from that predicted for a country with similar characteristics. An example is Leamer's (1988) openness index which presents a measure of openness generated on the basis of a modified Hecksher-Ohlin-Vanek (HOV) model of trade flows. The price based measures on the other hand, measure the deviation of the actual from the predicted outcome on the basis of price comparisons. They are usually measures of trade distortion and are frequently based on differences in purchasing power parity (PPP). Examples of studies using such a measure include Pritchett (1996) and Miller and Upadhyay (2000).

The third strand identified in the literature – incidence-based measures - attempt to measure trade policies by direct observation of the policy instruments. They have been employed in numerous trade-growth studies which include, among others, Balassa (1985), Dollar (1992), Edwards (1992), Leamer (1988) and Sachs and Warner (1995). Two of the most common incidence-based measures are the level (dispersion) of tariffs and the frequency of the various types of non-tariff barriers (NTBs). The Sachs-Warner (1995) openness index combines some incidence-based measures of trade policy with information on other aspects of trade restrictions to derive a composite measure of trade policy openness. Specifically, it is a zero-one dummy which takes the value of 1 if the economy is classified as open and 0 if the economy is deemed to be closed based on a set of criteria relating to tariffs, non-tariff barriers to trade (NTBs), the treatment of exports, the existing economic system

[30] Prictchett (1996) provides a detailed review of the strengths and weaknesses of some of the different measures of trade policy orientation constructed by a number of academic researchers and institutions

and the size of the black market premium (BMP).[31] Recent efforts to construct a similar composite measure include Wacziarg (2001).

Despite the great efforts and ingenuity that have gone into constructing satisfactory indices of openness, this area continues to be a source of controversy. Pritchett (1996) for example, provides evidence that there is little pairwise correlation between different measures of openness, and therefore little consistency between the three strands of the literature. This can be partly attributable to the fact that the various openness measures used in the literature may reflect different aspects of a country's trade regime which, given its complex and multi-faceted nature, is nigh impossible to summarise in a single measure. Therefore most, if not all, of the separate measures used in empirical trade-growth studies have their strengths and their limitations.

For example, while measures of trade intensity are useful for examining the effects of trade on growth since they measure actual exposure to trade interactions, they are less useful if one is interested in examining the effects of trade policy on growth (Dollar and Kraay, 2001). This is because they are not direct measures of trade policy per se but outcomes of trade policy (Pritchett, 1996; Edwards, 1998). According to Edwards, it is possible for a country to distort trade heavily and still have a high trade dependency or openness ratio. Second, measures such as the share of trade (or its components) in GDP are also influenced by geographical characteristics such as country size and proximity to major markets. Third, they are

over the last three decades (see also Baldwin, 1989; Edwards 1993, 1998).

[31] Sachs and Wraner (1995) classified an economy as closed if any one of the following five criteria is met : average tariff rates higher than 40 per cent, NTBs cover on average more than 40 per cent on imports, the presence of a socialist economic system, state monopolies of major exports, a BMP in excess of 20 per cent in either the 1970s or 1980s.

more likely to be subject to endogeneity problems with respect to growth compared to other openness indicators (Frankel and Romer, 1999).

These criticisms notwithstanding, trade intensity measures are still widely used in the empirical literature linking trade openness to economic performance; albeit often combined with other policy based measures of openness. This is particularly true for the cross-country studies using pooled cross-section and time series data. Examples include Söderbom and Teal (2001), Miller and Upadhyay (2000) and Dollar and Kraay (2001; 2003). One possible reason for their widespread use may be the fact that the data for these measures have fairly broad country and time period coverage. Dollar and Kraay (2001) also argue that in many countries the pervasiveness of NTBs constitute significant obstacles to trade that are not captured by average tariffs. They contend that the advantage of trade volumes is that they in part reflect these NTBs to trade. They thus view this measure as an "imperfect proxy for trade policy".

On the other hand, while incidence-based measures describe the institutional features of a country's attitude toward the rest of the world with respect to trade and factor flows and are likely to be less endogenous than outcome measures of openness, they are generally atheoretic. Consequently, when the construction of the openness index involves combining various incidence-based measures as in the case of the Sach-Warner, the absence of guidance from theory on how to weight the various trade policy variables thought to be important an element of judgement is required in both the scaling of the individual indicators and the relative weight to be attached to each (see Greenaway et al., 1998). Concerns have also been raised over the use of deviation measures as indicators of trade policy (see Rodriguez and Rodrik, 2000; Wacziarg, 2001)

Since the focus of this chapter is to examine the robustness of the trade openness-TFP growth relationship to alternative measures of the latter variable, we leave aside for the moment some of the concerns detailed above about some indicators of the former. We therefore employ in our empirical analyses several of the openness measures frequently used in the literature. These measures cut across the three broad classes of measures discussed above. For our cross-section analysis, we use the 9 indices of trade policy openness and the composite index of openness employed first in Edwards (1998) and in the later critique of that study, among others, by Rodriguez and Rodrik (2000). The 9 indices of trade openness (distortions) are: (i) the Sachs-Warner Openness Index (SWOPEN); (ii) the World Development Report Outward Orientation Index (WDR); (iii) Leamer's Openness Index (LEAMER); (iv) the Average Black Market Premium (BLACK); (v) the Average Import Tariff on Manufacturing (TARIFF); (vi) the Average Coverage for Non-Tariff Barriers (QR); (vii) the Heritage Foundation Index of Distortions in International Trade (HERITAGE); (viii) Collected Trade Taxes Ratio (CTR); (ix) Wolf's Index of Import Distortions (WOLF). The composite index (PCF) is computed as the first principal component of (i), (iv), (v), (vi) and (ix). These indices were supplemented by alternative measures of (iv) and (viii) constructed by Rodriguez and Rodrik (see Data Appendix to this chapter).

For our panel estimations, we use the ratio of exports plus imports to GDP (OPEN1); the Sachs-Warner openness index (SWOPEN); the collected taxes ratio (CTR) and the local price deviation from PPP (PRIDEV) as the measures of openness (trade orientation). The price deviation measure is essentially a measure of the price level of GDP (%) in PPP prices, relative to the U.S. dollar exchange rate. This variable is particularly useful in capturing the effects of non-tariff barriers to trade which can be quite pervasive in developing countries.

Data for these measures were obtained from the World Bank World Development Indicators CD ROM 2000 and the Penn World Tables (Mark 5.6) of Summers and Heston (1995).

3.6.2 Cross- section Estimations and Results

The starting point for our empirical analysis is the specification of the estimating equation that underlies the open economy TFP growth model postulated by Edwards (1998). From that model, the possible determinants of TFP growth are identified as: initial conditions (initial levels of GDP per capita and human capital) and trade policy openness. In the spirit of Edwards (1998), we thus specify the following equation:

$$TFPG_i = \alpha_0 + \alpha_1 GDP65_i + \alpha_2 HUMAN65_i + \alpha_3 OPENNESS_i + \mu_i \quad \textbf{(3.1)}$$

where TFPG in this instance is a variable that is proxied by three alternative measures of the average growth rate of total factor productivity for the decade 1980-1990, GDP65 is the log of initial per capita GDP in 1965 which is intended to capture the existence of TFP (conditional) convergence and so its coefficient is expected to be negative, HUMAN65 is the log of the initial level of human capital (average years of schooling) in 1965 and is intended to reflect the fact that countries with a more developed educational system have a greater ability to innovate and absorb new ideas. Our *a priori* expectation is for the coefficient of this variable to be positive.[32] OPENNESS is a variable proxied by 9 alternative indices of trade policy openness (distortions) as well as a composite index, all of which enter (3.1) sequentially. It is on the coefficients of these indices that we mainly focus. The expectations for these coefficients are that they are consistent with the hypothesis that more openness (less trade distortions) is associated with higher rates of TFP growth. i indexes countries which totals 93 (developed and developing).

Edwards uses weighted least squares (WLS) and instrumental variables weighted least squares (IVWLS) to estimate equation (3.1), and generally finds that countries with more open (less distorted) trade policies experienced faster TFP growth. This finding, he argues, is robust to the use of openness indicator, estimation technique and functional form. He also finds a positive and significant coefficient for the initial level of human capital in all 19 regressions and support for conditional convergence in 18 of them.

One of the criticisms levelled by Rodriguez and Rodrik (2000) against the findings of Edwards (1998) is that the latter's claim of robustness of his regression results to alternative indicators of openness (distortions) is " largely an artifact of weighting and identification assumptions that seem.....inappropriate" (Rodriguez and Rodrik, 2000, p.37). When they repeat Edwards' regressions using the natural log of per capita GDP (1985) as the weighting variable instead of per capita GDP (1985) used by Edwards, a number of the coefficients on the openness indicators now have the

[32] The use of the initial level of education by Edwards has its basis in a somewhat detailed exposition of the mechanics of TFP growth in the context of an open economy. It is based on a concept first proposed by Nelson and Phelps (1966) in the context of human capital accumulation. See Edwards (1992, 1998).

'wrong' sign while some lose their statistical significance.[33] They reason that by using WLS estimation, Edwards is presumably correcting for possible heteroscedasticity in the residuals. Further, by using per capita GDP as his weighting variable, he is implicitly assuming that the form of the scedastic function is known. To put aside doubts about the appropriateness of alternative assumptions regarding the nature of the scedastic function, Rodriguez and Rodrik (2000) re-estimated Edwards' regressions using White's (1980) heteroscedasticity consistent standard errors which are robust to the form of heteroscdeasticity. From among the 19 different specifications, they find evidence that more openness is significantly associated with higher productivity growth for only three (3) of the indices. These are: the Collected Taxes Ratio (CTR), the World Development Outward Orientation Index (WDR) and the Heritage Foundation Index of Trade Distortions (HERITAGE). Of these three, Rodriguez and Rodrik described the last two as subjective indices and thus are likely to suffer from the judgement biases of their authors.

In light of Rodriguez and Rodrik's finding that Edwards' results are sensitive to the choice of weighting variable, we take their results as our starting point and first estimate equation (3.1) by OLS with heteroscedasticity consistent standard errors. Unlike Rodriguez and Rodrik, who took Edwards' measure of TFP growth as given and focused their critique mainly on the proxies of trade policy openness, our emphasis is primarily on the left hand side variable: TFP growth. Table 3.1 presents results from cross-section estimations using our preferred measure of TFP growth from the previous chapter, TFPG-AMG2, and the nine indicators of openness

[33] Rodriguez and Rodrik postulate that the difference in results from weighting by GDP appears to be the existence of a relationship between the openness indices used by Edwards and TFP growth at high levels of income. They posited that this relationship in itself is apparently driven by the fact that the great majority of economies with restrictive trade practices and high levels of GDP per capita in 1985

(distortions) as well as the composite index (PCF). The first three indices are direct measures of openness and hence their coefficients are expected to be positively correlated with TFP growth. In contrast, the next six indices are measures of trade distortions and their coefficients are therefore expected to be negatively related to TFP growth. This is also true for the composite measure.

Table 3.1: Results of OLS Regressions
Cross-section Estimations

Dependent Variable :TFP Growth (Average 1980-1990)			
Openness Indicators (Expected Sign)	**TFPG-AMG2 (1)**	**TFPG (R & R) (2)**	**N**
1. SWOPEN (+)	0.0222** (2.57)	0.0102 (1.54)	52
2. WDR (+)	0.0112*** (4.86)	0.0068*** (3.67)	32
3. LEAMER (+)	0.0035 (0.55)	0.0041 (0.82)	44
4. BLACK (-)	-0.0163** (-2.16)	-0.0098* (-1.79)	76
5. TARIFF (-)	0.0121 (0.86)	0.0114 (0.88)	68
6. QR (-)	0.0046 (0.50)	0.0036 (0.43)	67
7. HERITAGE (-)	-0.0076*** (-3.15)	-0.0064*** (-2.87)	58
8. CTR (-)	-0.1654 (-1.13)	-0.2676** (-2.25)	45
9. WOLF (-)	-2.1E-5 (-0.16)	4.1E-5 (0.36)	53
10. PCF (-)	-0.0070* (-2.31)	-0.0043 (-1.37)	35

Source: Author's estimates; Rodriguez and Rodrik (2000), Table V.I

Notes: Each row corresponds to two separate TFP growth regressions for the respective openness (distortion) indicator. Each equation also includes a constant and the log of GDP per capita in 1965, and schooling in 1965 as additional regressors. Their values, however, are not reported due to space limitations. The numbers in parentheses are t-statistics based on heteroscedasticity consistent standard errors.

*** means significant at 1%; ** means significant at 5%; * means significant at 10%.

were oil exporters. Because of their high incomes, these economies are weighted very heavily in the WLS regressions.

Generally, Rodriguez and Rodrik's results (column 2) are robust to our measure of TFP growth based on OLS estimations. Of the four indicators of trade policy openness they find to be significantly correlated to TFP growth, three are also shown to be significantly correlated to the augmented mean group measure of TFP growth (TFPG-AMG2). However, some of the proxies of trade policy openness appear to be sensitive to the way TFP is measured. For example, we find both the Sachs-Warner openness index and the composite openness measure constructed by Edwards (1998) to be significantly related to TFPG-AMG2. In contrast, using the TFP growth estimates derived in Edwards (1998), Rodriguez and Rodrik do not.[34] This pattern of results is reversed for the collected taxes ratio (CTR) of openness (distortion).

To further explore these findings we present results using the two alternative TFP measures also derived in Chapter 2. These are shown in Table 3.2 along with those of Rodriguez and Rodrik (2000) for comparative purposes. The sensitivity of the openness proxies identified above to alternative measures of TFP growth appears to be confirmed by the results shown in Table 3.2. Now the Sachs-Warner measure of openness is statistically insignificant in the regression with the completely heterogeneous TFP measure (TFPG-HET) but significant in the regression using GMM based measure of TFP (TFPG-GMM) as the dependent variable. In contrast to Rodriguez and Rodrik, the composite openness indicator (PCF) is significantly correlated to the two alternative TFP measures while for the collected taxes ratio (CTR) it is insignificant.

[34] Recall, Edwards derived estimates of TFP growth as residuals following a random effects estimation of a Cobb-Douglas aggregate production function with the factor elasticities constrained to sum to one (i.e. constant returns to scale is assumed).

Table 3.2: Results of OLS Regressions Cross-section Estimations				
Dependent Variable :TFP Growth (Average 1980-1990)				
Openness Indicators (Expected Sign)	**TFPG (R & R) (1)**	**TFPG-HET (2)**	**TFPG-GMM (3)**	**N**
1. SWOPEN (+)	0.0102 (1.54)	0.0096 (1.46)	0.019** (2.24)	52
2. WDR (+)	0.0068*** (3.67)	0.0172*** (7.36)	0.014*** (6.57)	32
3. LEAMER (+)	0.0041 (0.82)	0.0051 (0.66)	0.0050 (0.91)	44
4. BLACK (-)	-0.0098* (-1.79)	-0.0222*** (-3.10)	-0.018** (-2.34)	76
5. TARIFF (-)	0.0114 (0.88)	0.0140 (1.21)	0.017 (1.45)	68
6. QR (-)	0.0036 (0.43)	0.0042 (0.38)	0.008 (0.90)	67
7. HERITAGE (-)	-0.0064*** (-2.87)	-0.0074* (-1.85)	-0.0080*** (-2.81)	58
8. CTR (-)	-0.2676** (-2.25)	0.0072 (0.04)	-0.1240 (-0.91)	45
9. WOLF (-)	4.1E-5 (0.36)	0.2E-5 (0.72)	0.5E-4 (0.44)	53
10. PCF (-)	-0.0043 (-1.37)	-0.0071** (-2.07)	-0.0070** (-2.24)	35

Source: Author's estimates; Rodriguez and Rodrik (2000), Table V.I
Notes: Each row corresponds to three separate TFP growth regressions for the respective openness (distortion)indicator. Each equation also includes a constant and the log of GDP per capita in 1965, and schooling in 1965 as additional regressors. Their values, however, are not reported due to space limitations. The numbers in parentheses are t-statistics based on heteroscedasticity consistent standard errors.

*** means significant at 1%; ** means significant at 5%; * means significant at 10%.

To control for the possibility of causality running from TFP growth to trade openness rather than vice versa, Edwards also performed IVWLS estimations.[35] These estimations were also replicated by Rodriguez and Rodrik but again because of concerns over the choice of weighting variable used in the original study, the latter

[35] In an earlier and closely related study, Edwards (1992), Edwards also justified his use of IV estimation by arguing that because the openness and trade intervention indices are, at best, rough proxies for the theoretical concept of trade orientation, then one should treat these indicators as being measured with error. He further notes that IV estimation is the standard way of dealing with this errors in variable problem.

authors chose the results obtained from IV (2SLS) regressions with robust standard errors as their preferred results. Once again, we take Rodriguez and Rodrik's results as our starting point and therefore undertake IV (2SLS) estimations with robust standard errors.[36] The results from these estimations are presented in Tables 3.3 and 3.4, respectively. The results in column 1 of Table 3.3, which uses TFPG-AMG2 as the measure of TFP growth, closely mirror the results obtained on the basis of OLS estimations and by extension the assumption that the trade indicators are exogenous. Consequently, Rodriguez and Rodrik's results are generally robust to the augmented mean group TFP measure even when the openness indicators are assumed endogenous. Interestingly, the signs on the openness coefficients correspond exactly for the two TFP measures.

However, as occurred when we assumed the measures of openness to be exogenous, there is evidence of sensitivity in the relationship between some openness indicators and TFP growth. For example, the average black market premium loses statistical significance in Rodriguez and Rodrik's IV estimation compared to their OLS estimation. For us, this variable is still shown to significantly explain variations in cross-country TFP growth. In the case of the Sachs-Warner index, the sensitivity appears to be caused by a combination of the measure of TFP and whether one assumes this particular openness index to be exogenous or endogenous. Recall, however, that Rodriguez and Rodrik find it to be insignificant regardless of the assumption made. For us however, the assumption about its exogeneity or endogeneity seems important for our preferred measure of TFP growth.

[36] We use the conventional IV estimator instead of the GMM-IV estimator due to the uncertainty over

Table 3.3: Instrumental Variables (2SLS) Regressions Cross-section Estimations			
Dependent Variable :TFP Growth (Average 1980-1990)			
Openness Indicators (Expected Sign)	**TFPG- AMG2 (1)**	**TFPG- R & R) (2)**	**N**
1. SWOPEN (+)	0.0131 (1.62)	0.0078 (1.06)	48
2. WDR (+)	0.0167*** (3.42)	0.0126** (2.13)	30
3. LEAMER (+)	-0.0039 (-0.21)	-0.0033 (-0.32)	43
4. BLACK (-)	-0.0173** (-2.39)	-0.0027 (-0.54)	70
5. TARIFF (-)	0.0095 (0.27)	0.0079 (0.28)	63
6. QR (-)	0.0323 (0.37)	0.0401 (0.79)	62
7. HERITAGE (-)	-0.0240*** (-3.85)	-0.0202*** (-3.24)	56
8. CTR (-)	-1.3072 (-1.16)	-1.8368 (-1.06)	42
9. WOLF (-)	-3.8E-4 (-1.23)	-3.3E-4 (-1.21)	51

Source: Author's estimates; Rodriguez and Rodrik (1999), Table V.I

Notes: Each row corresponds to two separate TFP growth regressions for the respective openness(distortion)indicator. Each equation also includes a constant, the log of GDP per capita in 1965 and schooling in 1965 as additional regressors. Their values, however, are not reported due to space limitations. The numbers in parentheses are t(z)- statistics based on heteroscedasticity consistent standard errors.

*** means significant at 1%; ** means significant at 5%; * means significant at 10%.

The instruments used (not all in the same equation) are: TFP growth in the 1970s(for each TFP measure), SWOPEN in the 1970s, the ratio of imports/GDP in the 1970s, the ratio of exports/GDP in the 1970s, the average black market premium in the 1970s, the Heritage Foundation index of property rights protection, and the change in the terms of trade.

Table 3.4 broadens the comparison by showing the results obtained when using the alternative TFP measures: TFPG-HET and TFPG-GMM. The results further highlight the sensitivity of some of the trade openness measure to alternative measures of TFP. For example, when we use the completely heterogeneous measure (TFPG-HET), Leamer's openness index (LEAMER) is highly significant (at less

the finite sample properties of the latter.

than 1 %). In contrast, it is not significantly different from zero when the GMM based measure is used. Additionally the latter TFP measure, yields the unexpected result that higher average tariffs on manufacturing (TARIFF) leads to higher TFP growth. Moreover, the average black market premium is again found to be a significant variable explaining differences in productivity growth when using the two alternative TFP measures.

Regarding their IV regressions, Rodriguez and Rodrik allude to the sensitivity of the only two significant coefficients - WDR and HERITAGE - to the specification of the instrument lists. They further indicate that these two regressions are among the only three in which the Heritage Foundation Index of Property Rights Protection is used as an instrument by Edwards (1998), and for which the Sargan test of overidentification shows the instruments to be valid.[37] Similarly for us, the coefficients on the trade policy indicators in our IV estimations are sensitive to the instrument lists specified. Consistent with the finding of Rodriguez and Rodrik, only for the regressions with the WDR and HERITAGE indices did the Hansen J (chi-square) statistic fail to reject the null hypothesis that the instruments are valid.

[37] Rodriguez and Rodrik argue that if the index of property rights protection is not excludable from the second stage regression, then Edwards' IV estimation will give biased estimates of the coefficient of openness on growth. They also questioned the omission of this variable as an important determinant of growth in light of the extensive literature examining such an effect.

Table 3.4: Instrumental Variables (2SLS) Regressions Cross-section Estimations				
Dependent Variable :TFP Growth (Average 1980-1990)				
Openness Indicators (Expected Sign)	**TFPG (R & R) (1)**	**TFPG-HET (2)**	**TFPG-GMM (3)**	**N**
1. OPEN (+)	0.0078 (1.06)	0.0097 (1.50)	0.0117* (1.66)	48
2. WDR (+)	0.0126** (2.13)	0.0259*** (3.34)	0.0264*** (3.62)	30
3. LEAMER (+)	-0.0033 (-0.32)	0.0346*** (3.30)	0.0047 (0.26)	43
4. BLACK (-)	-0.0027 (-0.54)	-0.0274*** (-2.99)	-0.0203*** (-2.72)	70
5. TARIFF (-)	0.0079 (0.28)	0.0554 (1.34)	0.0790** (2.09)	63
6. QR (-)	0.0401 (0.79)	0.0613 (1.19)	0.0631 (1.45)	62
7. HERITAGE (-)	-0.0202*** (-3.24)	-0.0240*** (-2.93)	-0.0141*** (-2.79)	56
8. CTR (-)	-1.8368 (-1.06)	-1.1542 (-0.92)	0.1857 (0.29)	42
9. WOLF (-)	-3.3E-4 (-1.21)	0.0002 (0.75)	-2.5E-5 (-0.13)	51

Source: Author's estimates; Rodriguez and Rodrik (1999), Table V.I

Notes: Each row corresponds to three separate TFP growth regressions for the respective openness (distortion)indicator. Each equation also includes a constant, the log of GDP per capita in 1965 and schooling in 1965 as additional regressors. Their values, however, are not reported due to space limitations. The numbers in parentheses are t(z)- statistics based on heteroscedasticity consistent standard errors.

*** means significant at 1%; ** means significant at 5%; * means significant at 10%.

The instruments used (not all in the same equation) are: TFP growth in the 1970s(for each TFP measure), SWOPEN in the 1970s, the ratio of imports/GDP in the 1970s, the ratio of exports/GDP in the 1970s, the average black market premium in the 1970s, the Heritage Foundation index of property rights protection, and the change in the terms of trade.

Rodriguez and Rodrik also raise concerns over both the data used by Edwards to calculate three of the openness (distortion) indicators found to be significant, namely the CTR, WDR and HERITAGE indices. On the issue of data, they questioned Edwards' use of IMF data to calculate the CTR index. This data, they argue, contains average tariff rates for some developing countries (e.g. India) that are implausible. Using more recent data from the World Bank Development Indicators (1998), not available to Edwards at the time of his study, they derive an index of the collected taxes ratio (CTR) in the spirit of Edwards.[38] They then sought to replicate Edwards' result for this variable and also gauge the effects of its individual components (export duties and import duties) on TFP growth. Additionally, Rodriguez and Rodrik argue that the HERITAGE index is calculated based on trade restrictions in 1996, whereas Edwards' sample period is for the decade 1980-1990. They also pointed to inconsistencies in this index as well as the World Development Report (WDR) outward orientation index. When they recomputed similar indices, using data for the 1980s for the Heritage Foundation (HERITAGE) index and correcting for perceived inconsistencies in both indices, their coefficients were now insignificant.

We attempt to replicate Rodriguez and Rodrik's results using their recalculated indices for the collected taxes ratio (DUTY), its individual components- import duties (MDUTY) and export duties (XDUTY) - and the Heritage index of trade distortions (HERITAGE 2). These results, together with Rodriguez and Rodrik's, are shown in Table 3.5 below. We also include the results for the CTR and HERITAGE indices from Tables 3.1 and 3.2 to facilitate comparison between the two sets of results. Focusing first on columns 1 and 2 in Table 3.5, the results obtained by Rodriguez and Rodrik (column 2) are very robust to the TFPG-AMG2 measure of TFP growth. It is only for XDUTY (bold row) that the results differ between the two columns. Export duties being negative and statistically significant with TFP growth for us, but not for Rodriguez and Rodrik. However, across both measures of TFP growth the coefficient on import duties (MDUTY) has the 'wrong' sign and is

[38] Arguing that when exports and imports are both taxed their distortionary effect is multiplicative rather than additive, Rodriguez and Rodrik used the formula [(1+ export duty)* (1+ import duty) –1] to derive their index. They argue however, that their results remained unchanged when they used the simple sum [export duty + import duty] to derive the index.

significantly different from zero. Further, whereas the heritage index of trade distortions (HERITAGE) constructed by Edwards robustly explains differences in cross-country TFP growth, the recalculated index of this trade indicator (HERITAGE2) by Rodriguez and Rodrik (2000) does not.

Table 3.5 : Results of OLS Regressions
Cross-section Estimations

Dependent Variable :TFP Growth (Average 1980-1990)					
Openness Indicators	**TFPG-AMG2 (1)**	**TFPG (R & R) (2)**	**TFPG-HET (3)**	**TFPG-GMM (4)**	**N**
CTR	-0.1654 (-1.13)	-0.2676** (-2.25)	0.0072 (0.04)	-0.124 (-0.91)	45
DUTY	0.0821 (1.55)	0.0225 (1.01)	-0.0347 (-0.99)	-0.0046 (-0.18)	43
MDUTY	**0.00070*** (1.92)**	**0.00070** (2.30)**	**0.00040 (0.97)**	**0.00060* (1.66)**	**43**
XDUTY	**-0.00050* (-1.78)**	**-0.00030 (-1.09)**	**-0.00120*** (-2.88)**	**-0.00070** (-2.56)**	
MDUTY	0.00020 (0.53)	0.00030 (0.884)	0.00010 (0.29)	0.00010 (0.38)	66
HERITAGE	-0.0076*** (-3.15)	-0.0064*** (-2.87)	-0.0074* (-1.85)	-0.0080*** (-2.81)	58
HERITAGE 2	-0.0022 (-1.03)	-0.0016 (-0.83)	0.00010 (0.02)	-0.0019 (-0.89)	68

Source: Author's estimates; Rodriguez and Rodrik (2000), Tables V.1 and V.2
Notes: Same as in Table 3.1

*** means significant at 1%; ** means significant at 5%; * means significant at 10%.

The robustness of Rodriguez and Rodrik's results to the augmented mean group TFP measure extends to the two additional measures of TFP growth constructed by us (columns 3 and 4). However, there is some evidence of sensitivity to alternative TFP linked to the individual components that comprise DUTY - MDUTY and XDUTY- when entered separately in the regressions.

Therefore our overall conclusion from the cross-section estimations is that the results obtained by Rodriguez and Rodrik (2000) based on their critique of Edwards (1998), are generally robust to our preferred measure of TFP growth and to a lesser extent the two alternative measures of TFP constructed by us. This is true both for the trade policy indicators used in Edwards (1998) and the additional indicators constructed by Rodriguez and Rodrik. However some trade policy indicators appear to be sensitive to the way TFP is measured. In terms of the more commonly used openness measures in the trade and growth literature, these include the Sachs-Warner openness index (SWOPEN), the average black market premium (BLACK) and to a lesser extent the collected taxes ratio (CTR) [and their individual components] and the average tariff on manufacturing (TARIFF). In light of the latter findings, some of Rodriguez and Rodrik's analysis and conclusions are therefore sensitive to how TFP growth is measured. For example, while Rodriguez and Rodrik (2000) find the average black market premium and duties on exports to be insignificant in their TFP growth regressions, we find both openness measures to be statistically significant in the different regressions using all three measures of TFP growth. Thus both for our preferred measure of TFP growth and the two alternative measures there is support for a positive trade liberalisation effect on TFP growth for more measures or proxies of liberalisation than those found in Rodriguez and Rodrik (2000).

Finally, for our three measures of TFP growth there is no consistent support for conditional convergence and the initial level of human capital being a significant determinant of TFP growth.[39]

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[39] Rodriguez and Rodrik (2000) did not report the values of the coefficients on the initial levels of GDP and human capital in the presentation of their results.

3.6.3 Panel Estimations and Results

To better compare our findings based on panel estimations with those obtained from our cross-section analysis, we specify an estimating equation that mirrors Equation (3.1) above.[40] Our estimating equation is thus:

$$TFPG_{it} = \beta_0 + \beta_1 GDP_{it}^0 + \beta_2 HUMAN_{it}^0 + \beta_3 OPENNESS_{it} + \sum_{j=1}^{6} \lambda_j + \sum_{t=1}^{6} \gamma_t + \varepsilon_{it} \qquad \textbf{(3.2)}$$

where TFPG once again proxies three alternative measures of TFP growth, GDP^0 is the log of per capita GDP at the beginning of each five year period from 1960-1990, $HUMAN^0$ is the log of human capital at the start of each five year period, OPENNESS is as defined in Equation (3.1) but in this instance proxying 3 indicators of trade openness, i indexes countries, t indexes time periods, λ_j is a region specific fixed effect, γ_t is a period specific fixed effect and ε_{it} a common independent and identically distributed term. The sample comprises a maximum of 79 developed and developing countries and covers the period 1960-1990.

Our priors for the coefficients on the variables proxying initial conditions and OPENNESS are the same as that expressed in the first part of our empirical analysis. That is, we expect the coefficients on initial GDP and human capital to be negative and positive respectively, while the coefficients on the measures of openness and trade orientation are once again expected to be consistent with the hypothesis that

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[40] Our decision to include the initial levels of GDP and human capital (for each sub-period) in our estimating equation means that for this specification we are constrained to perform estimations using data based on period averages (5-years in our case) rather than annually. We do however modify the estimating equation in order to undertake panel estimations based on annual data.

greater openness (less distortions) is associated with higher rates of TFP growth. Two of the measures, the trade intensity measure (OPEN 1) and the trade policy openness measure of Sachs and Warner (1995) – SWOPEN- are direct measures of openness and so their coefficients are expected to be positively signed. In contrast, the measure of price deviation from PPP (PRIDEV) is a measure of trade distortion and so its coefficient is expected to be negative.

Unlike the method adopted for the cross-section estimations, where the openness indicators were entered into the regressions sequentially, for our panel data analysis we consider the nexus between measures of trade openness (orientation) and TFP growth simultaneously. The advantage of this approach over the previous one is that since all the trade indicators used as proxies for openness do not capture the same aspect of trade policy, then considering them simultaneously reduces the possibility of information being lost.[41] This is the approach adopted by Miller and Upadhyay (2000). The disadvantage however, is that because most of the existing trade policy measures do not have a lengthy time dimension and broad country coverage, the number of openness measures available for our analysis is substantially reduced.

We estimate Equation (3.2) first using the fixed effects (Within) estimator and then the feasible efficient two-step GMM-IV estimator. As indicated in the previous chapter, this estimator is robust to heteroscedasticity of unknown form and is more efficient than the conventional IV estimator if heteroscedasticity is indeed present.[42] Together with using this estimator, we also allow for unspecified correlation of error

[41] Edwards (1998) sought to offset this potential loss of information by using a principal components approach to construct a "grand" composite index.

[42] Based on the Pagan-Hall test, we were able to reject the null hypothesis of homoscedasticity of the disturbance term for both the heterogeneous and homogeneous measures of TFP growth respectively, thus indicating the presence of heteroscedasticity.

terms within groups (i.e. countries) but not across groups. Results for both sets of panel estimations are shown in Table 3.6.

Taking the fixed effects regressions first (i.e. regressions 1-3), both the trade intensity and trade policy measures of openness have the expected signs in all three regressions and are significant at the 10% level or lower in two of them. Only in regression 1 is there evidence of sensitivity between one of the trade openness and the way TFP is measured. This relates to the price distortion measure which is not significantly different from zero when the augmented mean group measure of TFP (TFPG-AMG2) is used. Therefore, when the trade measures are assumed exogenous then they are largely robust to alternative measures of TFP growth.

The results for OPEN1 and PRIDEV in regression 3 are consistent with the findings of Miller and Upadhyay (2000) who, on basis of fixed effects estimations, find both the share of exports in GDP and the local price deviation from PPP to be significantly correlated with the level of TFP for a sample of 83 countries over a similar time period.[43] Finally, the results for the variables capturing the effects of initial conditions on TFP growth are mixed. There is support for conditional convergence in regressions 1 and 3, and for the initial stock of human capital at the start of each period explaining differences in TFP growth in regressions1 and 2. However, in regressions 1 there is an unexpected negative sign on the variable that proxies for human capital.[44]

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[43] The similarity between our finding and Miller and Upadhyay's for the homogeneous measure of TFP growth is not surprising since they used a measure of TFP generated from a production function that assumes homogeneity of the production parameters across countries, as well as data based on 5-year averages.

[44] Since the two variables proxying initial conditions are highly collinear (r=0.74), we checked whether the coefficient on both variables may be affected by the problem of multicollinearity. However, when we alternated in omitting one of the variables from our regressions while keeping the other, the results remained largely unchanged. Harrison (1996) cites the unsatisfactory results obtained

Table 3.6 : Panel Estimates (1960-90) 5-YEAR AVERAGES Dependent Variable: TFP Growth						
	FIXED EFFECTS			GMM-IV		
	TFPG-AMG2 (1)	TFPG – HET (2)	TFPG-GMM (3)	TFPG – AMG2 (4)	TFPG-HET (5)	TFPG-GMM (6)
GDP^0	-0.0293*** (-2.91)	0.0039 (0.92)	-0.0289*** (-3.04)	-0.0036 (-1.40)	0.0017 (0.45)	-0.0034 (-1.17)
$HUMAN^0$	-0.0138* (-1.89)	0.0133*** (3.61)	-0.0059 (-0.82)	0.0019 (0.95)	-0.00060 (0.20)	0.0025 (1.19)
OPEN1 (X+M/GDP)	0.0254*** (3.40)	0.0085*** (2.58)	0.0207*** (2.94)	0.00020 (0.08)	0.0027 (1.03)	-0.00010 (-0.04)
SWOPEN	0.0098** (2.02)	0.0064* (1.86)	0.0122** (2.55)	0.0133*** (2.57)	0.0092* (1.93)	0.0129** (2.47)
PRIDEV	-0.0168 (-1.42)	-0.0083** (-2.48)	-0.0187* (-1.69)	-0.0070 (-1.24)	-0.0209*** (-3.41)	-0.0076 (-1.27)
Trade Measures Endogenous?	NO	NO	NO	YES	YES	YES
Hansen J χ^2 (p-value)				0.048 (0.827)	30.637 (0.000)	0.244 (0.621)
R^2	0.40	0.74	0.39	0.22	0.36	0.22
# of Observations	463	463	463	384	384	384
# Countries	79	79	79	79	79	79

Notes: The numbers in parentheses are robust t (Fixed Effects Regressions) and z (GMM-IV Regressions) statistics. *** means significant at 1%; ** means significant at 5%; * means significant at 10%.

All variables are in logs except the Sachs-Warner index of openness (SWOPEN). All regressions include a constant as well as country and period dummies. These are not reported due to space constraints. The instruments for GMM-IV regressions are: TFP growth, the log of the share of trade in GDP (OPEN 1), the Sachs-Warner index of openness (SWOPEN), and the log of the price deviation from PPP (PRIDEV), all lagged one period (5 years), as well as region and period dummies.

However, before we make any definite statements about the significance (or insignificance) of the trade variables in explaining differences in TFP growth, we first control for the possibility of the trade measures being endogenous. This possibility is particularly strong for the trade share measure of openness (OPEN1) which, as was indicated earlier, can be heavily influenced by geographical factors.

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when using initial GDP as the reason for excluding this variable from her fixed effects regressions based on 5-yearly data.

Additionally, there is convincing evidence at the microeconomic level (see Bernard and Jensen, 1995, 1998; Clerides, Lach and Tybout, 1998) that much of the observed correlation between firm performance and exports is driven by larger and more productive firms self-selecting into export markets. In other words, causality seems to go from productivity to exports, not vice-versa. The problem of reverse causation however, is not limited to outcome measures such as trade volumes. Trade policies can themselves be endogenous to growth with countries choosing to liberalise during a period of economic growth.

In light of the above arguments, we also estimate Equation (3.2) for the three measures of TFP growth using the GMM-IV estimator. The results from these estimations are shown as regressions 4-6 in Table 3.6. As the table shows, there is a marked difference in these results compared to those obtained when we assumed the trade measures to be exogenous. OPEN1 is now insignificantly correlated with TFP growth for all three measures of TFP. These results differ from those obtained by Dollar and Kraay (2001, 2003b) for this variable, based on per capita growth regressions with panel data.[45] It should be noted however, that the latter authors used the conventional IV estimator and also estimated a different model to ours.[46] Further, despite having the expected sign, the price distortion measure (PRIDEV) is only significant when we employ the completely heterogeneous measure of TFP growth. For the other two TFP measures, this variable loses significance and the magnitude

[45] Cross-section estimations using trade volumes have also yielded conflicting results. For example, Frankel and Romer (1999), and Dollar and Kraay (2003b) find a positively significant relationship between trade volumes and growth based on IV estimations. In contrast, Rodrik et al. (2002) find no such relationship.

[46] Dollar and Kraay (2001, 2003b) estimated dynamic regressions of decadal changes in real per capita GDP on lagged growth, and changes in decadal averages of trade shares and measures of institutional quality. We tried to capture the 'spirit' of Dollar and Kraay's approach by using the growth in trade share instead of its level. However, this variable was also statistically insignificant in all our GMM-IV estimations.

of its coefficient falls. In fact, from among the three trade indicators, the Sachs-Warner openness index (SWOPEN) appears to be the most robust. This variable is statistically significant at conventional levels for the regressions with the intermediate mean group and homogenous TFP measures respectively. Further, the value of the coefficient on this variable is given to less fluctuation than the other two trade indicators.

Therefore, from our panel estimations based 5-year data period we can conclude that the measure of local price deviation from PPP (PRIDEV) is not robust to alternative measures of TFP and also to whether one assumes the measure to be exogenous or endogenous. The outcome measure (OPEN1) on the hand is robust to alternative measures of TFP but not to the exogeneity/endogeneity assumption. If we assume the former, it is significantly correlated with TFP growth across the three measures of TFP. However, if we assume the latter then it loses statistical significance, also across measures of TFP. In contrast, the Sachs-Warner openness index is robust in both dimensions i.e. to the way TFP is measured and to whether we assume that causality runs from trade openness to TFP growth (exogeneity) or allow for the possibility that it is the other way around, in which case we assume it is endogenous. This finding for the Sachs-Warner index is directly opposite to that based on the cross-section estimations.

Based on the point estimates obtained in regressions 4 and 6, it can be argued that countries that are open have on average a TFP growth rate of between 1.3%-1.5% higher than countries that are closed based on the Sachs and Warner (1995) criteria. This compares favourably with the average per capita GDP growth effect of 2.7% found by Greenaway et al. (2002) for this openness index based on their Levine and

Renelt type 'core variables' specification. Additionally, the finding that SWOPEN is the most robust of the trade measures is consistent with Sala-i-Martin (1997). In proposing an alternative robustness test to Levine and Renelt (1992), he finds this measure to be the only significant openness measure when confidence intervals were constructed for the entire distribution of coefficients for different growth determinants (see Harrison and Hanson, 1999 for an opposite view).

Finally, both the initial level of GDP and the initial stock of human capital are statistically insignificant. Further, based on Hansen's test for the validity of overidentifying restrictions, only the regressions using the augmented mean group and homogenous measures of TFP growth are validly overidentified and thus to have valid sets of instruments.

To complete our empirical analysis, we test for robustness using annual data. This requires us to modify Equation (3.2) by dropping the two variables proxying for initial conditions. We however include a contemporaneous measure of human capital that allows us to test whether this variable has a significant impact on TFP growth (as suggested by Benhabib and Spiegel, 1994 and Islam, 1995) rather than output growth.[47] This model is similar to the core model of Miller and Upadhyay (2000) but with fewer trade indicators. Once again we undertake both within (fixed effects) and GMM-IV estimations. The results from these estimations are shown below in Table 3.7. Taking the fixed effects estimations first, all the openness measures have the expected signs and are all statistically significant at the 10% level and lower. Therefore, for these regressions the openness variables are robust to the choice of

[47] Recall from the previous chapter that human capital was consistently found to be insignificant in our
estimations of the production function.

TFP measure. However, only for the heterogeneous measure of TFP growth (TFPG-HET) is human capital coefficient 'rightly' signed and significantly correlated with TFP growth.

Table 3.7 : Panel Estimates (1960-90) ANNUAL Dependent Variable: TFP Growth						
	FIXED EFFECTS			GMM-IV		
	TFPG-HET (1)	**TFPG – AMG2 (2)**	**TFPG-GMM (3)**	**TFPG-HET (4)**	**TFPG – AMG2 (5)**	**TFPG-GMM (6)**
HUMAN	0.0170*** (8.33)	-0.0073 (-0.87)	-0.00040 (-0.05)	0.0011 (0.40)	-0.0010 (-0.52)	0.0003 (0.12)
OPEN1 (X+M/GDP)	0.0095*** (6.02)	0.0130* (1.66)	0.0128* (1.68)	0.0012 (0.43)	0.00080 (0.30)	0.0011 (0.69)
SW OPEN	0.0085*** (4.55)	0.0128** (2.48)	0.0168*** (3.38)	0.0094** (2.41)	0.0115*** (3.06)	0.0100*** (2.73)
PRIDEV	-0.0029* (-1.83)	-0.0285** (-2.14)	-0.0293** (-2.21)	-0.0092* (-1.72)	-0.0087* (-1.74)	-0.0122** (-2.37)
Regressors Endogenous?	NO	NO	NO	YES	YES	YES
R^2	0.68	0.14	0.14	0.31	0.10	0.10
Hansen J χ^2 (p-value)				0.081 (0.776)	0.004 (0.951)	0.512 (0.474)
# of Observations	2057	2057	2057	1928	1928	1897
# Countries	79	79	79	79	79	79

Notes: The numbers in parentheses are robust t (Fixed Effects Regressions) and z (GMM-IV regressions) statistics.

*** means significant at 1%; ** means significant at 5%; * means significant at 10%.

All variables are in logs except the Sachs-Warner index of openness (SWOPEN). All regressions include a constant as well as country and time dummies. These are not reported due to space constraints. The instruments for the GMM-IV regressions are: TFP growth, the log of human capital, the log of the share of trade in GDP (OPEN 1), the Sachs-Warner index of openness (SWOPEN), and the log of the price deviation from PPP (PRIDEV), all lagged two periods, as well as region and time dummies.

Turning now to the IV estimations where we assume all the variables (both trade and human capital) to be endogenous, all the openness measures once again have their expected signs. However, similar to the GMM-IV estimations based on 5-year averages of the data, OPEN1 is insignificantly correlated with TFP growth for all three measures of this variable. In contrast, both SWOPEN and PRIDEV are statistically significant at conventional levels for all three TFP measures. Therefore, it appears that for annual data, the latter two trade policy measures are robust to the measurement of TFP growth and also to the assumption of exogeneity or endogeneity. For the Sachs-Warner index this is consistent with the finding on the basis of five-yearly data. All three TFP growth regressions pass the instrument validity test. Based on the point estimates for SWOPEN in these estimations, economies that are open have on average a TFP growth rate of between 0.9% - 1.1% higher than economies that are closed. These estimates are, not unexpectedly, marginally lower than those obtained previously but they seem quite plausible.

For the variable measuring the local price deviation from PPP (PRIDEV), an increase in the magnitude of this variable implies that the countries' currency becomes more overvalued. Therefore, trade policies that raise the real exchange rate above its PPP value are associated with lower TFP growth. For instance, a one standard deviation increase in this variable from its mean level will, other things equal, lower TFP growth by (on average) between 0.4% and 0.6% annually across the three TFP measures.[48]

[48] The mean for PRIDEV is 4.0843 and the standard deviation is 0.4605. Multiplying the latter by the coefficient and taking the exponent of this product yields the percentage change.

Finally, human capital is not significantly associated with TFP growth in all three regressions. This finding is consistent with Söderbom and Teal (2003) who find no empirical support for the level of human capital significantly affecting underlying productivity growth. The mixed results for human capital, including the negative coefficient, are consistent with the findings of many researchers in this literature (see Pritchett, 2001).

Before concluding our panel estimations, we also entered the variable proxying for the collected taxes ratio-DUTY- into all of the regressions.[49] However, while the coefficient on this variable has the expected negative sign, in all of the regressions it was not significantly correlated with TFP growth. Moreover, the findings for the other variables remained qualitatively the same. Additionally, we experimented with entering the openness measures sequentially as was done in the cross-section estimations. Again, the pattern of results obtained using period and annual data respectively remained unchanged.

3.7 CONCLUSIONS

The manner in which trade policies affect economic performance is one of the most emotive and contentious issues in economics. It is an issue that has generated a prolonged debate that shows little signs of abating, as well as a large empirical literature. Most of this literature has concluded that trade reforms which lead to an outward oriented trade regime are associated with superior economic performance either in terms of higher output or productivity (levels and growth). However,

[49] Because of multicollinearity problems brought about by the high collinearity between the price deviation and collected taxes measures, which resulted in the former changing sign but not

questions have been raised over the robustness of these findings to better measures of trade policy, the inclusion of other growth determinants in the specifying equations, appropriate econometric techniques and the like. In this chapter we explored another dimension of the robustness debate that has been neglected in the literature at the macroeconomic level. That is, the robustness of the measures of trade policy to alternative measures of TFP growth. We explored this issue on the basis of both cross-section and panel data estimations.

For the cross-section estimations, using the results obtained by Rodriguez and Rodrik (2000) as comparator, we find that while most of the measures of trade openness used in Edwards (1998) as well as those constructed by Rodriguez and Rodrik are generally robust to the three alternative measures of TFP growth derived in this thesis, some of the openness indicators are sensitive to alternative measures of TFP growth. These include the Sachs-Warner openness index, the average black market premium and the individual components that comprise the collected taxes ratio constructed by Rodriguez and Rodrik. On the basis of the relationship between the latter openness variables and TFP growth, we find support for a positive and significant effect from trade liberalisation on TFP growth for more of the proxies of trade policy openness compared to Rodriguez and Rodrik (2000). This is true both for our preferred measure of TFP growth and the two additional measures.

In terms of our panel results, when the data are in 5-year periods only the Sachs-Warner openness index (SWOPEN) is robust to alternative measures of TFP and the alternative assumptions about the direction of causality between this variable and TFP growth. This finding is in direct contrast to that found for this variable based on

significance, we decided to omit this variable (PRIDEV) from our regressions. The introduction of cross-section estimations. On the other hand, the price deviation measure is sensitive in both dimensions outlined above. Finally, the outcome measure (OPEN1) is robust in one dimension only i.e. to the way TFP is measured. For the three TFP measures this measure is shown to be positive and significantly correlated with TFP growth. However, when we assume it to be endogenous it is statistically not different from zero in the three TFP growth regressions. For the panel estimations using annual data, both the Sachs-Warner openness index (SWOPEN) and the local price deviation from PPP (PRIDEV) are robust to the three alternative measures of TFP growth and to the estimator used. For the outcome measure of openness (OPEN1), robustness is again established in one dimension as in the panel estimations using five-yearly data.

Overall, one can conclude that the precise openness-productivity growth relationship identified in cross-country analysis is sensitive to how both openness and TFP growth are measured, to whether the model is estimated by cross-section or panel methods, whether we use data in 5-year periods or annually, and whether the openness measure is treated as an exogenous or endogenous variable. Our own preference is to use panel estimation methods and to include several alternative dimensions of trade openness and distortion simultaneously (some of which are more likely to be endogenous than others). It is difficult to conclude other than that our panel estimates provide support for the view that reduced trade policy distortion increases aggregate productivity growth, but that this effect may well not be appropriately captured by the standard trade to GDP measure of openness.

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the collected taxes variable (DUTY) also substantially reduced our sample (period and annual).

Finally, over the different types of estimations (cross-section and panel) there is no consistent support for conditional convergence and that the initial level of the stock of human capital is a significant determinant of end of period TFP growth.

In closing this chapter, we draw attention to the fact that the results from our estimations are based on a sample comprising both developed and developing countries. Consequently, the issue of whether our findings are robust across different groups of countries have not been explored. Researchers have however shown that the relationship between trade openness and growth differs between developed and developing countries, and also within groups of developing countries. Further, some have shown the trade-growth relationship to be contingent on some other determinant of growth such as human capital. These studies therefore point to heterogeneity in the openness-growth relationship. It is this issue that forms the subject of inquiry in the next chapter.

CHAPTER 4

OPENNESS AND PRODUCTIVITY GROWTH : THE SEARCH FOR THRESHOLD AND INTERACTION EFFECTS

4.1 INTRODUCTION

Are there differences between countries and regions in the way in which openness affects economic performance? For some researchers (see Blomström, Lipsey and Zejan, 1992; Borensztein, De Grogorio and Lee, 1998; Miller and Upadhyay, 2000), there are differences between countries in the nature of the openness-growth relationship. In fact, Baldwin and Sbergami (2000) argue the fragility in the trade and growth results recently demonstrated by Harrison and Hanson, 1999; Rodriguez and Rodrik, 2000 and others stem from the false imposition of a linear relationship between openness and growth by empirical researchers. In their view, a linear relationship has no support beyond the most basic of theoretical models; non-linearity is the rule rather than the exception.

Further, Rodriguez and Rodrik argue that the continued search for a positive relationship between trade policy openness and economic growth is futile. They believe that a more fruitful line of research in cross-national work might be to look for contingent relationships between these two variables. For instance, do trade restrictions operate differently in low versus high income countries? In small versus large countries? The search for contingent relationships between openness and growth is the principal research objective of this chapter. It seeks to determine whether there is cross-national evidence of heterogeneity in the openness-productivity growth relationship that is related to aspects of geography (transport costs) as well as institutions. Specifically, it hypothesises that the productivity payoffs from openness or trade liberalisation are conditioned by the quality of a country's institutions and the extent of the natural barriers to trade it faces. We also postulate that there exists some critical level of both institutional quality and transport costs above and below which the positive contribution of openness to TFP growth differs.

Although the basic research question of heterogeneity in the openness-growth nexus across countries has a fairly long history in the empirical trade and growth literature (see Michaely, 1977; Tyler, 1981), the research in this chapter departs from previous research on this subject in two important respects. First, the form of the non-linearity and the appropriate means of modelling it are explored in some depth. This involves searching for the nature of the heterogeneity, determining whether it is best captured by the traditional approaches such as the exogenous splitting of the sample or by the imposition of interaction effects as in Miller and Upadhyay (2000), or yet still by an endogenous threshold model as in Papageorgiou (2002).

Second, the variables used to capture the contingent relationships - i.e. institutional quality and natural barriers – have, to our knowledge, not been previously employed as conditioning variables in the search for non-linearities in the link between openness and growth. Although both institutions and geography, along with trade openness, have been singled out in the recent literature as being among the fundamental or 'deeper' determinants of superior long-run economic performance (see North 1990, Frankel and Romer, 1999; Rodrik, 2003b; Sachs, 2003), researchers have primarily focused on their direct rather than indirect effects on economic performance. To the extent that they consider the relationship between institutions, geography and trade openness, on the one hand, and per capita income growth (levels) on the other (e.g. Rodrik et al., 2002), the methods employed are different from those used here.

Much of the recent literature on the role of trade openness, institutions and geography in explaining the vast cross-national differences in per capita income levels and growth has tended to focus on which of these three fundamental determinants of growth "trumps" the other (see Rodrik et al., 2002; Easterly and Levine, 2003; Dollar and Kray, 2003; Sachs, 2003). This chapter attempts to take the research on the role of trade openness, institutions and geography in explaining the cross-country variations in economic growth in a different direction: that is, to consider the effects of both geography and institutional quality on TFP growth through the medium of trade openness.

After comparing the traditional approaches of exogenous sample splitting and the imposition of linear interaction terms with the formal endogenous threshold method, we argue in favour of the latter method for capturing this heterogeneity. Our preferred choice of methodology is informed by econometric theory, the possibility of the existence of multiple (rather than a single) threshold(s) and the pattern of results obtained using the alternative methodologies. Using the endogenous threshold regression methodology for a panel of up to 83 countries for the period 1970-1989, we find a number of interesting results. For natural barriers, we find that there does appear to be heterogeneity in the openness-productivity growth relationship captured by this variable. Moreover, formal testing suggests that this heterogeneity is of a threshold type, with a break in the relationship around specific critical values. Two thresholds are identified by the data, but only one has a confidence interval sufficiently small that we might consider it to be accurately identified.

Interestingly, the position of the single threshold is robust to alternative measures of openness to international trade, although the nature of the relationship differs. In addition for one of the measures of openness used we find there is some sensitivity of the results to tests for endogeneity bias, although this relates to the position of the threshold not to its existence. For a conventional trade volume measure of openness, we find that countries with high natural barriers are less responsive to changes in trade openness than countries with low natural barriers. In contrast, we find that when we use measures that might better reflect trade policy openness this relationship is reversed. It is now countries with high natural barriers that benefit most from a change in policy openness.

For institutional quality the evidence that this matters for openness and productivity growth is much weaker. We find evidence of heterogeneity only for the policy based measured of trade, but the confidence interval placed round this single threshold is very large and therefore limits its use as a description of the data. Again for the policy-based measures of openness it is those countries with weak institutions that appear to benefit most from openness. Overall we conclude against the use of this variable as the threshold variable, arguing instead that the elements of institutional quality important for trade (e.g. an efficiently functioning customs and excise division) are better captured by the measure of natural barriers used.

In terms of the methodology advocated in this study for adequately modelling heterogeneity in the openness-TFP growth relationship, we share common ground with Papageorgiou (2002). We diverge from the latter study however, in terms of the threshold variables employed, the model estimated, the estimation methodology and the research question investigated. The rest of this chapter is organised as follows. Section 4.2 reviews the empirical literature on the role of institutions and transport costs in fostering and/or hindering trade, and the resulting impact on economic performance. Section 4.3 reviews previous research on threshold effects within the context of the openness-growth relationship. Section 4.4 first specifies the base model for exploring the relationships between openness, institutions and natural barriers, and TFP growth. It then details the different approaches we employ to model threshold effects. Section 4.5 describes the data (and their sources) used for the empirical analysis as well as the estimation method employed. Section 4.6 presents the results of our estimations, while conclusions are presented in Section 4.7.

4.2 THE ROLE OF INSTITUTIONS AND NATURAL BARRIERS IN THE OPENNESS-GROWTH RELATIONSHIP

Over the last decade a number of papers have provide empirical evidence confirming the importance of institutions as a key determinant of economic growth and development (e.g. Knack and Keefer, 1995; Mauro, 1995; Hall and Jones, 1999; Acemoglu, Johnson and Robinson 2001).[1] Some of these studies have shown that institutional quality either impacts growth directly through its effect on TFP (Dawson ,1998; Ayal and Karrass 1998; Klein and Luu, 2001) and/or indirectly through its effect on investment (capital accumulation) [Dawson ,1998; Ayal and Karrass 1998], geography (Easterly and Levine, 2003) and trade (Rodrik et al., 2002).

In terms of the literature on the indirect effects of institutional quality on economic performance through the medium of trade, the argument advanced by "the new institutional economics" is that growth requires that the potential hazards of trade (shirking, opportunism, risk etc.) be controlled by institutions such as property rights, the rule of law, uniform commercial codes, standard weights and measures, organised financial markets and the like (North, 1990; 1991). It is argued that these institutions reduce information costs, encourage capital formation and capital mobility, allow risks to be priced and shared, and facilitate co-operation. Similarly, Besley (1995) argues that institutions which facilitate economic transactions between individuals and firms enhance the gains from trade and therefore increase the potential return to investment. Further, it is argued that 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 (North, 1981). Finally, Rodrik (1998) argues that societies that benefit the most from integration with the world economy are those that have the complementary institutions at home that manage and contain the conflicts that economic interdependence triggers.

Empirical support for a significant relationship between institutions and trade is provided by Anderson and Marcouiller (1999). The authors find corruption and imperfect contract enforcement dramatically reduce trade. However, when supported by strong institutions, specifically by a legal system capable of enforcing commercial contracts and by transparent and impartial formulation and implementation of government economic policy, Anderson and Marcouiller find evidence of a marked

[1] See Aron (2000) for a detailed review of the large body of empirical literature that attempts to link quantitative measures of institutions with economic growth across countries and over time.

increase in trade. They estimated that if the indexes of institutional quality for the Latin American countries in their sample improved to European Union (EU) levels, then trade in these countries would increase by 34%. Additionally, they provide evidence demonstrating that inadequate institutions constrain trade to a greater extent than tariffs.

In addition to the literature on institutions and growth, some researchers (e.g. Gallup et al., 1999; Gallup and Sachs, 2001) have demonstrated that geographical and ecological variables such as climate zone, disease ecology, and distance from the coast are strongly correlated with levels and growth rates of per capita income. In contrast to these recent studies, there is a more dated empirical literature that links geography to trade. For example, the use of the gravity model for explaining bilateral trade flows dates back to the 1960s. This model relates bilateral trade to distance between countries and the gravity variable, GDP. The rationale is that trade is generated by mass or economic size (proxied by GDP), and is inhibited by distance (a proxy for transport costs) which increases transportation and other transactions costs. Therefore the greater the distance between two markets, the higher the expected transport cost for their trade. Consequently, countries that face natural barriers to trade either because they are landlocked or remote will more than likely face higher trade costs compared to countries that have more favourable geographical characteristics, and so will have greater difficulty in integrating into the world economy (see Radelet and Sachs, 1998).

The early gravity literature only used distance as a proxy for transport costs rather than modelling it (transport costs) explicitly. However, while distance is the most obvious and studied determinant of transport costs, it is not the sole determinant of transport costs. As demonstrated by Limão and Venables (2001), infrastructure is also an important determinant of transport costs, particularly for landlocked countries (see also Bougheas et al., 1999; Milner et al., 2000). They present results showing that a deterioration of infrastructure from the median to the 75th percentile raises transport costs by 12 percentage points and reduces trade volumes by 28%. Conversely, the authors argue that an improvement in own and transit countries' infrastructure from the 25th percentile to the 75th percentile overcomes more than half of the disadvantage associated with being landlocked. Based on an analysis of African trade flows, Limão and Venables concluded that the relatively low level of trade flows that this region exhibits is largely due to poor infrastructure.

In the context of Latin America, the Inter-American Development Bank (IDB, 2000) argues that in light of the wave of global trade liberalisation of the 1980s and 1990s, the effective protection provided by high transport costs represents a greater obstacle for some countries integrating successfully in the global economy than that provided by trade policy barriers (e.g. tariff and non-tariff barriers). For example, in Latin America average tariffs declined from almost 26% at the beginning of the 1980s to 10% by the end of the 1990s. In contrast, the effective rate of protection provided by transport costs is in many countries of the region higher than the rate provided by import tariffs. For instance, import freights paid by Peru are almost twice as large as the average import tariff of 12%, while in several Central American countries freight costs account for more than double the average import tariff of less than 5% (Economic and Social Progress in Latin America, 2000).

There has been a number of recent studies (Milner, 1997; Milner, Morrissey and Rudaheranwa, 2000) which have shown that trade policy liberalisation in specific low-income developing countries have only partially lowered the total barriers to trade from policy and 'natural' sources. Clearly the extent to which total barriers in different developing countries are lowered by a given trade policy liberalisation will depend upon the relative importance of natural and policy barriers, which in turn is fashioned by locational (remoteness, landlocked) and other (e.g. efficiency and competitiveness of international transport services) characteristics. It will also depend on whether policy and related barriers contribute to the total barriers in an additive or multiplicative sense. In the latter case for example, *ad valorem* border taxes may be applied to the international transaction – inclusive of valuation (i.e. c.i.f.) of traded goods. In which case a given reduction of border taxes on trade will lower the total barrier to trade more in a high, than a low international transaction cost country. One might argue therefore that a given policy liberalisation will have more impact as far as opening up of the economy and the stimulation of productivity growth in a 'high' than 'low' natural barrier country. On the other hand, one may well expect the absolute level of post-liberalisation trade barriers to influence the extent to which there are international competitive and relative domestic incentive effects to raise productivity growth. In which case one would anticipate a greater productivity growth premium on increased policy openness in 'low' rather than 'high' natural barrier countries.

Although we have discussed the relationship between transport costs and trade on the one hand, and institutional quality and trade on the other, independently, there is a clear overlap between the three variables in practice. For example, IDB (2000) argue that the huge differences in port efficiency between locations like Hong Kong, Singapore and Belgium, on the one hand, and some of the Latin American or African countries on the other, is only partly explained by differences in the physical infrastructure of ports. They contend that many of the least efficient ports are the consequence of an inadequate regulatory and institutional environment that impedes competition, fosters organised crime and slows the introduction of modern techniques of cargo handling and port management. The end result is higher transport costs and a reduced volume of trade. This makes disentangling the separate effects of natural barriers (transport costs) and institutions on trade more complicated. It is a point we will return to when discussing the results.

4.3 THRESHOLD AND INTERACTION EFFECTS IN THE OPENNESS-GROWTH RELATIONSHIP: A REVIEW OF THE LITERATURE

The notion of a threshold effect has long been the subject of inquiry in the empirical trade and growth literature[2] (see for example, Michaely, 1977; Tyler, 1981; Balassa, 1984; and Kavoussi, 1984); albeit as an appendage to the main export-growth hypothesis. The early studies essentially sought to test the hypothesis that the effect of exports on economic growth differs between countries above or below the critical level of some observed variable: the threshold variable. The variable commonly used was the level of per capita income which proxied for the level of development. Evidence of such a difference was taken as the existence of a "threshold effect". According to Greenaway and Sapsford (1994), the evidence from the early studies on the existence of a threshold effect is mixed.

In the traditional approach (which we label the exogenous threshold literature), the threshold procedure involves splitting the sample into classes (groups) based on the value of the threshold variable. Among the studies finding evidence of a threshold

[2] Table 1 in Greenaway and Sapsford (1994) lists some of the export and growth studies between 1977-1993 which also tested the threshold hypothesis.

effect (Michaely, 1977; Tyler, 1981; Kavoussi, 1984; Moschos, 1989) all, except Moschos, simply divided their sample of developing countries into two groups – higher and lower income- on the basis of an exogenously determined level of per capita income. They then determined the effect of export growth on the economic performance of these two groups of countries by comparing the coefficient on exports from the two sets of estimates, in terms of their magnitude and significance. For instance, Michaely (1977) found that the positive correlation between economic growth and export growth was significant for the 23 higher income countries, but that the statistical significance for the lower-income group was "practically zero". Consequently, he concluded that "growth is affected by export performance only once countries achieve some minimum level of development" (p.52). A similar conclusion was reached by Tyler (1981). [3] Using the same exogenous sample splitting technique but a different estimation procedure, Kavoussi (1984) states that while "in low income countries too, export expansion tends to be associated with better economic performance" (p.240), "the contribution of exports.... is greater among the [more advanced developing countries]" (p.242).

In contrast to previous researchers, Moschos (1989) employed a completely different technique for determining the existence or non-existence of a threshold level of development. He employed a switching regression technique whereby the critical switching point (threshold level) is arrived at from the data itself rather than it being determined exogenously. Based on this endogenous sample splitting methodology, Moschos found evidence of "the existence of a critical development level below and above which the responses of output growth to its determining factors differ

[3] Though reaching a similar conclusion to Michaely (1977), Tyler used OLS to estimate a production function in contrast to the rank correlation methods used by Michaely.

substantially." (p.93). His results also suggested that the effect of export expansion on aggregate growth is stronger in the "low income" regime compared to the "high income" regime, thus contradicting the previously held view that the effect of export expansion on growth is stronger among 'more advanced' developing economies compared to the 'less advanced' ones.

To determine whether the effect of foreign direct investment (FDI) on per capita income growth differs between countries based on their level of development, Blomström, Lipsey and Zejan (1992) exogenously split their sample of developing countries and find the coefficient on FDI to be positive and significant only for the higher income developing countries. This result supported their priors premised on the view that higher income developing countries have local firms that are advanced enough to learn from foreigners and therefore benefit from spillovers. In contrast, domestic firms in lower income developing countries are likely to be too backward in their technology levels to be either imitators or suppliers to the multinationals. They argued that from this comparison one might conclude that there is a threshold level of income below which foreign investment has no significant effect.

In a critique of the methodology employed in earlier studies, Moschos argues that the basic or critical level of development is chosen rather arbitrarily, with the splitting of the sample based on some ad hoc level of per capita income. Consequently, he argues that the results are likely to be sensitive to the choice of per capita income used as the critical level of development. Similarly, Hansen, in a series of papers on the subject of threshold regression analysis [see Hansen, 1999; Hansen, 2000 and; Caner and Hansen, 2001], criticises the use of ad hoc and arbitrary sample splitting in many areas of economic inquiry. Hansen (2000) noted that econometric estimators generated on the basis of such procedures might pose serious inference problems.

Utilising the endogenous threshold regression methodology of Hansen (2000), Papageorgiou (2002) uses the share of trade in GDP as a threshold variable, along with initial per capita income and initial literacy, and finds significant evidence of a threshold related to trade for middle income countries. Papageorgiou argues that this finding suggests that openness may not be as crucial in the growth process of high and low income countries but is instrumental in clustering middle income countries into high and low growth groups.

Other studies test for heterogeneity of a different form. Miller and Upadhyay (2000), adopting a linear interaction approach, interacted a measure of the stock of human capital with a measure of openness (exports-to-GDP ratio). They find the coefficient of the interaction term to be positive and statistically significant, while those of the human capital stock and the measure of openness were negatively and positively significant respectively. Based on this finding, the authors concluded that countries must reach a critical level of openness before human capital contributes positively to TFP. Below this level of openness, the contribution of human capital to TFP is negative. When they subsequently divided their sample of countries into lower, middle and high-income groups, they find that only low income countries conform to this "threshold effect".

Borensztein, De Grogorio and Lee (1998) also employ the linear interaction method to search for heterogeneity in the openness-growth relationship, but this time in the context of the relationship between FDI and growth for a sample of 69 developing countries. Like Miller and Upadhyay, they interacted a measure of the stock of human capital with the variable proxying for openness (inflows of FDI). Borensztein, De Grogorio and Lee obtain results which indicate that FDI is an important channel for the transfer of technology. Additionally, the authors find the effect of FDI on economic growth to be dependent on the level of human capital available in the host country, with higher growth benefits from FDI accruing once a minimum threshold stock of human capital is attained (see also Xu, 2000).

However, there are inherent limitations to this type of approach (see Girma, 2002). The linear interaction term *a priori* restricts the externalities generated by openness to trade (e.g. improvements in the quality of human capital) to be monotonically increasing (or decreasing) with openness. It may be that after reaching the critical level of openness, human capital despite contributing positively to TFP may be doing so at a declining rate; that is the relationship between openness and human capital may be quadratic rather than linear. Further, the analysis does not allow the data itself to reveal the critical value of any threshold nor does it allow for the possibility of multiple thresholds.

4.4 MODELLING THRESHOLD AND INTERACTION EFFECTS

4.4.1 Base Model

Given that the aim of the chapter is to investigate how the effects of openness on TFP growth may be influenced by the quality of a country's institutions and the natural barriers to its international trade, we need a base analytical framework within which to explore these relationships. Consistent with the models specified in Chapter 3, we hypothesise that the rate of national productivity growth depends on national policies, including trade policy or openness, and on initial conditions. It is assumed that more open economies have a greater capacity to absorb new ideas from the rest of the world, and a higher steady state level of knowledge. Initial conditions might for example include initial human capital, since this captures the country's capacity to innovate and absorb new ideas; lower initial human capital reducing this capacity and lowering the steady-state rate of knowledge accumulation (see Edwards, 1998). Here we include initial GDP which proxies both the initial human capital effect, and may also capture any conditional convergence effect. The sign on these combined effects is therefore ambiguous.[4] Further, we incorporate two additional (direct) hypotheses about, firstly the productivity growth-enhancing effects of good national institutions, and secondly the growth retarding effects of high 'natural' barriers to trade arising out of transport infrastructure deficiencies or geographical disadvantages of remoteness or landlockness. Thus the base model is:

$$TFPG_{it} = \alpha_0 + \alpha_1 GDP_{it}^{0} + \alpha_2 OPEN_{it} + \alpha_3 INSTIT_{it} + \alpha_4 NATBARR_{it} + \mu_{it} \qquad \textbf{(4.1)}$$

where TFPG is the growth rate of total factor productivity; GDP^0 is the log of per capita GDP at the beginning of each five year period from 1970-89 and represents a country's initial conditions. OPEN is a variable proxied by four alternative measures of openness (trade distortion) and its behaviour is expected to be consistent with the hypothesis that more openness (less trade distortions) is associated with higher levels of TFP growth. INSTIT is a measure of institutional quality. NATBARR is a measure of international transport costs that a country incurs when engaging in international trade; μ is the disturbance term; i indexes countries and t time periods.

[4] The two variables are highly co-linear (r=0.80) in the present sample of countries.

The expected signs on our coefficients are therefore: $\alpha_1 \gtrless 0$; $\alpha_2 > 0$; $\alpha_3 > 0$ and $\alpha_4 < 0$.

4.4.2 Augmented Model with Traditional Specification of Threshold Effects

As stated previously, the incorporation of linear interaction terms and the exogenous splitting of the sample are the traditional methods commonly employed to investigate threshold influences in the trade-growth relationship. Here we employ both approaches. In order to compare the results obtained from both methods with those from our preferred formal threshold model, to illustrate the limitations of the traditional approaches and to better facilitate comparisons between the different approaches, we begin with the linear interaction method. This method assumes that there is a continuous conditioning influence of institutions or natural barriers on the productivity growth impact of openness. Thus, we separately add the terms ($OPEN_{it} * NATBARR_{it}$) and ($OPEN_{it} * INSTIT_{it}$) to Equation (4.1). The augmented models are thus:

$$TFPG_{it} = \alpha_0 + \alpha_1 GDP_{it}^0 + \alpha_2 OPEN_{it} + \alpha_3 INSTIT_{it} + \alpha_4 (OPEN_{it} * NATBARR_{it}) + \mu_{it} \quad (4.2)$$

$$TFPG_{it} = \alpha_0' + \alpha_1' GDP_{it}^0 + \alpha_2' OPEN_{it} + \alpha_3' NATBARR_{it} + \alpha_4' (OPEN_{it} * INSTIT_{it}) + \mu_{it}' \quad (4.2')$$

where the expected signs are: $\alpha_4 < 0$ and $\alpha_4' > 0$.

In Equation (4.2), we hypothesise that higher natural barriers will reduce the benefits of increased (policy-induced) openness or trade liberalisation since it will constrain the country's access to new ideas and/or increase the costs of accessing new ideas through international exchange. While in Equation $(4.2')$, the ability of a country to benefit from increased openness is hypothesised to be fashioned by the quality of its institutions, with the productivity growth return to openness increasing as institutional quality increases.

As an alternative to expecting there to be a continuous conditioning influence of institutions or natural barriers on the productivity growth impact of openness, one might hypothesise that the relationship between openness and productivity growth is constant within particular sub-sets of the sample of countries but varies between the sub-sets of countries. Countries characterised as being represented by higher quality institutions or by lower natural barriers might for example be expected to benefit more from increased openness than other countries in the sample. For the current analysis the sample of countries is split in turn into HIGH, MEDIUM and LOW natural barrier and institutional quality countries, with one-third (approximately) of the countries falling each time into each category. The revised estimating equations are therefore:

$$TFPG_{it} = \alpha_0 + \alpha_1 GDP_{it}^0 + \alpha_2 OPEN_{it} + \alpha_3 INSTIT_{it} + \alpha_4 NATBARR_{it} + \alpha_5 (OPEN_{it} * Dmednatbarr) + \alpha_6 (OPEN_{it} * Dhighnatbarr) + \mu_{it} \quad \textbf{(4.3)}$$

where *Dmednatbarr* is a country dummy (=1) for countries with MEDIUM natural barriers; and *Dhighnatbarr* is a country dummy (=1) for countries with HIGH natural barriers. The expected signs are:

either

α_5 and $\alpha_6 < 0$ (lower benefits of openness for all countries without LOW natural barriers)

or

$\alpha_5 = 0$ and $\alpha_6 < 0$ (lower benefits only for HIGH natural barrier countries)

and

$$TFPG_{it} = \alpha'_0 + \alpha'_1 GDP^0_{it} + \alpha'_2 OPEN_{it} + \alpha'_3 INSTIT_{it} + \alpha'_4 NATBARR_{it} + \alpha'_5 (OPEN_{it} * Dlowinstit) + \alpha'_6 (OPEN_{it} * Dmedinstit) + \mu'_{it} \qquad (4.3')$$

where *Dlowinstit* is a country dummy (=1) for countries with LOW quality institutions and *Dmedinstit* is country a dummy(=1) for countries with MEDIUM quality institutions. The expected signs are:

either

α'_5 and α'_6<0 (lower benefits of openness for all countries without HIGH quality institutions)

or

$\alpha'_5 < 0$ and $\alpha'_6 = 0$ (lower benefits of openness only for low institution quality countries)

4.4.3 Formal Threshold Model[5]

Threshold regression models specify that individual observations can be divided into classes based on an observed variable. They allow one to determine whether regression functions are identical across all observations in a sample, or whether they fall into discrete classes. Given our *a priori* belief that the effects of openness on TFP growth differ across countries based on the countries' institutional and infrastructural capabilities, we argue that they fall into discrete classes. That is, the openness-growth relationship is characterised by heterogeneity conditional on

[5] The GEP Working Paper "Threshold and Interaction Effects in the Openness-Productivity Growth Relationship", draws heavily on this section of the chapter (see Girma, Henry, Kneller and Milner, 2003).

institutional quality and natural barriers to trade (proxied by transport costs). We do not know, however, how the coefficients on the openness variables vary with institutional quality and transport costs. In light of this, we employ the endogenous threshold regression techniques based on Hansen (2000) and estimate the unknown threshold or cut-off values. Doing so, however, renders the standard econometric theory of estimation and inference invalid (discussed below). The seminal contribution of Hansen (2000) is to provide an asymptotic distribution theory which enables one to make valid statistical inferences on the basis of threshold models.

Assuming for simplicity that the openness-productivity growth relationship is captured by either of the single threshold equations below, where in equation (4.4) natural barriers is the threshold variable and in equation (4.4') institutional quality the threshold variable :

$$TFPG_{it} = \gamma X_{it} + \beta_1 OPEN_{it} I(NATBARR_{it} \leq \alpha) + \beta_2 OPEN_{it} I(NATBARR_{it} > \alpha) + \varepsilon_{it} \tag{4.4}$$

$$TFPG_{it} = \gamma' X_{it} + \beta_1' OPEN_{it} I(INSTIT_{it} \leq \alpha') + \beta_2' OPEN_{it} I(INSTIT_{it} > \alpha') + \varepsilon_{it}' \tag{4.4'}$$

In each equation I(.) is the indicator function and X is a vector of other control variables for Equations (4.4) and (4.4′), and includes both threshold variables. In estimating Equation (4.4), three main econometric and statistical problems need to be addressed. The same three problems and the procedures we adopt for resolving them apply to Equation (4.4′) in an analogous manner. The first is to jointly estimate the threshold value α and the slope coefficients γ, β_1, and β_2. The second is to test the null hypothesis of no threshold (i.e. $H_0 : \beta_1 = \beta_2$) against the alternative of a threshold regression model (i.e. $H_a : \beta_1 \neq \beta_2$) and the third, to construct confidence intervals for α.

To estimate the parameters of the equation we use the algorithm provided by Hansen (2000) that searches over values of α sequentially until the sample splitting value $\hat{\alpha}$ is found.[6] 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 χ^2 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.[7] We follow Hansen (2000) and bootstrap the p-value based on a likelihood ratio (LR) test.[8]

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 regime 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: $H_o : \alpha = \alpha_0$. It should be noted that the test of the null

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[6] This is the value of α that minimises the concentrated sum of squared errors based on a conditional OLS regression (see Appendix 4.1).
[7] Hansen (1996) demonstrates that bootstrapping generates asymptotically correct p-values.
[8] The technique of bootstrapping is used to obtain a description of the sampling properties of empirical estimators using the sample data themselves, rather than the theoretical results. It provides a way of

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 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 derives the correct distribution function and provides a table of the appropriate asymptotic critical values.[9]

Although equations (4.4) and $(4.4')$ assume that there exists only a single threshold, it is straightforward to extend the analysis to consider multiple thresholds. In fact, the possibility of the existence of more than one threshold represents another advantage of this method for capturing threshold effects over the traditional approaches, which allow for only a single threshold. We thus allow for the possibility of multiple thresholds in our estimations. In the case of a threshold effect associated with natural barriers, for example if $\beta_1 \neq \beta_2$, $\beta_1 > 0$ 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, though positive, productivity growth effects for those with above threshold level of natural barriers. Analogously in Equation $(4.4')$ the expected threshold effect would also be revealed by $\beta_2' > 0$ and $\beta_2' > \beta_1' > 0$; higher productivity growth effects from openness for those countries with above the

obtaining measures of statistical precision when no formula is otherwise available, or when available formulas make untenable assumptions (Greene, 2000).

[9] See Table I on page 582 of Hansen (2000).

threshold level of institutional quality and lower, though positive, productivity growth effects for those with below threshold institutional quality.

4.5 DATA AND ESTIMATION

4.5.1 Productivity Growth

We employ the augmented mean group measure of TFP growth (TFPG-AMG2) derived on the basis of the methodology outlined in the previous chapter. Recall, this measure allows for heterogeneity in the parameters of the production function across countries but assumes that production technologies are the same for countries within the same regional grouping.

4.5.2 Openness

In light of the concerns raised over the ability of some trade openness (distortions) measures to capture particular aspects of a country's trade policy (Edwards, 1998; Rodriguez and Rodrik, 2000), as well as the suitability of a single such measure to adequately proxy something as complex and multi-faceted as a country's trade regime (Edwards, 1998; Greenaway et al., 1998), we use four alternative measures of trade openness (distortions). Three of these measures were utilised in the panel regression exercises in Chapter 3. These are: OPEN1 (the log of exports plus imports to GDP), the Sachs-Warner openness index (SWOPEN) and PRIDEV (the log of the price level of GDP in PPP prices relative to the U.S. dollar exchange rate). For the purposes of this chapter we will refer to the latter two openness (distortion) measures as OPEN2 and OPEN3, respectively. The fourth measure is a collection taxes ratio (labelled OPEN4) for which we follow Rodriguez and Rodrik (2000) in multiplicatively expressing import and export duties as a proportion of total trade.[10]

4.5.3 Natural Barriers

We use transport costs as our proxy for natural barriers. As noted by Milner et al., (2000) this measure conflates two types of barriers (natural barriers and infrastructure inefficiencies) into one. The natural component relates to the physical geographical factors like distance (from the coast and core markets) while infrastructure relates to roads, telephones, ports and general telecommunications. Our measure of transport costs is the estimated average c.i.f./f.o.b. margins in international trade. The c.i.f./f.o.b. ratio measures, for each country, the value of imports (inclusive of carriage, insurance and freight) relative to their free on board value i.e. the cost of the imports and all charges incurred in placing the merchandise aboard a carrier in the exporting port. Data for this ratio were obtained from the International Monetary Fund's (IMF) International Financial Statistics (IFS) Yearbook (various years) for the period 1965-1990.

The c.i.f./f.o.b. measure is not without its drawbacks. The principal one is that it is prone to measurement error. The ratio is a crude estimate undertaken by the IMF for countries that report the total value of imports at c.i.f. and f.o.b. values, which themselves contain some measurement error. Added to that, is the fact that some countries do not report these figures every year. Finally, the measure aggregates over all commodities imported.[11] However, three factors contribute to make the c.i.f./f.o.b.

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[10] As indicated in the previous chapter, the formula used by Rodriguez and Rodrik (2000) for the collection ratio is [(1+ mdut)x(1+xdut) – 1]/(X+M) where mdut represents import duties and xdut represent export duties. The data sources for all the openness measures are detailed in Chapter 3.

[11] Limao and Venables (2001) and, before them, Moneta (1959) provide a fuller discussion on the problems associated with the c.i.f./f.o.b. data.

ratio our preferred measure of transport costs. First, the country coverage is broader than alternative measures. Second, a fairly lengthy time series exists for this ratio. Third, the c.i.f./f.o.b. ratio allows us to capture both the overland transport costs borne by landlocked countries as well as the international component (either air or marine or both) [see Milner et al, 2000; Limão and Venables, 2001].

4.5.4 Institutional Quality

To assess the impact of institutional differences on TFP growth we use an index 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.[12] 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 are supportive of the principles of the rule of law. A 0-10 scale is used to assign country ratings, with countries having a 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

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[12] Our use of Legal Structure and Security of Property Rights to proxy a country's institutional quality rather than the overall Economic Freedom index is 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) measures - most notably the Sachs and Warner index - are used as a basis for constructing the latter.

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 1989). Given that institutional arrangements are likely to change slowly through time, the year to year variation may be rather small. In which case the use of data in 5 year periods may not be unreasonable.[13] In fact, similar reasoning was employed by Barro (1997) and, Chong and Calderón (2000).

Summary statistics and the correlation matrix for the variables used in the estimation exercises are provided in Tables A4.1 and A4.2 respectively, in Appendix 4.2.

4.5.5 Estimation

To examine the relationships between TFP growth and openness, institutions and natural barriers for the base model and models using the traditional approaches we use feasible GLS (FGLS) estimation of pooled cross-section and time series data. Our justification for using FGLS estimation is largely based on the need to account for heteroscedasticity across countries within the framework of our panel estimations and also the fact that we don't know the nature of the scedastic function. We believe that it is plausible to assume that there will be some variation of scale in our broad cross-section of countries. That being the case, the variance of each country will differ and so one needs to take this into account in one's estimations. Thus we allow

[13] 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.

for heteroscedasticity across countries but no autocorrelation either across or within countries. [14] Given that our data are in five-year periods, we believe that with only four time periods not accounting for autocorrelation will not fundamentally affect our estimation results. Additionally, the FGLS estimator is equivalent to the GLS estimator asymptotically.[15]

Finally, we treat all the regressors as exogenous and so make no claims about casual relationships running from the right hand side variables to TFP growth.

4.6 RESULTS

4.6.1 Base Model

The GLS estimates for the base model incorporating only direct effects on TFP growth are reported in Table 4.1, for panels covering up to a maximum of eighty three (83) countries. Four alternative openness measures (equations a-d) are employed along with the proxies for institutional quality (INSTIT) and natural barriers (NATBARR). All of the openness measures, except OPEN4, are statistically significant and have the expected signs. In the case of OPEN4, despite having the expected sign, it is not significantly correlated with TFP growth at conventional levels. For the other measures of openness (distortions), significance is at the 1% level thus indicating that greater openness or reduced trade distortions is associated with higher productivity growth. There is also support in these regressions for the expected direct effects of institutions and natural barriers.

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[14] We also estimated the base model allowing for autocorrelation within panels assuming both a common AR (1) coefficient for all panels as well as a panel specific AR(1) coefficient. Generally, our results match those obtained from assuming no autocorrelation.

[15] The use of alternative estimation methods did not fundamentally change the thrust of the results.

INSTIT has a positive sign in all the equations, and is also significant at the 1% level in all the equations except equation (b). This latter result may be a consequence of the fairly high collinearity between the Sachs-Warner index (OPEN2) and the proxy for institutional quality. NATBARR also has a negative sign in all the estimations, with significance at the 1% level in three cases and at the 5% level in the case of equation (b).

Table 4.1: GLS REGRESSIONS OF DETERMINANTS OF TFP GROWTH				
DEPENDENT VARIABLE TFP GROWTH (TFPG-AMG2)				
INDEPENDENT VARIABLES	**(a)**	**(b)**	**(c)**	**(d)**
GDP^0	-0.00690*** (5.54)	-0.00741*** (7.15)	-0.00516*** (4.18)	-0.00998*** (6.64)
OPEN1 (X+M/GDP)	**0.00844*** (6.21)**			
OPEN2 (SW)		**0.01759*** (8.37)**		
OPEN3			**-0.01059*** (6.48)**	
OPEN4				**-0.00041 (1.33)**
INSTIT	0.00133*** (2.81)	0.00047 (1.11)	0.00262*** (6.41)	0.00272*** (5.29)
NATBARR (c.i.f./ f.o.b.)	-0.0502*** (3.15)	-0.02971** (2.19)	-0.05369*** (3.33)	-0.06415*** (3.53)
PERIOD==2(1975-79)	-0.00852*** (3.37)	-0.00810*** (4.11)	-0.00279 (1.16)	-0.00249 (0.83)
PERIOD==3(1980-84)	-0.02364*** (11.33)	-0.01961*** (13.11)	-0.02032*** (10.33)	-0.01742*** (6.85)
PERIOD==4(1985-89)	-0.00894*** (4.53)	-0.00775*** (5.77)	-0.00662*** (3.37)	-0.00267 (1.08)
Observations	253	243	253	201
Number of countries	83	78	83	78

NOTES :TFPG-AMG2 is a residual measure of TFP growth calculated using the mean factor elasticities by region from single country estimations of a Cobb-Douglas production function. OPEN1 is the log of the share of exports plus imports in GDP (%); OPEN2 is the Sachs and Warner (1995) openness index; OPEN3 is the log of the price level GDP (%)in PPP prices, relative to the U.S. dollar exchange rate. INSTIT is an index of Legal Structure and Security of Property Rights. NATBARR is a measure of international transport costs and is proxied by the c.i.f./f.o.b. ratio. OPEN4 is the log of the collected taxes ratio (CTR)calculated using the multiplicative formula of Rodriguez and Rodrik (2000).

Absolute value of z-statistics in parentheses.* significant at 10%; **significant at 5%; *** significant at 1%.

The consistency of the support for the hypothesised direct effects across the alternative measures of openness is encouraging for two reasons. Firstly, it offers some accommodation for the criticisms that may be made over trying to capture the multi-faceted concept of policy openness in a simple summary measure. Secondly, it reduces the concerns arising from any co-linearity between openness and institutions or natural barriers. For example in equation (a), one may legitimately point to the fact that a trade to GDP measure of openness incorporates aspects of both policy and functional openness, with natural barriers being one influence on functional openness (see Dollar and Kray, 2001). That is, as indicated previously in this thesis, OPEN1 may be influenced by geographical factors. We return to this issue later in this chapter.

In these, as in all the subsequent estimations, initial GDP (GDP^0) consistently has a negative coefficient with a high level of significance. For this set of countries and time periods, we consistently have support for the conditional convergence hypothesis, or at least for conditional convergence effects swamping any technological absorptive capability effect.

4.6.2 Linear Interaction Models

Initially, the full specification of the augmented models (models 4.2 and 4.2′ in Section 4.4) were estimated. Given some implausible signs on the direct effects and on the threshold values (i.e. where $\partial TFPG/\partial NATBARR$ or $\partial TFPG/\partial INSTIT$ switched from zero to positive), possibly associated with induced co-linearity problems, the model(s) were estimated with the direct effect (NATBARR in Table 4.2 and INSTIT in Table 4.3) excluded.

The results in Table 4.2 are consistent with natural barriers having indirect effects, via the influence of openness, on TFP growth. The pattern of signs and significance on all the direct relationships are as in the base results (Table 4.1), except for the collected taxes ratio variable (OPEN4) [in equation (d) of Table 4.2]. The interaction terms OPEN1(2)(3)*NATBARR are consistently negative with significance at the 1% level [except equation (b) at the 10% level]. This finding is consistent with the view that as natural barriers increase the positive effect of openness on productivity growth steadily decreases, [or in equations (c) and (d) with the idea of the negative effects of price and trade tax distortions on productivity growth steadily increasing].

Table 4.2: GLS REGRESSIONS WITH LINEAR INTERACTIONS BETWEEN OPENNESS AND NATURAL BARRIERS

DEPENDENT VARIABLE TFP GROWTH (TFPG-AMG2)

INDEPENDENT VARIABLES	**(a)**	**(b)**	**(c)**	**(d)**
GDP^0	-0.00692*** (5.46)	-0.00771*** (8.60)	-0.00523*** (4.37)	-0.01030*** (7.17)
OPEN1(X+M/GDP)	**0.07457*** (3.90)**			
OPEN2(SW)		**0.06807*** (2.61)**		
OPEN3			**-0.00935*** (6.17)**	
OPEN4				**0.01867*** (4.78)**
INSTIT	0.00123** (2.57)	0.00039 (1.00)	0.00244*** (5.90)	0.00289*** (5.50)
OPEN1*NATBARR	**-0.06603*** (3.46)**			
OPEN2*NATBARR		**-0.04488* (1.88)**		
OPEN3*NATBARR			**-0.01849*** (3.96)**	
OPEN4*NATBARR				**-0.01819*** (4.98)**
PERIOD==2(1975-79)	-0.00883*** (3.50)	-0.00847*** (4.74)	-0.00325 (1.36)	-0.00102 (0.33)
PERIOD==3(1980-84)	-0.02365*** (11.34)	-0.02042*** (15.64)	-0.02056*** (10.52)	-0.01722*** (6.50)
PERIOD==4(1985-89)	-0.00920*** (4.71)	-0.00798*** (6.45)	-0.00695*** (3.59)	-0.00179 (0.69)
Observations	253	243	253	201
Number of countries	83	78	83	78

NOTES: Same as in Table 4.1

Absolute value of z-statistics in parentheses.* significant at 10%; ** significant at 5%; *** significant at 1%.

By imposing a continuous (and linear) relationship or an indirect effect of natural barriers on TFP growth, we do allow for the possibility of a specific type of threshold; namely we allow for the critical or threshold value of NATBARR where the growth effects of openness switch from being positive to being negative. It is only for equations (a) and (b) in Table 4.2 that the critical values of NATBARR are feasible or fall within the actual sample range of values for this variable. Modelled in this manner, openness has positive but declining productivity growth effects up to a c.i.f.–f.o.b. ratio of 1.129 [equation (a)] and 1.52 [equation (b)], but beyond these threshold values of NATBARR increasingly negative growth effects.

Again in Table 4.3 there is some support for institutions having indirect effects via openness on TFP growth. The alternative openness measures, initial GDP and natural barrier variables have the expected signs with strong significance. The interaction term also has the expected positive sign in equations (a), (c) and (d). Thus modelled in this way [equation (a)] increases (falls) in institutional quality increase (reduce) productivity growth benefits of openness. Alternatively [equations (c) and (d)], increases (falls) in institutional quality reduce (increase) the productivity losses associated with distortions. For equation (b), which uses the Sachs-Warner index (OPEN2), there is no support for an indirect effect of institutions on TFP growth.

Table 4.3: GLS REGRESSIONS WITH LINEAR INTERACTIONS BETWEEN OPENNESS AND INSTITUTIONS				
DEPENDENT VARIABLE TFP GROWTH(TFPG-AMG2)				
INDEPENDENT VARIABLES	**(a)**	**(b)**	**(c)**	**(d)**
GDP^0	-0.00608*** (4.84)	-0.00721*** (7.34)	-0.00555*** (4.10)	-0.00920*** (6.12)
OPEN1(X+M/GDP)	**0.00740*** (4.09)**			
OPEN2(SW)		**0.01894*** (5.41)**		
OPEN3			**-0.01224*** (6.38)**	
OPEN4				**-0.00564*** (5.86)**
NATBARR (c.i.f./f.o.b.)	-0.04738*** (3.01)	-0.03482*** (2.59)	-0.05021*** (3.09)	-0.07756*** (4.31)
OPEN1*INSTIT	**0.00025** (2.06)**			
OPEN2*INSTIT		**-0.0000 (0.00)**		
OPEN3*INSTIT			**0.00060*** (5.90)**	
OPEN4*INSTIT				**0.00064*** (5.16)**
PERIOD==2 (1975-79)	-0.00955*** (3.77)	-0.00947*** (5.43)	-0.00304 (1.22)	-0.00543** (2.19)
PERIOD==3 (1980-84)	-0.02422*** (11.54)	-0.02125*** (19.47)	-0.02009*** (9.93)	-0.01854*** (7.89)
PERIOD==4 (1985-89)	-0.00943*** (4.74)	-0.00945*** (12.40)	-0.00656*** (3.23)	-0.00326 (1.41)
Observations	253	243	253	201
Number of countries	83	78	83	78

NOTES: Same as in Table 4.1
Absolute value of z-statistics in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

Although there is support for indirect effects in estimations (a), (c) and (d), only in the last of the three estimations does the critical threshold value fall within the range of values for the institutional quality index. There is no possibility of a threshold effect (as defined above) in equation (a) for any feasible (positive) measure of institutional quality. In the case of equation (c), the positive value the institutional quality index has to reach before the beneficial effect of reducing distortions disappears is beyond the upper limit of the index. But this, in any case, would be a rather non-credible threshold to hypothesise. One would expect distortions reduction to be productivity growth enhancing at all levels of institutional quality. Similarly, one would not expect increased openness to actually reduce (long-term) productivity growth at any level of natural barriers. Rather it would be more credible to argue that the productivity growth response to increased openness may be different for groups of countries with different levels of natural barriers; 'lower' natural barrier countries tending to have greater positive responses to increased openness than 'higher' natural barrier countries. Such thresholds between 'higher' and 'lower' indexed countries (indexed in terms of natural barriers or institutional quality) might be imposed (exogenously) upon the data or explored endogenously within the data itself.

4.6.3 Exogenous Sample Splitting

The results for what effectively splits the sample of countries into first 'HIGH', 'MEDIUM' and 'LOW' natural barrier countries and secondly 'HIGH', 'MEDIUM' and 'LOW' institution quality countries are reported in Tables 4.4 and 4.5 respectively. Consider Table 4.4 first. The pattern of results on the direct terms is largely as in the base results, except for the coefficient on the collected taxes ratio proxy (OPEN4) in equation (d) which is now statistically significant; albeit marginally. In the case of the interaction terms, openness proxies interacted with dummies used to split the sample, the table shows that there are no growth benefits for high natural barrier countries from either increased trade openness or reduced trade distortions relative to low natural barrier countries. In contrast, the evidence for medium natural barrier countries is mixed. Equation (a) shows there are very small productivity growth benefits for medium natural barrier countries resulting from an increase in the trade share in GDP (OPEN1). However, since the joint test of the coefficient for this group of countries and that of the high natural barrier group indicates that they are not significantly different from zero, there are doubts over the interpretation of the results for the medium natural barrier countries.

For the local price deviation measure (OPEN3) there is evidence here that increased distortions reduce TFP growth more for medium natural barrier countries, but not strong support for a similar effect for high natural barrier countries. In this instance their joint coefficients are different from zero. Finally, for the collected trade taxes proxy (OPEN4), we obtain the unexpected result that medium natural barrier countries receive positive benefits from increased trade taxes. There is therefore only limited evidence for the hypothesised threshold effects of natural barriers on the effects of openness on productivity growth using the thresholds imposed here.

The results for the indexing of the split on the basis of the quality of countries' institutions (Table 4. 5) is overall more in line with the priors discussed in Section 4.4. For example, equations (a), (c) and (d) are consistent with the alternative hypotheses proposed in this paper that the ability to reap the productivity growth benefits of openness are contingent upon the institutional quality (directly) and the extent of natural barriers (inversely). In equations (c) and (d), both low and medium quality institution countries experience greater productivity declines for increases in distortions relative to high quality institution countries (i.e. $\alpha_5' < 0$ and $\alpha_6' < 0$), while in equation (a) ($\alpha_5' < 0$ and $\alpha_6' = 0$), with lower productivity growth benefits of increased openness for low quality institution countries only. However, the equation using Sachs-Warner based measure [equations (b)] has interaction terms that are insignificant.

Table 4.4: GLS Regressions with Exogenous Splitting Based on HIGH and MEDIUM NATURAL BARRIER COUNTRY DUMMIES				
Dependent Variable TFP GROWTH (TFPG-AMG2)				
Independent Variables	**(a)**	**(b)**	**(c)**	**(d)**
GDP^0	-0.00597*** (4.61)	-0.00758*** (7.02)	-0.00508*** (4.94)	-0.00985*** (6.02)
OPEN1(X+M/GDP)	**0.00725*** (4.62)**			
OPEN2(SW)		**0.01873*** (7.21)**		.
OPEN3			**-0.01282*** (10.21)**	
OPEN4				**-0.00062* (1.89)**
INSTIT	0.00133*** (2.70)	0.00036 (0.83)	0.00255*** (6.64)	0.00292*** (5.57)
NATBARR (c.i.f./f.o.b.)	-0.05859*** (3.44)	-0.02814** (2.02)	-0.05730*** (3.00)	-0.06390*** (3.09)
OPEN1*MEDNATBARR	**0.00001* (1.82)**			
OPEN1*HIGHNATBARR	**0.00001 (1.38)**			
OPEN2*MEDNATBARR		**-0.00052 (0.23)**		
OPEN2*HIGHNATBARR		**-0.003325 (0.94)**		
OPEN3*MEDNATBARR			**-0.00119** (2.08)**	
OPEN3*HIGHNATBARR			**-0.00020 (0.30)**	
OPEN4*MEDNATBARR				**0.00136* (1.87)**
OPEN4*HIGHNATBARR				**-0.00012 (0.16)**
Observations	253	243	253	201
Number of countries	83	78	83	78
chi2Test, OPEN1*MEDNATBARR = OPEN1*HIGHNATBARR =0	3.62			
prob>chi2	0.16			
chi2Test OPEN2*MEDNATBARR = OPEN2*HIGHNATBARR =0		0.89		
prob>chi2		0.64		
chi2Test OPEN3*MEDNATBARR = OPEN3*HIGHNATBARR =0			5.05	
prob>chi2			0.08	
chi2Test OPEN4*MEDNATBARR = OPEN4*HIGHNATBARR =0				4.28
prob>chi2				0.039

NOTES: All variables except the interaction terms are as defined in Table 4.1. HIGHNATBARR refers to countries categorised as having high natural barriers (i.e. a c.i.f./f.o.b. factor greater than the 66.67 percentile); MEDNATBARR refers to countries categorised as having medium natural barriers (i.e. a c.i.f./f.o.b. factor greater than the 33.333 percentile but less than or equal to the 66.67 percentile. The reference group consist of those categorised as having low natural barriers(i.e. a c.i.f./f.o.b. factor less than or equal to the 33.333 percentile). To conserve space period dummies are not shown.
Absolute value of z-statistics in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

Table 4.5: GLS REGRESSIONS WITH EXOGENOUS SPLITTING BASED ON LOW & MEDIUM QUALITY INSTITUTION COUNTRY DUMMIES

DEPENDENT VARIABLE TFP GROWTH (TFPG-AMG2)				
Independent Variables	**(a)**	**(b)**	**(c)**	**(d)**
GDP^0	-0.00661*** (5.08)	-0.00726*** (6.68)	-0.00644*** (5.30)	-0.01299*** (13.94)
OPEN1(X+M/GDP)	**0.00971*** (6.71)**			
OPEN2(SW)		**0.01768*** (5.95)**		
OPEN3			**-0.00666*** (3.16)**	
OPEN4				**0.00004 (0.94)**
INSTIT	-0.00005 (0.07)	0.00054 (1.00)	-0.0000 (0.00)	0.00182*** (3.43)
NATBARR (c.i.f./f.o.b)	-0.05253*** (3.34)	-0.02958** (2.15)	-0.05815*** (3.81)	-0.06597*** (3.96)
OPEN1*LOWINSTIT	**-0.00284** (2.54)**			
OPEN1*MEDINSTIT	**-0.00104 (1.42)**			
OPEN2*LOWINSTIT		**0.00285 (0.60)**		
OPEN2*MEDINSTIT		**-0.00030 (0.13)**		
OPEN3*LOWINSTIT			**-0.00483*** (3.79)**	
OPEN3*MEDINSTIT			**-0.00272*** (3.61)**	
OPEN4*LOWINSTIT				**-0.00407*** (6.69)**
OPEN4*MEDINSTIT				**-0.00379*** (7.24)**
Observations	253	243	253	197
Number of countries	83	78	83	78
chi2 test, OPEN1*LOWINSTIT = OPEN1*MEDINSTIT =0	8.07			
Prob.>chi2	0.02			
chi2 test, OPEN2*LOWINSTIT= OPEN2*MEDINSTIT =0		0.61		
Prob.>chi2		0.74		
chi2 test, OPEN3*LOWINSTIT = OPEN3*MEDINSTIT =0			14.90	
Prob.>chi2			0.00	
chi2 test, OPEN4*LOWINSTIT =OPEN4*MEDINSTIT =0				0.44
Prob.>chi2				0.51

NOTES: All variables except the interaction terms are as defined in Table 4.1 LOWINSTIT refers to countries categorised as having low institutional quality (i.e. a value for Security of Property Rights less than or equal to the 33.333 percentile); MEDINSTIT refers to countries categorised as having a medium level of institutional quality (i.e. a value for Security of Property Rights greater than the 33.333 percentile but less than or equal to the 66.67 percentile). The reference group consists of those categorised as having high quality institutions (i.e. a value for Security of Property Rights greater than the 66.67 percentile). To conserve space period dummies are not shown.

Absolute value of z-statistics in parentheses.* significant at 10%; ** significant at 5%; *** significant at 1%.

One needs to be cautious however in drawing any conclusions on the basis of this particular exogenous splitting of the sample. There has been no attempt to see if there is a convenient clustering of countries or to assess from other research whether there is an appropriate degree of homogeneity of the country groupings. Additionally, the robustness of the results and the magnitude and significance of specific interaction terms may be sensitive to the arbitrarily selected splits.

Overall, the results from the traditional methods are unsatisfactory either because they are not robust or in some instances the estimated thresholds values fall outside the range of values taken by the threshold variable. We now present the results based on the preferred endogenous threshold regression method for modelling threshold effects.

4.6.4 Endogenous Splitting Using Formal Threshold Model

Taking natural barriers as the threshold identifying variable and OPEN1 as the measure of openness, Hansen's (2000) endogenous threshold modelling technique (set out in Section 4.4.4) identified two statistically significant cut-off values. The first of the identified thresholds (the upper threshold) corresponds to a NATBARR value of 1.15 (or the 86th percentile) with a bootstrapped p-value[16] of 0.045. Denoting the percentiles of the natural barriers variable (NATBARR) 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 (e.g. 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 4.1 below shows the

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

95% confidence interval for the first threshold, which is NATBARR ∈ [1.1214, 1.163] or in terms of percentiles [p (74), p (94)].

A second threshold (the lower threshold) which corresponds to a NATBARR value of 1.075, or the 33rd percentile, is also identified. It is marginally significant with a bootstrapped p-value of 0.098. In contrast to the first threshold estimate, the 95% confidence interval for this threshold is wide and encompasses most of the region below the first threshold. Consequently, we are less sure in this case as to where the "true" value at which the break-point in the parameter lies. Below we consider the effect of this uncertainty on the slope estimate based on this lower threshold value when discussing our regression results.

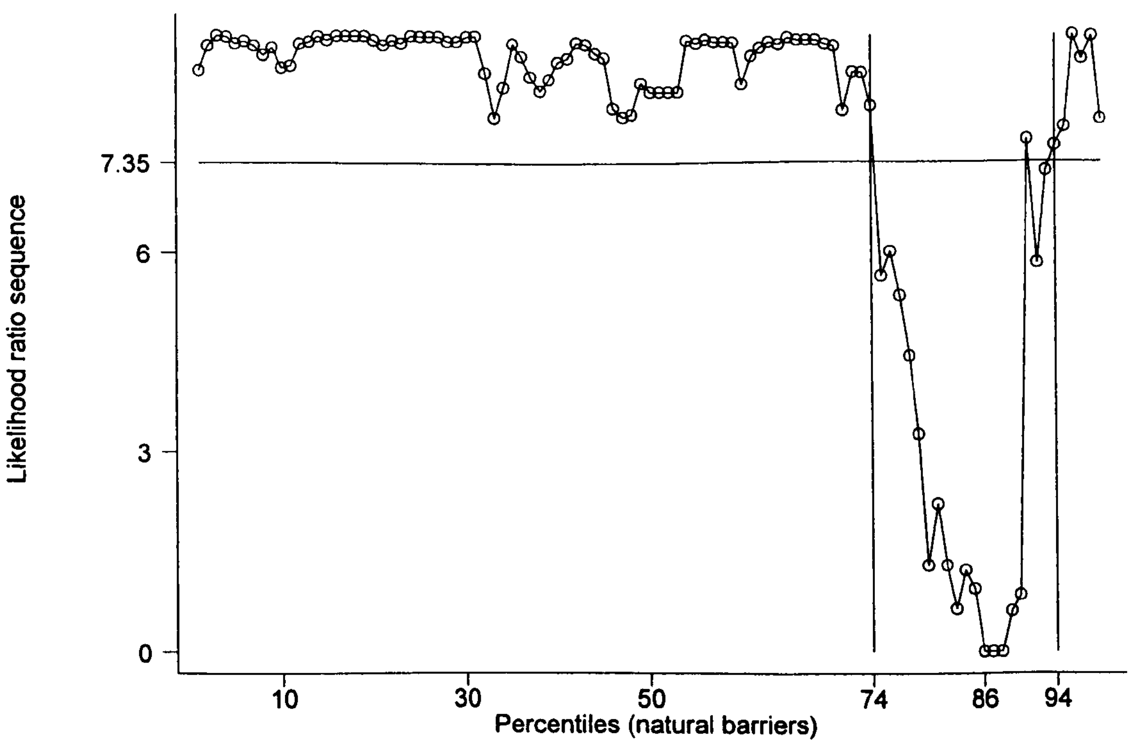

Figure 4.1: 95% percent confidence interval for upper threshold on natural barriers (OPEN1).

Table A4.3 in Appendix 4.3 presents a list of the natural barrier values for each country in each of the four time periods, ordered by their value in period 1 (1970-1974), to show for each country its position in the low natural barrier group, the confidence interval or the high natural barrier group.[17] Given the location of the threshold, it is of no surprise that most countries are located in the class which have low natural barriers. Some 67 of the 83 countries have two or more observations in the low natural barrier group.

As the Table also suggests, the confidence interval for OPEN1 and natural barriers is reasonably tight. Only 17 of the 83 countries have at least two of the four 5-year period observations within the 74th to the 94th percentiles.[18] There is, therefore, not much uncertainty about the location of the threshold. It follows however that the number of countries that we can be reasonably sure fall into the high natural barrier class is relatively small; only 9 countries have at least 2 observations in this group. This highlights the importance of including confidence intervals around the threshold estimate. Included in the high natural barrier group are mostly African and Latin American countries, for example Ethiopia, Rwanda, Peru and Paraguay.

To determine whether the results obtained and conclusions drawn on the basis of the first measure of trade openness (OPEN1) are robust to alternative measures of openness/trade liberalisation, we employ the two policy oriented measures, OPEN3 and OPEN4. Since the results obtained using the collected taxes ratio measure (OPEN4) meet all three estimation and inference requirements set out in Section 4.4.4, unlike those obtained using OPEN3, we present results from the former

[17] Given the lack of a confidence interval for the second threshold we assume there exists only one threshold for this variable.

measure of openness (distortion) first. Thus using natural barriers as the threshold variable and OPEN4 as the measure of policy openness, we again find two thresholds. The first, the upper threshold, corresponds to a NATBARR value of 1.1462 (or 79th percentile). The bootstrapped p-value is 0.002. The second, the lower threshold, has a NATBARR value of 1.1110 (or 58th percentile). However, this threshold is statistically insignificant since it has a bootstrapped p-value of 0.325. This suggests that in this case we have a single, rather than a double, threshold model. The 90% confidence interval for the significant threshold estimate (Figure 4.2) is derived in an analogous manner to the one shown in Figure 4.1. Figure 4.2 shows that in terms of percentiles, the confidence interval for the threshold estimate is [p(68), p(91)]. The corresponding natural barriers values are given by NATBARR $\in$ [1.1214, 1.1772]. The countries that fall in each threshold and the confidence interval are listed in the remaining columns of Table A4.3 in Appendix 4.3.

Although we are less certain about the "true" value of the threshold relative to the confidence interval shown in Figure 4.1, the confidence interval in Figure 4.2 is still reasonably tight; less than a quarter of the 78 countries having at least two observations lying in the interval. Additionally, there is considerable overlap in the countries located in the confidence bands shown in Figures 4.1 and 4.2, respectively (see Appendix 4.3). An examination of Table A4.3 shows that most of the countries with two and three observations lying within the interval shown in Figure 4.1, have all four of their natural barriers values located in the interval shown in Figure 4.2. Therefore, while there is a slight increase in the uncertainty about whether some countries can be placed in the high natural barrier and low natural barrier groups, in

[18] When we consider countries with at least one observation falling within the confidence interval, the number increases to 26.

general the results appear reasonably robust to the measure of openness used. There are now 7 countries that can be confidently placed into the high natural barrier group (Paraguay and Bolivia drop out because of a lack of data on OPEN4).

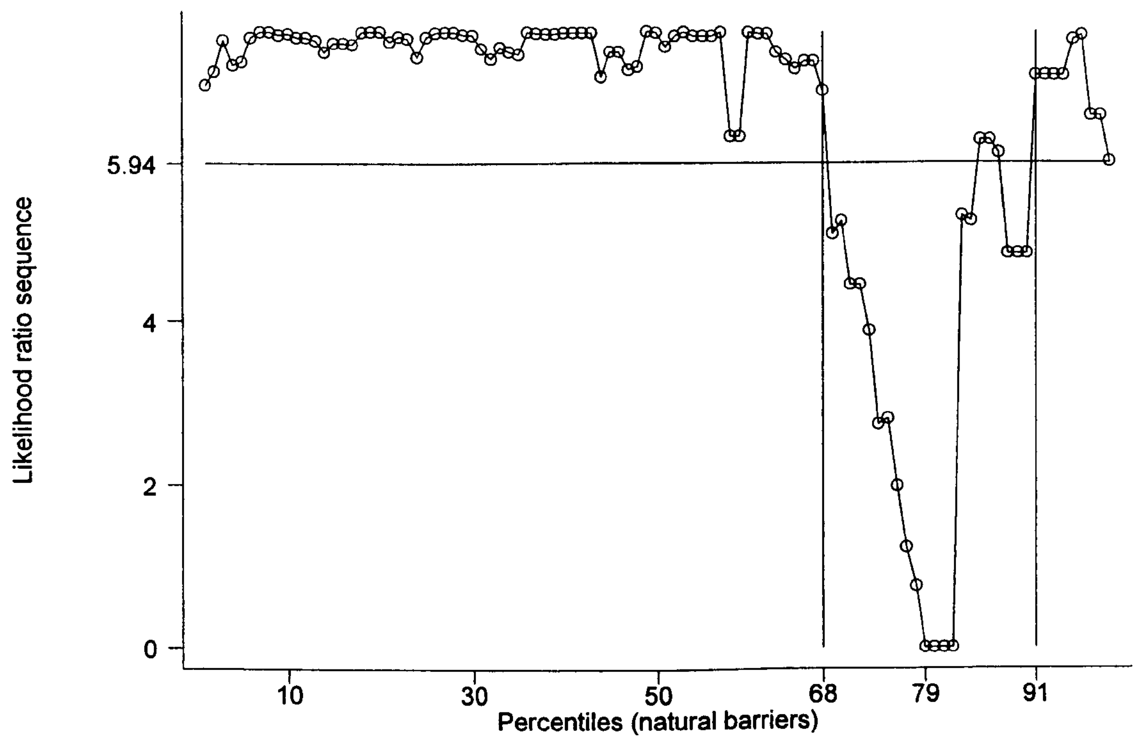

Figure 4.2: 90% percent confidence interval for the upper threshold on natural barriers (OPEN4).

Table 4.6 reports OLS estimates of TFP growth regressions for the double threshold model based on OPEN1(exports plus imports to GDP), and the single threshold model based on OPEN4 (collected trade taxes ratio). In regression (a), the coefficients on the variables GDP^0 and INSTIT have the expected signs and achieve significance at the 1% and 5% levels respectively. Given that the mean value of INSTIT for the sample is 5.655 log points and its standard deviation 2.793 log points (approximately the average institutional quality difference between Korea and the Philippines), then the estimated coefficient for this variable implies that, *ceteris paribus*, a one standard deviation increase in INSTIT from its mean leads to a 0.6% average annual increase in TFP growth.[19] The coefficient on NATBARR has an unexpected sign but without significance. This finding suggests that there is no direct effect of natural barriers on TFP growth, only an indirect role in mediating the openness-TFP growth relationship.

Our major finding in regression (a) is that there are positive and significant TFP growth benefits associated with openness for 'low' (NATBARR < 1.075) and 'medium' natural barriers countries (1.075=<NATBARR< 1.15).[20] In contrast, the growth benefit for 'high' natural barriers countries (NATBARR>= 1.15) from openness is not significantly different from zero. In other words, countries with high natural barriers (transport costs) receive no (or insignificant) TFP growth benefits associated with openness relative to the other two groups of countries. The mean value of OPEN1 for the entire sample is 3.881 log points. Thus controlling for other variables, regression (a) suggests that the TFP growth effect at the mean level of trade openness is 3.1 percentage points per annum for countries with 'low' natural barriers.[21] The comparative figure for the 'medium' natural barriers countries is 2.5 percentage points. In short, the message conveyed by regression (a) is that the predicted productivity growth payoff from increased openness differs for groups of countries based on the regime in which they are located, countries in the regime

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[19] Multiplying the standard deviation by the coefficient and finding the exponential of this product gives the percentage change.

[20] Recall that we are using the c.i.f.-f.o.b. ratio as a proxy for natural barriers. The c.i.f.- f.o.b. ratio is itself a proxy measure for transport costs incurred through engaging in international trade.

[21] The TFP growth effect for countries below the lower threshold value is the product 3.881* 0.00799 = 0.0310.

below the lower threshold or critical level of natural barriers receiving the highest productivity growth benefits from openness.

TABLE 4.6: ENDOGENOUS THRESHOLD REGRESSION ESTIMATES WITH OPEN1 AND OPEN4

DEPENDENT VARIABLE: TFP GROWTH (TFPG-AMG2)[1]			
Openness Variable	**(a)** *Trade Share (OPEN1)*	*Openness Variable*	**(b)** *Collected Tax Ratio (OPEN4)*
GDP^0	-0.00953 (2.86)***	GDP^0	-0.01073 (2.34)**
INSTIT	0.00221 (2.08)**	INSTIT	0.00346 (2.29)**
NATBARR	0.00378 (0.14)	NATBARR	-0.01104 (0.42)
BELOW LOWER THRESHOLD *OPEN1*I(NATBARR < 1.075)*	***0.00799*** ***(3.16)****	***BELOW THRESHOLD*** *OPEN4*I(NATBARR < 1.1462)*	***-0.00024*** ***(0.35)***
INTER-THRESHOLDS *OPEN1*I(1.075=< NATBARR <1.15)*	***0.00641*** ***(2.23)***		
ABOVE UPPER THRESHOLD *OPEN1*I(NATBARR >= 1.15)*	***0.00248*** ***(0.58)***	***ABOVE THRESHOLD*** *OPEN4*I(NATBARR>= 1.1462)*	***-0.00477*** ***(3.23)****
PERIOD==2	-0.00927 (2.00)**	PERIOD==2	-0.00111 (0.21)
PERIOD==3	-0.02611 (6.08)***	PERIOD==3	-0.01798 (3.82)***
PERIOD==4	-0.01160 (2.99)***	PERIOD==4	-0.00259 (0.61)
Constant	0.05059 (1.33)	Constant	0.09063 (1.64)
Observations R-squared Number of countries	253 0.25 83	Observations R-squared Number of countries	201 0.21 78

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%.
OPEN1 is the log of the share of exports plus imports in GDP(%); INSTIT is an index of Security of Property Rights. NATBARR is a measure of international transport costs and is proxied by the c.i.f./f.o.b. ratio. OPEN4 is the log of the collected taxes ratio (CTR) calculated using the multiplicative formula of Rodriguez and Rodrik (2000).

Although these results are consistent with the results obtained when we exogenously split the data into high, medium and low natural barrier countries [regression (a), Table 4.4], we view this as being purely coincidental. Another arbitrary splitting of the sample might have produced completely different results. In any case, we have already alluded to the inference problems posed by such ad hoc procedures. Further, in Girma, Henry, Kneller and Milner (hereafter, GHKM, 2003), the authors directly tested the linear interaction model specified in equation (4.2) against the endogenous threshold model of equation (4.4) using OPEN1 as the measure of openness/trade liberalisation. The sequential testing for thresholds identified two significant threshold values, thus rejecting the linear interaction model specified in (4.2) and by implication those of Borensztein et al. (1998) and Miller & Upadhyay (2000) . The threshold values (both in terms of percentiles and c.i.f.-f.o.b. ratios) in GHKM (2003) correspond identically to that obtained earlier within the formal threshold framework. Similarly, only a confidence interval (95%) for the upper threshold value of 1.15 (86^{th} percentile) obtained. This finding clearly suggests that the endogenous threshold model better captures the conditioning influences of natural barriers on the openness-TFP growth relationship.

Given the relatively wide confidence interval associated with the low/medium natural barrier threshold (value 1.075) and thus the degree of uncertainty about the location of the threshold parameter, the slope coefficient associated with this lower threshold value (though not 'invalid') is a less precise estimate of the population parameter. This is because some countries classified as belonging to the 'lower' natural barriers group may rightfully belong to the 'medium' natural barriers group and vice versa. 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 slope coefficients.[22] The similarity of the point estimate for the two groups perhaps providing some intuition of why this might be the case. The reader thus needs to bear this caveat in mind with regards to our predicted differentiated TFP growth effects from increased openness for the 'low' as opposed to the 'medium' natural barrier group. However, we can have greater confidence regarding the higher TFP growth returns from increased openness to low and medium barrier countries collectively over that of high natural barrier countries.

Regression (b) in Table 4.6 provides results for the TFP growth regression based on the single threshold value of 1.1462 for OPEN4 (trade taxes collection ratio) as the measure of trade distortion. All of the variables controlling for direct effects have the expected signs. However, only the variables GDP^0 and INSTIT have statistical significance; both being significant at the 5% level. Once again we find that natural barriers has no significant direct effect on TFP growth. For INSTIT, the results indicate that a one standard deviation increase in this index (Legal Structure and Property Rights) above its mean level is associated with approximately a 1% increase in the average annual rate of productivity growth over a 5-year period.

Regression (b) does not identify a significant TFP growth-enhancing effect for the increased openness or reduced distortion measure for the group of countries below the natural barrier threshold, rather it finds a greater growth-enhancing effect for the group of countries above the threshold (i.e. with high natural barriers). This would appear to contradict the finding in regression (a) that countries with low natural barriers are more responsive to trade, but is consistent with evidence from Moschos (1989). One possible explanation for this combination of results is that the alternative

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

openness proxies capture alternative influences of trade and trade policy on TFP growth, and these alternative channels of influence are differentially affected by natural barriers. At 'high' levels of natural barriers it appears to be important to reduce trade tax distortions, especially given that there may be interactive or multiplicative influences of trade taxes and natural barriers. In many developing countries, for instance, import duties are levied on the c.i.f. (or international trade cost-inclusive) value of imports. Lowering import duties for 'high' natural barrier (i.e. 'high' trade cost) countries will in this context bring about larger reductions in the overall distortion between world and domestic prices, and have greater effects at the margin on competition between home and foreign suppliers. By contrast, these results show that actual increases in total trade's share of GDP have a positive productivity growth effect for 'low' natural barrier countries. Here it may be that the capacity of countries to absorb (or imitate) technological improvements embodied in trade goods is greater where trade expansion is not as highly skewed towards less trade-cost intensive goods.

Thresholds were also explored on the final policy based measure of openness, OPEN3. The endogenous sample splitting procedure identified two statistically significant threshold values. The first corresponds to a natural barrier (NATBARR) value of 1.1496 (or 80th percentile) with a bootstrapped p-value of 0.064. The second threshold occurs at NATBARR=1.075 (or the 24th percentile) with a bootstrapped p-value of 0.014. The confidence intervals at conventional levels for both thresholds are however very wide, indicating that there is considerable uncertainty as to where the threshold values lie. Therefore, we take our finding of two significant thresholds as evidence of the existence of thresholds but that the data are not informative about their exact location. We note, however, the threshold values (if not the percentiles) of

NATBARR when we use OPEN3 as our measure of openness, are almost identical to those obtained from the use of OPEN1.

As indicated above, when the threshold value is imprecisely estimated this carries over to the slope coefficient that is "interacted" with the imprecisely estimated threshold value. This should therefore be borne in mind for the regression results shown in Table 4.7. Regression (a) reports OLS estimates for a TFP growth regression based on the double threshold model. Interestingly we find positive openness effects for all groups of natural barriers, but with the magnitude of the effect increasing as we move over thresholds to higher levels of natural barriers. Again therefore for a policy based measure of trade openness we find greater returns to reduced distortions for high natural barrier countries, this would appear to support the interpretation of the results made above. Note that the 'high' natural barriers group of countries include a mix of coastal countries (e.g. Tanzania, Kenya, Peru, Ecuador); island economies (e.g. Jamaica, Mauritius, Madagascar) and landlocked countries (e.g. Bolivia, Mali, Malawi, Rwanda and Zambia). This clearly suggests that factors other than being landlocked or being located far away from core markets also determine high transport costs (see Radelet and Sachs, 1998; Limao and Venables, 1999; Gallup et al. 1999; IDB, 2000).[23] As the latter authors argue, other key determinants of transport costs are the quality of a country infrastructure (roads, rail, ports and telecommunications) and the regulatory and institutional environment (e.g. transparency of customs procedures, efficiency of the bureaucracy etc.) governing international trade.

[23] Among our group of high natural barrier (transport costs) countries four – Dominican Republic, Haiti, Jamaica and Mauritius- were listed by Radelet and Sachs (1998) as having 100% of their populations residing within 100km of the coast, as well as being among the top 15 exporters of non-primary manufactured goods by developing countries between 1965-90.

TABLE 4.7: ENDOGENOUS THRESHOLD REGRESSION ESTIMATES WITH OPEN3 AND OPEN4

DEPENDENT VARIABLE: TFP GROWTH (TFPG-AMG2)[1]			
	(a)		**(b)**
Openness Variable	*Price Distortion (OPEN3)*		*Collected Tax Ratio (OPEN4)*
GDP^0	-0.00551 (1.41)		-0.01273 (2.70)***
INSTIT	0.00251 (2.46)**		0.00271 (1.67)*
NATBARR	0.00263 (0.12)		-0.06773 (2.19)**
BELOW LOWER THRESHOLD *OPEN3*I(NATBARR < 1.075)*	***-0.01217*** ***(2.15)*****	***BELOW THRESHOLD*** *OPEN4*I(INSTIT < 7.145)*	***-0.00253*** ***(1.81)****
INTER THRESHOLDS *OPEN3*I(1.075=< NATBARR <1.15)*	***-0.01452*** ***(2.45)*****		
ABOVE UPPER THRESHOLD *OPEN3*I(NATBARR >= 1.15)*	***-0.01768*** ***(3.19)******	***ABOVE THRESHOLD*** *OPEN4*I(INSTIT >= 7.145)*	***0.00107*** ***(1.32)***
PERIOD==2	-0.00719 (1.58)		-0.00068 (0.12)
PERIOD==3	-0.02430 (5.72)***		-0.01891 (4.05)***
PERIOD==4	-0.01236 (3.12)***		-0.00311 (0.71)
Constant	0.10070 (2.89)***		0.17674 (2.88)***
Observations R-squared Number of countries	253 0.26 83		201 0.20 78

NOTES:

1. Estimates of threshold values are based on least squares estimation (see Hansen, 2000).
2. Absolute value of (robust)t-statistics in parentheses * significant at 10%; ** significant at 5%; *** significant at 1%.
3. OPEN3 is the log of the price level GDP (%) in PPP prices, relative to the U.S. dollar exchange rate. All other variables are as defined for Table 4.6.

It can reasonably be argued that the extent to which a country is integrated into the world economy and productivity growth are simultaneously determined (see Acemoglu et al., 2001; Rodrik et al., 2002). Causality runs from growth to openness and the reverse. Two methods of dealing with endogeneity have typically been adopted in the empirical growth literature. The first involves using lagged values of the suspected endogenous regressor(s) and the second, the use of instrumental variable estimation, where the suspected endogenous regressors are instrumented by a separate set of variables, that are correlated with the endogenous right hand side variables but not the error term. Included among the potential list of instruments are lagged values of the suspected endogenous variables. While instrumental variable estimation might be considered the 'first best' solution, the difficulty in finding suitable instruments along with the complexity of applying this technique whilst simultaneously estimating thresholds (see Caner and Hansen, 2001) led us to choose the alternative approach to gauge the extent of the problem, ignored so far in the existing literature (see Papageorgiou, 2002). In addition, this allows us to incorporate variables into the endogenous sample splitting framework of Hansen (2000) without altering the estimation procedure upon which it is premised.

The number and the position of any thresholds along with the confidence interval around these values were re-estimated in the same manner as above but using the lagged values of the trade share (OPEN1) and the collected tax ratio (OPEN4). It is clear from this set of results that controlling for the possible effects of endogeneity when searching for threshold effects of openness on productivity growth is important, at least for some measures of openness. According to the results for the lag of OPEN1, there exists a single threshold level occurring at the 51st percentile which corresponds to a c.i.f.-f.o.b. ratio of 1.10. The position of the threshold for this measure of openness is somewhat lower than that found before, and in contrast to previous results no confidence interval could be established for this threshold. Therefore, we conclude that while it is difficult to determine the exact location of any threshold outside of that for contemporaneous effects, evidence remains for the existence of threshold effects.

For lagged values for OPEN4 greater robustness is found, evidence of a single threshold with a reasonably tight confidence interval is uncovered. Moreover, the critical threshold level both in terms of percentile (80th) and value (1.1496) is almost identical to that obtained using contemporaneous values of OPEN4, while the confidence interval [p (67), p (91)] around the threshold value is identical.

4.6.6 Using Institutional Quality as the Threshold Variable

Unlike natural barriers, when we search for evidence of threshold effects between trade openness and productivity growth using measures of institutional quality, no such relationship emerges. Using OPEN1, a threshold level of institutional quality at the 6th percentile is identified, but it is statistically insignificant based on the bootstrapped p-value. According to this result, to the extent trade openness is correlated with productivity growth this relationship is linear. Even when we use the policy-based measures of openness the evidence is not strong for institutions. Using the countries' Legal Structure and Security of Property Rights as the measure of institutional quality and OPEN4 as the measure of trade policy, we identified one significant threshold level. This occurs at a value of INSTIT = 7.145 (or 67th percentile). The corresponding bootstrapped p-value is 0.035. However, we are again unable to generate a confidence interval at conventional levels for this threshold due to the width of the interval. Again the results should be viewed with caution.

Regression (b) in Table 4.7 shows estimation results for the two regimes suggested by the threshold value of INSTIT and OPEN4. The finding of a direct TFP growth effect for the threshold variable (INSTIT), albeit a weak one, in this analysis represents a departure from previous results when we used NATBARR as the threshold variable. It suggests that in addition to mediating the openness-TFP growth relationship, there are direct TFP growth benefits associated with high institutional quality. The coefficient on the institution quality variable indicates that a one standard deviation increase of this variable away from its mean results in an average increase in TFP growth of 0.76% over the period.

The main finding is that for countries characterised by high institutional quality (i.e. those at or above the threshold value of 7.145) there are no significant TFP growth effects resulting from increased openness or reduced distortions. In contrast, increased policy openness/liberalisation is shown to increase TFP growth for countries below the threshold level of institutional quality. This is an unexpected finding since one might expect that institutional quality is a positive conditioning influence, with high quality institutions more likely to make openness effective. Rather this result suggests that increased openness is only needed to increase TFP growth where the quality of a country's institutions is relatively poor. Note, of course, that this conclusion holds only to the extent that the coefficients on the imprecisely defined threshold variables are relatively robust.

Indeed, the fact that the difference between the effect of openness differs statistically for high/low quality institution countries also highlights the dangers of exogenously imposing thresholds onto the regression. Exogenously setting the threshold (and assuming one managed to choose a value that is close to that estimated endogenously above) might lead to the false conclusion that the quality of institutions mediates the relationship between openness and productivity-growth. Making the same conclusion from the endogenous threshold methodology would not be possible.

We also experimented with other measures of openness with institutional quality as the threshold variable. Using OPEN3 we found one statistically significant threshold at INSTIT= 6.921 (or 63rd percentile) with a bootstrapped p-value of 0.018. It was not possible to ascribe a confidence interval for this threshold variable however. The results from estimations of TFP growth regressions (not reported) showed, unlike when we used OPEN4, that high institutional quality countries do have positive TFP growth effects from increased policy openness. These are, however, lower than those experienced by low institutional quality countries.

Finally, the interaction model with institutional quality as the conditioning influence on openness (OPEN4) is rejected in favour of the threshold model (GHKM, 2003).

4.7 CONCLUSIONS

In this chapter we ask the question whether the dependence of the correlation between openness to international trade and growth to the measure of openness and sample of countries used, found by Rodriguez and Rodrik (2000), and Harrison and Hanson (1999) is caused by non-linearity. If so, what causes the nature of the relationship to change across countries, what form does the heterogeneity take and what empirical framework best captures it. Taking the last question first, we argue that because of the inherent estimation, inference and methodological flaws associated with the traditional methods coupled with the pattern of results obtained when using them, the threshold regression method best captures heterogeneity in the openness-growth relationship.

With respect to the other questions posed, there is support for the hypothesis that there is a critical level of natural barriers (proxied by transport costs) above and below which the contribution to TFP growth from openness differ. We find that this relationship depends on the measure of openness used however. For instance, based on trade share as a percentage of GDP we uncover evidence that 'high' natural barriers countries receive lower or insignificant TFP growth benefits from increased openness relative to countries below this upper threshold. Alternatively, using the policy-based (trade tax) measures of openness/liberalisation, 'high' natural barrier countries are predicted to experience TFP growth benefits linked to reductions in trade taxes as a proportion of GDP, while countries below the threshold are predicted to experience no significant TFP growth effects. In this regard this work contributes to a deeper understanding of why other researchers (eg Block, 2001) have found that being closed to trade is more costly to growth in Africa than elsewhere. Africa is a region with relatively high 'natural barriers'. These differences in the nature of the threshold effects may account for differences in the nature of the productivity growth-openness relationship when trade performance and policy-based indicators of openness have been used in the previous literature. The composition of the 'high' natural barriers group of countries suggest that factors other than physical geographical characteristics also contribute to high transport costs. This clearly has implications for government policy, and for the importance to a broad group of developing countries of improving infrastructure and efficiency in the international transport sectors.

We find some evidence also of threshold level(s) based on natural barriers when using the alternative policy-based openness measure (OPEN3), and weak evidence that institutional quality affects the correlation between productivity growth and openness. In both instances there is imprecision over the location of the thresholds. Consequently, the slope coefficients based on the estimated thresholds are not necessarily accurately measured. While one possible conclusion from the result for institutions might be that institutional quality does not mediate the effects of openness, to the extent that measure of natural barriers used in this study includes the effects of institutional quality this conclusion is likely to prove premature. This is especially true given the inextricable link between the institutional and regulatory environment that governs for example a country's ports, transport costs and the volume of trade. Therefore, instead we conclude that the general quality of the institutional framework does not appear to be important for the openness-productivity growth relationship (there are direct effects from this variable), but there are likely to be specific aspects of institutional quality related to the level of natural barriers that are important.

While the finding of threshold effects is robust to the test of endogeneity that we employ, most noticeably for the policy based measure, it was not possible to accurately pin-point the location of threshold effects for the trade-GDP ratio. Although this suggests that future research into the sources of these differences are warranted, we are still able to conclude that accounting for heterogeneity in the openness-productivity growth relationship using the techniques adopted in this chapter will yield additional insights.

Having said that however, we recognise that there are limitations to the study, the main one being the inability to address the issue of possible endogeneity bias (resulting from likely endogenous regressors such as trade openness and institutional quality) based on the 'first best' solution of instrumental variable estimation. This inability is partly a reflection of the current state of the literature on endogenous threshold regression models. Second, in studying the conditioning influences of natural barriers and institutions on trade, we held constant all other possible conditioning influences.

Finally, the evidence provided in this chapter of heterogeneity in the trade-growth relationship means that the conventional assumption of a simple linear relationship between the two variables in previous cross-country studies is not supported by the data, and therefore appears to be misplaced.

CHAPTER 5

TECHNOLOGY DIFFUSION AND NATIONAL EFFICIENCY IN DEVELOPING COUNTRIES: THE ROLE OF INTERNATIONAL TRADE

5.1 INTRODUCTION

Recent studies by Coe and Helpman (henceforth CH, 1995), Coe, Helpman and Hoffmaister (henceforth CHH, 1997), Keller (2002) and Eaton and Kortum (1999) have demonstrated the importance of foreign R&D and international trade to domestic productivity growth of both advanced and developing economies. According to Keller (2004), foreign sources of technology account for 90% or more of domestic productivity growth. The central message of these studies is that international diffusion of technology is a major determinant of per capita income in the world. It is important because it determines the pace at which the world's technology frontier may expand in the future (see Keller, 2004).

In light of the above findings, technology diffusion and therefore international trade takes on even greater importance for increasing productivity growth in developing countries, which as a group undertake little domestic R&D and therefore have few domestic sources of new technology. According to CHH (1997), 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. In 1990, this amounted to 22 billion US dollars. Clearly, the spillovers to developing countries through international trade are substantial and therefore represent a medium through which this group of countries can catch up with the more advanced countries.

Yet, by focussing primarily on technology transfer, it is likely that this literature provides only a partial explanation of cross-country productivity differences. This is because the literature implicitly assumes that once the foreign technology is acquired through trade (imports) then the stock of foreign technology will be used efficiently by countries. However, countries are also likely to differ in the efficiency with which they use technologies (Fagerberg, 1994). 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) [author's emphasis]. The notion of absorptive capacity refers to a country's effort and ability to adopt new technologies even if knowledge is global. With regard to the efficiency of technology absorption, Fagerberg (1994); Griffith et al. (2000); and Kneller and Stevens (2003) have found variables such as human capital, R&D, social institutional measures and international trade to be important.

The implication of the above is clear. 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. For developing countries this is even more of an imperative.

In this chapter we use the methodology of stochastic frontier analysis (SFA) to consider the effects of both technology transfer and absorptive capacity on the output levels of 57 developing countries over the period 1970-1998. Using SFA allows us to explore jointly the determinants of the developing countries' production frontier and their 'efficiency' in using their available resources and technology. Moreover, it allows us to consider the role of international trade in both respects. This is a novel aspect of this chapter. Previous studies that have investigated the role of trade in explaining cross-country efficiency differences, either using SFA (e.g. Mastromarco, 2002; Kneller and Stevens, 2003) or the related non-stochastic methodology of data envelopment analysis (DEA) [Milner and Weyman-Jones, 2003], have only focused on its role as a determinant of relative technical efficiency or distance from the frontier. Consequently, the role of trade as a conduit for technology transfer or specifically in our case, for international R&D spillovers, have not been investigated within the SFA framework. This chapter seeks to fill this void. We do so by including, along with the traditional inputs of production (capital and labour), foreign machinery R&D stock as a determinant of the level of frontier technology.[1] To capture the technology transfer effect, we weight this variable by machinery imports from developed countries. In keeping with previous studies in this literature we also consider the absorptive capacity role of trade, namely whether trade narrows the gap between frontier countries and those that are behind it.

To preview our results, we find evidence that physical capital, labour and foreign R&D all contribute positively to output in developing countries, but that the effect of human capital is more complex. While it is positive in many countries, its contribution is negative in the Sub-Saharan African group of countries. This result appears to support the argument of Pritchett (2001) that human capital has a positive

[1] As indicated by Griffith et al. (2000) the substantive assumption is separability between R&D and the other factors of production.

direct effect on production when the social institutional structure is such that additional education does not lead to rent seeking. Additionally, we find significant and positive contributions to efficiency from both the policy and outcome measures of international trade. A country's location (i.e. whether it is tropical or not) as well as its share of agriculture in GDP are also shown to significantly affect efficiency.

Finally, even when we control for the possibility that not all technologies will have yet diffused to all developing countries, large differences in efficiency are still apparent. The time variation in these efficiency scores suggests convergence i.e. differences in average efficiency levels have narrowed across time. This coincides with a period of improvements in the trade openness and general macroeconomic policy environments. Thus by the end of the period, differences in efficiency appear less important than differences in factor inputs and technology transfer, although low efficiency is still evident in some countries.

The rest of the chapter is organised as follows, Section 5.2 briefly surveys the theoretical and empirical literatures that highlight international trade as one of the main channels of technology diffusion/transfer. Section 5.3 outlines the methodology upon which this study is based; specifies the estimating equations; and discusses the data used in the empirical analysis. The results from this empirical exercise are presented in Section 5.4. Section 5.5 concludes the chapter.

5.2 TRADE AS A CHANNEL OF TECHNOLOGY DIFFUSION: A BRIEF SURVEY OF THE LITERATURE

The recent 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. Thus with respect to the second channel, if expenditures on research and development (R&D) create new intermediate goods that are different (the horizontally differentiated inputs model) or better (the quality ladder model), and if these goods are exported to other economies, then the importing country's productivity will increase through the R&D efforts of its trade partner (see Keller, 2000). International knowledge flows raise growth in both channels.[2] This chapter however is primarily concerned with the second channel.[3]

In the Grossman and Helpman (1991) [Chapter 9] model, see also Rivera-Batiz and Romer (1991), international trade in goods has three effects upon the economy's rate of innovation and long-run growth. First, there is a 'redundancy effect'. International trade eliminates the incentives for entrepreneurs in one economy to duplicate the

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[2] Though the focus in this chapter is on trade as a conduit for technological spillovers, there are also growth effects from trade that are not related to international technology diffusion (see Keller, 2004).

research undertaken in a second economy. Second, there is an 'integration effect' in the market for intermediate inputs. With international trade each entrepreneur enjoys a larger market for their variety of intermediate inputs. Third, there is a 'competition effect': international trade increases the range of varieties of intermediate inputs produced thus resulting in an increase in the intensity of competition facing the producer of each variety. The first two effects have an unambiguously positive effect upon the economy's rate of innovation and growth. The competition effect on the other hand, reduces the equilibrium flow of profits received by a successful researcher and therefore tends to decrease innovation and growth. The net effect of international trade in goods (and flows of ideas) upon economic growth is a combination of the integration and the redundancy effects. Additionally, there is a static gain from trade: increases in the number of varieties of intermediate inputs raises productivity in final goods production and affects the level of per capita income in each economy (Redding, 1998).

The study by CH (1995) is the first empirical study based on the theory of endogenous technological change to provide evidence of the importance of trade as a channel of international technology diffusion.[4] In this literature the level of imported R&D is calculated as the R&D stock of foreign countries weighted by some appropriate variable. Differences across studies are concentrated largely on differences in the choice of weights. For example, CH (1995) estimate a spillovers regression of the following form:

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[3] Grossman and Helpman (1991) also identified the international movements of capital as another channel through which economic behaviour in one economy may influence that in another (see Redding, 1998).

[4] We focus only on those studies that propose international trade (specifically imports) as the principal channel for the diffusion of technological knowledge. Other channels identified in the literature are: foreign direct investment, Foreign Technology Payments and disembodied R&D spillovers (e.g.

$$\log TFP_{it} = \alpha_i + \alpha_t + \beta_r \log R_{it} + \beta_s \log S_{it} + \varepsilon_{it} \qquad \textbf{(5.1)}$$

where *TFP* is total factor productivity; *R* measures domestic R&D stock; *S* foreign R&D stock; α_i and α_t are country and time varying intercepts; ε is an error term; *i* indexes countries and *t* indexes time. CH (1995) measure foreign R&D spillovers (S) on the domestic economy as the bilateral-imports-share weighted sum of R&D capital stocks of trade partners. That is:

$$S_i = \sum_{h \neq i} \frac{M_{ih}}{M_i} S_h \qquad \textbf{(5.2)}$$

where M_{ih} is the flow of imports of goods and services of country *i* from country *h;* and $M_i = \sum_{h \neq i} M_{ih}$. Thus CH's (1995) bilateral weight captures the relative importance of R&D in country *h* for productivity in country *i*.

Based on a sample of 22 industrialised countries (21 OECD countries plus Israel), the authors evaluated the effects of trade embodied R&D spillovers among this group of countries over the period 1971-90. Using bilateral import shares as weights in their computation of the foreign R&D capital stock, Coe and Helpman present results which suggest that countries will benefit more (in terms of higher productivity levels) if they import more from high (instead of low) knowledge countries, other things being equal. Further, a country's productivity is shown to be higher, the higher its overall import share. Thus for Coe and Helpman, the extent to which technology

scientific literature, international patenting, international conferences etc.) [see Keller, 2004; Cincera and Van Pottelsberghe de la Potterie, 2001].

can be internationally diffused depends on the composition of a country's imports as well as its overall level of imports.

Doubts over the conclusions reached by CH (1995) were raised however, by Keller (1998) and Lichtenberg and van Pottelsberghe de la Potterie (henceforth LP, 1998). Keller (1998) repeated CH's (1995) regressions using counterfactual (or made up) 'import' shares and obtained similarly high coefficients and levels of explained variation. This led him to conclude that the import composition of a country does not have a strong influence on the regression results. Subsequent work by Keller (1997b, 2000) based on industry level data for industrialised countries have however given partial support to the import composition effect by CH (1995). The composition of a country's imports is important only when it receives a disproportionately high share of its imports from one country.

Extensions of this approach can be found in Xu and Wang (1999), CHH (1997) and in Mayer (2001). The first study finds (for OECD countries) that the foreign R&D variable, when weighted by capital goods imports, explains more of the variation in productivity across countries compared to total manufacturing imports. Similarly, CHH (1997) find stronger and more robust evidence for spillovers from the North (industrialised countries) to the South (77 LDCs) when using machinery and equipment import data (SITC class 7) instead of either all-manufacturing or total import data as their weighting variable. They also argue that the use of capital goods imports is "more consistent with the theory and does a better job empirically"(p.140). Finally, Mayer (2001) finds that the coefficient on the machinery imports variable is twice as large as the coefficient on the machinery and equipment imports variable for a corresponding regression.[5] Mayer argues that the entire class of SITC 7 imports includes many consumption and equipment goods which are unlikely to lead to much technology diffusion.

Previous research has also concentrated on the choice of denominator in equation (5.2). In questioning CH's weighting methodology, LP (1998) demonstrated that the import-share weighting scheme of CH (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 CH's measure and also to empirically outperform it.

Following this literature, we measure the stock of frontier technology as the stock of machinery R&D in 15 OECD countries and weight this variable by the ratio of developing countries' machinery imports in the OECD countries' GDP.[6] That is, we follow best practice from the existing literature. The stock of foreign machinery R&D is therefore given by :

$$RD_i^m = \sum_{j \neq i} \frac{MM_{ij}}{Y_j} RD_j^m \qquad \textbf{(5.3)}$$

[5] The theoretical basis of Mayer's (2001) study is an augmented model of Nelson and Phelps (1966) which really addresses the issue of absorptive capacity. Specifically, the role of human capital in helping countries that are technological laggards to successfully close the gap with countries at the technological frontier. However, as Mayer also considers the direct impact of capital goods on productivity we review his study under technology diffusion studies.

[6] 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.

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.

In closing this section, it should be noted that the empirical studies reviewed, with the exception of Mayer (2001), employ a two-step approach as that adopted in Chapter 2 to capture the effects of foreign and domestic R&D on TFP. This is the approach generally adopted in the technology transfer literature. Productivity estimates are generated as residuals from a production function (where the parameters are either estimated or imposed) in the first stage. Then in the second stage these are regressed on domestic and/or foreign R&D stocks and measures of international trade. The implicit assumption is that countries are efficient in the use of all technologies imported (see Grosskopf, 1993). As indicated above, frontier analysis allows one to focus simultaneously on the factors that determine the frontier and those that explain deviations from it. We now turn to a discussion of the empirical methodology used in this study.

5.3 EMPIRICAL METHODOLOGY, ESTIMATING EQUATIONS AND DATA[7]

As indicated above, the methodology that we employ to undertake our empirical inquiry is stochastic frontier analysis (SFA). A frontier function is basically a bounding function, of which there are several in microeconomic theory (e.g. production, cost and profit functions). For example, the production frontier refers to the maximum technically feasible output attainable from a given set of inputs. In a cross-country context, countries (the producers of output for given inputs) either operate on or within this frontier. The first outcome represents a technically efficient outcome while the latter admits to some level of technical inefficiency.

Technical efficiency therefore refers to the ability to avoid waste or slack by producing as much output as input usage allows. In micro or firm level applications of efficiency measurement it is appropriate to view X-inefficiency as the product of market and policy conditions that allow slack in input usage. At the aggregate or national level it is rather more appropriate to view any measured technical inefficiency as a composite of unconstrained slack in the usage of national factors (facilitated by policy conditions that do not foster competitive pressures), and constrained under-utilisation of capacity or output loss imposed by 'natural' factors (floods, drought, disease etc.).

In addition to efficiency improvements as a means of achieving productivity increases, another source of productivity growth is through technical progress which leads to an outward shift of the frontier. In this chapter however, our focus is not on

[7] The empirical methodology and the results presented in the GEP Working Paper "Trade, Technology Transfer and National Efficiency in Developing countries" are based largely on this section of the chapter (see Henry, Kneller and Milner, 2003).

decomposing output growth into its constituent sources (see Koop et al., 1999, 2000; Kumar and Russell, 2002) but on examining factors that help determine the production frontier as well as explain deviations from it.[8] Unlike data envelopment analysis (DEA) which employs a deterministic mathematical programming technique for estimating the frontier, SFA as the name suggests estimates the frontier using econometrics.

5.3.1 Technical Frontier

This section outlines the stochastic frontier methodology on which this study is based. Since its development independently by Aigner, Lovell and Schmidt (1977), and Meeusen and van den Broeck (1977), a large empirical literature utilising SFA has developed. This literature straddles a diverse range of economic inquiry and incorporates both cross-section and panel data. Forsund, Lovell and Schmidt (1980); Bauer (1990); Greene (1993) and Coelli (1995) provide comprehensive reviews of this literature.

In this study we assume that output, Y, is a function of the production technology set out in (5.4):

$$Y_{it} = f\left(K_{it}, L_{it}, H_{it}, RD_{it}^{m}\right)\eta_{it}\varepsilon_{it}, \quad i=1,2, \ldots N; t=1,2,\ldots T \qquad \textbf{(5.4)}$$

where Y is output (GDP); $f(.)$ is a suitable functional form; K is the stock of physical capital; H is a measure of the stock of human capital; L is the labour supply; RD^m is the stock of foreign technical knowledge; η $(0 < \eta \leq 1)$ measures technical

[8] In addition to the two sources of productivity growth – technical change and efficiency improvements- factor accumulation (movement along the frontier by changing inputs) represents another source of output growth.

efficiency and is unique to the SFA approach; ε reflects the random character of the frontier, due to measurement error or other effects not captured by the model. Finally, i indexes country and t indexes time.

In light of the questions raised over the suitability of the Cobb-Douglas functional form (Duffy and Papageorgiou, 2000; Kneller and Stevens, 2002), we adopt a translog production function to characterise the production frontier facing developing countries.[9] Equation (5.4) can be expressed in log-linear form to give:

$$\ln Y_{it} = \beta_0 + \sum_{r=1}^{4} \beta_r \ln X_{rit} + \tfrac{1}{2} \sum_{r=1}^{4} \sum_{s=1}^{4} \beta_{rs} \ln X_{rit} \ln X_{sit} + \sum_{j=1}^{3} d_j D_{ji} + \sum_{j=1}^{56} \gamma_j D_j t + v_{it} - \upsilon_{it}$$

$$D_{ji} = 1 \text{ if } i \in j,\ D_{ji} = 0 \text{ if } i \notin j\ ;\ D_j = 1 \text{ if } j = i \qquad \textbf{(5.5)}$$

where Y remains as defined in Equation (5.4), X is a vector of the factor inputs also defined in (5.4) i.e. X_r (X_s) equals physical capital, labour, human capital and the stock of machinery R&D respectively. $v_{it} = \ln \varepsilon_{it}$, and $\upsilon_{it} = -\ln \eta_{it}$. Equation (5.5) also contains region specific dummy variables (D_{ji}) for Latin America and the Caribbean (LAC), Sub-Saharan Africa (SSA) and Asia (ASIA). These capture differences in the initial level of technology for these regions and are preferred to country specific fixed effects (Temple, 1999). Country specific time trends ($D_j t$) are included to measure elements of domestic technical progress not captured by imported foreign R&D.

[9] As is well known, the translog production function is a flexible functional form and provides a local approximation to any production frontier. Before adopting the translog specification however, we estimated a Cobb-Douglas production function and tested against the alternative of the translog. Based on a log-likelihood ratio test we were able to reject the former in favour of the latter.

This representation of the frontier can be viewed as the intermediate case between on the one hand a commonly available or universal frontier technology approach (with no regional or country specific effects), and on the other a view of extreme heterogeneity in technologies (with individual country and time specific fixed effects). The latter may allow for greater scope for efficiency in estimating econometrically the relationship between actual inputs and actual output. If it was the actual production function of each country we were seeking to represent it would be unambiguous that this was preferable. However our current purpose is to represent the technological frontier (potential output to actual inputs relationship) available to each country. The comprehensive capturing of specific effects runs the risk of 'mopping-up' the very differences in efficiency between countries that we are seeking to explain. By contrast an assumption of total homogeneity, with a common technology available to all countries, does not appear to accord with reality. Our intermediate case seeks to avoid the potential biases of these two more extreme representations.

Having said that however, both extreme alternatives of allowing for no fixed effects (complete homogeneity) and for both individual country and time specific effects simultaneously (complete heterogeneity), were in fact explored. The first approach resulted in unusually low average efficiency scores for the countries while the second, not surprisingly, had the opposite effect. The intermediate case remained our preferred representation of the frontier.

Given our focus on the production side, and in the absence of information on relative factor prices, we are unable to comment on allocative efficiency issues. The computation of technical efficiency is therefore conditional upon the actual inputs chosen, which may or may not be the allocatively efficient factor mix. It is possible therefore that some countries may be identified as technically efficient (i.e. define the frontier) but may not have defined the frontier with the allocatively efficient mix. Recall also that we are measuring efficiency in relative terms. The adequacy of the measure is therefore fashioned by the appropriateness of the coverage of countries, at any range of factor mixes. This may be particularly relevant for 'outlier' or extreme factor mixes or for countries for whom a more appropriate technological comparator may have been the developed rather than developing countries.

Further, because our entire sample comprises only developing countries, then it should be noted that the technical frontier that we measure is not the global frontier. The latter is likely to be defined by the industrialised countries in general, which in 1990 accounted for 96% of total world R&D expenditures, and by the G-7 OECD countries (U.S.A., Japan, U.K., France, Germany, Italy and Canada) in particular. The latter group accounting for about 84% of total OECD R&D expenditure in 1995 (See CHH, 1997; Keller, 2004).

In terms of the inputs into the production function, as stated in Chapter 2, there is some debate in the literature over the role of human capital in economic growth. While Mankiw, Romer and Weil (henceforth MRW, 1992) advocate the inclusion of human capital as a separate term in the production function, Benhabib and Spiegel (1994), Islam (1995) and Pritchett (2001) argue instead that human capital influences growth indirectly through its effect on TFP. Given that we addressed this issue in Chapters 2 and 3, in this chapter we choose to follow Griliches (1969) and MRW (1992) and allow for possible complementarity between human and physical capital by including the former as a separate input in the production function.[10] Consequently, the technical efficiency scores produced from our estimation are net of the influences of human capital (see Coelli et al., 1999).

Apart from the usual set of factor inputs in Equation 5.4, 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.[11] 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.

5.3.2 Inefficiency Effects

Equation (5.4) recognises that countries may differ in their level of productivity through the term η. If a country is 100% efficient (η = 1), it can utilise all frontier knowledge, otherwise impediments to absorption or internal inducements to slack will cause the country to produce below the frontier. Following Battese and Coelli (1995), the inefficiency effects are obtained as truncations at zero of the normal distribution $N(\mu_{it}, \sigma_{\upsilon}^2)$. Where $\upsilon = -\eta$. Inefficiency is thus specified as:

$$\mu_{it} = z_{it}\delta \qquad \textbf{(5.6)}$$

[10] Of course there may be *a priori* grounds for believing that human capital might simultaneously influence both production and efficiency levels. There are, however, estimation problems of doing so in a one stage approach.

[11] 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. In contrast, Koop (2001) and Koop *et al.* (1999, 2000) use an alternative assumption that technology growth depends on a (quadratic) time trend.

where μ_{it} are technical inefficiency effects in the SFA framework and are assumed to be independently, but not identically distributed; z_{it} is a vector of variables which may influence the technical efficiency of a country, and δ is a vector of parameters to be estimated.

In determining the set of variables to include in the technical efficiency vector we draw on the previous literature. It is argued that a key determinant of a country's success in adopting foreign technology is the extent to which it invests in 'imitative' or 'adaptive' research activities (see Geroski, 1995). Griffith et al. (2000) using human capital and R&D to capture these effects, find strong empirical support for this argument in the context of OECD countries. As explained earlier, we include human capital in the production function only and base the efficiency scores reported here on this specification of the simultaneously estimated production function and determinants of efficiency. We do, however, include a variable that may capture human capital influences indirectly; namely the agricultural intensity of the country.[12]

Developing countries have relatively little indigenous R&D capacity, but we seek to capture their absorptive capacity for foreign R&D through their importation of capital goods. Machinery imports embody knowledge of foreign technology and production know-how; the greater these imports, the greater the scope for direct absorption of foreign innovations by the importing firms and for spillover of this knowledge to other firms. With greater absorption of foreign technology through

[12] The estimating programme does allow for a variable to be included in both the frontier and inefficiency determinants. We explored the inclusion of human capital in this way, and it did have the expected negative sign with significance. The variable is however collinear with our agricultural

capital imports the nearer a country can be to the production frontier and the lower the measured inefficiency.

Imports of capital goods is not the only way in which international trade may affect national efficiency. Other measures of international trade have been used in this literature. Generally, the variables employed come in two main forms : indicators of trade policy openness and measures of trade volume. For instance, Kneller and Stevens (2003) using SFA for a cross-country study of developing countries include the Sachs-Warner (1995) measure of policy-openness to international trade amongst the determinants of efficiency. They find that policy-open countries were more efficient than those that were closed to international trade. Mastromarco (2002) on the other hand, also using SFA, considers the effect of the volume of trade (specifically capital good imports) on efficiency. Again evidence is found to suggest that more open countries have greater efficiency.

We also attempt to determine the importance of trade policy openness in explaining deviations from the frontier. To do so, we use the Sachs and Warner (1995) indicator of openness to international trade, as updated by Wacziarg and Welch (2002). The latter two researchers make use of additional data sources to correct some of the perceived misclassifications of countries in the original study and extend the data period up to 1998. It is this augmented Sachs and Warner indicator that we use to capture the pro-competition and reduced input cost effects of policy openness on efficiency. On the import side, trade liberalisation may reduce inefficiency in a number of ways. The reduction or elimination of non-tariff barriers (NTBs) may

intensity variable and may induce problems associated with multicollinearity of the variables when included as both an explanator of the frontier and efficiency.

reduce the opportunity for rent-seeking activity and the diversion of resources away from productive activities. The shift away from NTBs to the use of tariffs only also allows for increases in competition at the margin for domestic producers vis-à-vis imported goods. This increase in competition in the domestic market, combined with greater access and cheaper imported inputs, provides a stimulus and opportunity to increase efficiency. Further the lowering of the relative price of importables post-liberalisation provides an incentive for more domestic resources to be drawn into exportables production, with a resulting greater proportion of a country's production being subject to competition at world prices. The expectation therefore is that increased trade policy openness will reduce aggregate inefficiency.[13]

We next include a dummy variable (TROP) that takes the value of 1 if the developing country has a tropical climate and 0 if it does not. This variable is intended to capture the effects of climate on public health, and by extension the quality of human resources. Increasing empirical evidence has been adduced which shows physical geographical and climatic factors, along with correlates like disease burden and life expectancy at birth, help explain variations in per capita income levels across countries (see Diamond, 1997; Gallup et al., 1998; Hall and Jones, 1999; Sachs, 2001). For example, for a cross-section of countries Hall and Jones found per capita income to be positively correlated with the absolute value of latitude. Additionally, Gallup et al. (1998) in stressing the lower levels of per capita GNP in the tropics, argue that human health and agricultural productivity are

[13] Following Rodriguez and Rodrik (2000) we recognise that the Sach and Warner openness variable may capture other elements of policy liberalisation in addition to trade policy. This is of some advantage in the current context, given that capital goods imports might well not be exogenous to trade policy openness. Dealing with endogeneity of explanatory variables within an SFA estimating framework is problematic. The broader policy liberalisation nature of our openness variable may help to reduce the endogeneity problem. By retaining both trade variables we are able to try to distinguish between the foreign technology absorption effect and the domestic efficiency effect.

adversely impacted upon by tropical climate. In a later paper, Sachs (2000) argued that tropical climates are burdened by many infectious diseases (e.g. malaria) which have much lower incidence and prevalence in temperate ecozones and are much easier to control in these zones.

Finally, it is argued that developing countries may face special problems of agricultural management and are characterised by lower average food output per unit input. There is likely to be greater dependence on subsistence or relatively backward agriculture as agricultural intensity increases. This is likely to involve agriculture activity which is less likely to use fertilisers and new seed varieties. Of course this does not necessarily mean that individual, small farmers are 'inefficient', given the technology and resources available (see Schultz, 1964). Poverty restricts access to alternative technologies and mechanisation etc. Nonetheless, aggregate output for given national resources may be increased through the wider domestic diffusion of existing know-how and by greater commercialisation of agricultural activity. By increasing efficiency and productivity in agriculture the scope for an agricultural surplus and for releasing resources from agriculture to higher productivity activities increases. To test these arguments, as well as account for the fact that for many of the countries in our sample (particularly those from SSA) the agricultural sector has the highest share in GDP, we include this sector's share in GDP as our final determinant of efficiency.[14] Higher agricultural intensity is expected, *ceteris paribus*, to increase 'distance' from the production frontier.[15]

[14] If this variable and the variable TROP are found to be statistically significant, we can reasonably argue that the tropical dummy is not solely picking up factors related to agricultural productivity but is also capturing effects related to the health of the population. As noted in the later discussion of the results, we also explored the use of an alternative input-based measure of agricultural intensity.

[15] Of course this measured 'distance' may be some mixture of aggregate under-utilisation of productive potential and of measurement error. Measurement errors in both inputs and output are no

We thus specify the mean level of inefficiency as:

$$\mu_{it} = \delta_0 + \delta_1 AY_{it} + \delta_2 SW_{it} + \delta_3 KM_{it} + \delta_4 TROP_j \qquad \textbf{(5.7)}$$

where AY refers to the share of agriculture in GDP; SW the Sachs-Warner openness index ; KM is machinery imports ; and TROP the tropical index discussed above.

In summary, since capital imports promote the absorption of technology and openness increases competition, we would expect to find negative coefficients on δ_2 and δ_3, respectively; that is they reduce the distance from the frontier. In contrast, if a higher share of agriculture in GDP as well as having a tropical climate increase inefficiency (or the distance from the frontier) then δ_1 and δ_4 would be positive.

5.3.3 Data

Data on GDP, the share of agriculture in 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. These data are 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 to Chapter 5 provides greater detail of the construction of variables used in the empirical exercise, as well as full data

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doubt an issue in the present analysis. It is, however, potentially more important where agricultural and in particular subsistence activity is relatively important, since non-marketed output increases in importance.

sources. Human capital is measured by mean years of schooling in the population aged 25 and over and are taken from Barro and Lee (2000).[16]

R&D investment data on machinery for the 15 OECD countries were taken from the OECD's ANBERD Database. These data cover 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.

The Sachs-Warner and the tropical indexes were obtained from Wacziarg & Welch (2002) and the World Bank, respectively. Summary statistics for the variables used for our empirical exercise are shown in Table A5.1 of Appendix A to Chapter 5.

5.4 RESULTS

5.4.1 Frontier

The parameters of the models defined by (5.5) and (5.7) were estimated simultaneously using FRONTIER Version 4.1 (Coelli, 1996) for 57 developing countries over the period 1970-1998. The log-likelihood function for this model is presented in Battese and Coelli (1993) as are the first partial derivatives of this function with respect to the different parameters of the model.[17] The results from this estimation are shown in Table 5.1.

[16] The data in Barro and Lee (2000) are in five-year averages, which we annualised by linear interpolation.

[17] This parameterisation originates in Battese and Corra (1977).

Table 5.1 : Maximum-Likelihood Estimates for Stochastic Translog Production Function with Inefficiency Component[a]

	Coeff.	*std. error*	*t-stat.*
	Production Function		
Constant	19.61	1.50	13.11
k	-1.26	0.23	-5.57
l	0.83	0.18	4.52
h	-1.17	0.35	-3.39
rd^m	0.49	0.16	3.14
k^2	0.05	0.03	1.85
l^2	-0.15	0.02	-9.78
h^2	0.21	0.05	4.56
$(rd^m)^2$	0.06	0.01	6.75
k*l	0.08	0.02	4.18
k*h	0.09	0.03	3.34
k* rd^m	-0.05	0.01	-3.59
l* h	-0.02	0.02	-0.92
l*rd^m	-0.01	0.01	-0.76
h* rd^m	-0.05	0.02	-2.53
LAC	0.78	0.04	19.34
SSA	-0.09	0.04	-2.12
ASIA	0.78	0.05	16.37
	Inefficiency Effects		
Constant	1.31	0.20	6.58
SW	-0.60	0.07	-8.63
km.	-0.21	0.02	-12.33
TROP	0.57	0.07	8.40
AY	0.20	0.03	6.34
σ^2	0.13	0.01	9.68
γ	0.96	0.01	108.88
Log-likelihood	662.10		
Countries	57		
Years	29		
Observations	1414		

[a] The dependent variable is the log of GDP. All other variables except SW, TROP and the Regional Dummies are in logs. Country specific time trends are not reported. All variables are as defined in the text.

Rather than comment on each of the coefficients of the translog production function, we instead report and discuss the elasticities of output with respect to each of the inputs, E_r. These were calculated in the following manner:

$$E_r = \frac{\partial Y}{\partial X_r} = \beta_r + \sum_{s=1}^{4} \beta_{rs} X_{sit}, \quad r = k,\ l,\ h,\ rd^m \qquad \textbf{(5.8)}$$

The full set of parameters from the production function in Table 5.1 are used to determine the various output elasticities. Since E_r is a linear function of X_s (a vector of the logarithms of the s factor inputs), the elasticities evaluated at the mean of the data for the entire period are the same as the mean elasticities. Returns to scale (elasticity of scale) is calculated from the sum of the input elasticities as:

$$RTS = \sum_r E_r \qquad \textbf{(5.9)}$$

The input elasticities vary both over time and countries, we therefore present the input elasticities and returns to scale calculated for different groups of countries in Table 5.2. The first row of the table reports the elasticities evaluated at the mean of the data for the entire period and all countries; while rows 2-5 report them for various regional groups.[18] The results appear plausible and compare well with those from the previous literature. At the mean for the entire period the elasticity of output with respect to physical capital is 0.47, for labour 0.24 and for human capital 0.11. The estimated capital elasticity is within the range estimated for developing countries reported in Table 1 of Koop et al. (1999) using SFA, while the three input elasticities

[18] Since the elasticity of each input is a linear function of the other factor inputs, the elasticities evaluated at the mean are the same as the mean elasticities (Kumbhakar et al., 1997).

are close to that found by Miller and Upadhyay (2000) for a group of developed and developing countries based on a Cobb-Douglas production function. Finally, the combined elasticity of physical and human capital (0.58) is of a similar magnitude to that found in MRW (1992).

One interesting result in Table 5.2 relates to the estimated output elasticity of human capital. The estimated elasticity passes through zero; varying between –0.04 in Sub-Saharan Africa and 0.20 in Latin American and the Caribbean, and Asia respectively. This finding is consistent with Pritchett (2001). As argued by Pritchett, the effect of human capital on the economy depends in part upon the institutional and social environment. If the institutional and social structure is such that the returns to education are greater for 'rent-seeking' than 'entrepreneurial' activities, then increases in human capital induce wealth transfer rather than wealth creation and increases in GDP. The result for Sub-Saharan Africa is consistent with the presence of a relatively weak institutional environment (see Aron, 2000).

Table 5.2 : Mean Estimates of Input (K, L, H, R&D) and Elasticity of Scale (RTS)

	VARIABLES				
	K	**L**	**H**	**R&D**	**RTS**
All countries	0.47*** (0.022)	0.24*** (0.015)	0.11*** (0.035)	0.05*** (0.013)	0.87
Latin America & Caribbean	0.47*** (0.022)	0.31*** (0.017)	0.20*** (0.042)	0.03** (0.013)	1.01
Sub-Saharan Africa	0.39*** (0.024)	0.22*** (0.020)	-0.04 (0.036)	0.06*** (0.015)	0.63
Asia	0.61*** (0.032)	0.11*** (0.023)	0.20*** (0.047)	0.04** (0.018)	0.96
Others	0.40*** (0.019)	0.32*** (0.018)	0.05 (0.034)	0.08*** (0.017)	0.85

Notes: standard errors in parentheses . *** significant at 1%; * *significant at 5%.

As expected, foreign R&D contributes positively to the level of output in developing countries. The coefficient indicates that, ceteris paribus, a 1 per cent increase in the stock of foreign R&D will raise the level of output by 0.05 per cent. This elasticity is of a similar magnitude to that found by CHH (1997) for developing countries based on their preferred specification, and Xu and Wang (1999) for OECD countries based on the weighting scheme adopted in this study. The estimates for these two studies are based on TFP growth regressions and as indicated previously, employ a different methodology from the one employed in this chapter. Our finding thus indicates that technologies embodied in capital goods (machinery) imports are an important source of output growth in developing countries and by extension, trade is an important channel for transferring these technologies from R&D performing countries to these (developing) economies.

In terms of regional country groupings, OTHERS (comprising countries mainly from the Middle East and North Africa) is shown to receive the largest contribution to output (on average) from foreign R&D, followed by the SSA countries. Though these two groups have a higher foreign R&D elasticity than the ASIA group which comprises the South East Asian NICs that are known to have invested heavily in imitating and adapting technologies embodied in foreign capital goods, the latter group (ASIA) is not restricted to these economies. It also contains some of the poorer and less technologically advanced developing countries (certainly for the period under review) from South Asia such as Bangladesh, Sri Lanka and Pakistan among others. This will be clearly reflected in our profile below of the most efficient and inefficient countries at different points over the sample period.

Table 5.2 also shows that the elasticity of scale (RTS) for the group of developing countries as a whole is below 1, i.e. there are decreasing returns to scale. In the case of individual country groupings however, the Latin American and Caribbean grouping exhibit constant returns to scale. Of the country specific time trends (not reported in Table 5.1), the majority are negative and significant, suggesting technical regression over the period.[19] Duffy and Papageorgiou (2000) find similar negative trends for a sample of developed and developing countries over the period 1960-87. Given that the contribution of foreign R&D has tended to be positive over the period, this result seems somewhat surprising. To explain this, we turn to a similar result in Koop et al. (1999). They interpret this result as suggesting that large negative shocks to the economies close to the frontier will tend to move the frontier inwards over time, and in the SFA methodology this will be interpreted as inward shifts of the frontier (or technical regress) [see Koop et al., 1999]. Recall, the estimated production frontier does not measure the position of the global frontier, only the frontier for developing countries. It is likely that the global frontier moved outward over this period. Given the increase in efficiency identified below, this result is also consistent with the bunching of developing country GDP found by Quah (1997).

5.4.2 Efficiency Levels

Table 5.3 presents efficiency scores across all countries and for the respective regions at four points in time (1970, 1980, 1990 and 1998) as well as the average (and standard deviation) for the entire time period. More detailed information on the

[19] Only Cameroon, Mauritius, Rwanda, Singapore, Tunisia, Uganda and Uruguay have been found to have a positive and significant time trend coefficient. Hong Kong, Jordan and Senegal while also having a positive time trend, it is not significantly different from zero.

countries that make up the sample are presented in Table B5.3 of Appendix B to Chapter 5.

The table shows a marked increased in the average level of efficiency for the entire group of countries for the period 1970-98, with improvements being higher in the post-1980 period. The average efficiency level increased from 0.76 in 1970, to 0.78 in 1980 through to 0.92 in 1998. This pattern of convergence in efficiency scores is demonstrated clearly in Figure 5.1 (at the end of this chapter). For instance, in 1980 only 36% of the sample had an efficiency score between 0.90 and 1. This increased to 53% in 1990. By 1998 however, 84% of the sample of countries had an efficiency score between 0.90 and 1.[20]

Table 5. 3: Average Efficiency Scores (1970-1998)

	1970	1980	1990	1998	mean	s.d.
All countries	0.76	0.78	0.86	0.92	0.83	0.15
Latin America & Caribbean	0.73	0.82	0.90	0.93	0.85	0.13
Sub-Saharan Africa	0.78	0.63	0.75	0.91	0.74	0.19
Asia	0.78	0.83	0.92	0.96	0.88	0.12
Others	0.83	0.87	0.89	0.88	0.88	0.10

The findings for the entire group of countries mask some country and region specific trends, however. As a regional group, the largest average efficiency gain over the entire period has been in LAC countries. In 1970, the average efficiency level for the LAC group of countries was below the average for all countries (0.73 against 0.76). By 1998 the efficiency level for this group rose to 0.93. Of the countries that make

[20] Although the degree of convergence is fashioned by how technical progress is modelled, overall convergence is clearly identified for alternative specifications to that reported.

up this group (i.e. LAC) three distinct trends are evident. First, for some countries there were large increases in efficiency over the period; albeit from initially low levels. Honduras, Jamaica, Dominican Republic and Ecuador are included in this group. For a second group of countries, there was a large increase in efficiency between 1970 and 1980 and then small increases thereafter. Brazil, Chile and Paraguay are included in this group. In the final group of Latin American countries, efficiency levels were high on average and remained high. Peru, Uruguay, Venezuela and Mexico form this group (efficiency declined slightly in Mexico and Uruguay).

In contrast to LAC countries, much of the increase in efficiency levels in the Sub-Saharan African group occurred between 1990 and 1998. In fact, at the average, this latter group of countries has recorded the biggest improvement in efficiency levels between 1980 and 1998 compared to the other groups. However, this sharp increase is against the background of a decline in average efficiency level between 1970 and 1980 for the Sub-Saharan Africa group as a whole. Again there is large variation in performance within the group. For example, there were large increases in efficiency in Gambia; Zambia; Mozambique and Niger but falls in efficiency in Zimbabwe; the Democratic Republic of the Congo (formerly Zaire); and Rwanda. In the case of Rwanda, the decline has been catastrophic with the efficiency level falling from 0.93 in 1970 to 0.51 in 1998.

Additionally, the Sub-Saharan countries in which efficiency levels rose did not have high initial levels of efficiency.[21] Indeed as a group, even accounting for the general improvement in efficiency, the Sub-Saharan African countries are much less efficient

[21] One exception within Sub-Saharan Africa is Mauritius which started with a reasonably high level of efficiency in 1980 (the first decadal value available) and increased it over the period.

than the average developing country. For example Gambia, Malawi, Niger and Mozambique all have a mean efficiency score of less than 65 per cent; amongst the lowest of all developing countries in the sample. Finally, across all regions the countries that consistently recorded the highest efficiency scores are concentrated in Asia; the average efficiency score in Korea, Singapore, India, Hong Kong, Indonesia and China being over 90 per cent. As such, while there were notable increases in average efficiency for this group over the period, these changes are less marked than the other regions.[22]

The most efficient and inefficient countries in our sample are shown in Table 5.4 at four distinct time periods.[23] In 1970 and 1980 respectively, Latin American (e.g. Mexico, Uruguay, Peru) and Asian (e.g. Korea, Singapore, India) countries dominate the group of most efficient countries. Middle East and North African countries (Algeria, Tunisia and Jordan) are also represented, while the Democratic Republic of the Congo (formerly Zaire) is the only SSA country amongst the list of efficient economies.

In 1990 Asian countries overwhelmingly dominate the list of most efficient developing countries; Colombia and Chile are the only two Latin American countries listed. As was indicated earlier and is demonstrated in Figure 5.1, the post 1990 period witnessed a general rise in the average efficiency scores of developing countries. This convergence in efficiency levels is evidenced by the fact that in 1995 Iran, with an efficiency level of 0.98, is shown to be the most efficient country while

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[22] The exceptions to this are Bangladesh and Sri Lanka which had efficiency levels of less than 60 per cent in 1980 (51 and 58 respectively) but rose to 97 per cent in 1998.

[23] Due to the absence of data on the share of agriculture in GDP in 1998 for Korea, Malaysia and Singapore among others, we use 1995 instead of 1998 for the purpose of making individual country comparisons of efficiency scores.

Malaysia and Korea with a slightly lower efficiency score of 0.94 are ranked 27^{th}. Additionally, Latin American countries now make up the overwhelming majority of the ten most efficient countries; Singapore and Thailand are the only two countries from ASIA. Among the countries from the LAC grouping are some (such as Costa Rica, Brazil and Argentina) that never previously featured amongst the most efficient producers.

Of the countries listed as the most inefficient in Table 5.4, SSA countries (e.g. Niger, Mali, Malawi, Rwanda, Mozambique, Togo) dominate this group in all time periods bar one- 1970 - when countries from the LAC region (Honduras, Jamaica, Ecuador, Nicaragua, the Dominican Republic and Paraguay) made up the majority. Indeed since 1970, SSA countries account for at least seven of the ten countries listed as most inefficient in Table 5.4. This, despite the fact that by 1995 most countries within this regional grouping – Rwanda being the notable exception- had significantly increased their efficiency levels relative to the earlier periods.

5.4.3 Determinants of Technical Efficiency

Turning to the factors used to explain technical inefficiency in Table 5.1. First, all four variables have the expected sign and are statistically significant at a level below 1%. Thus these variables offer significant power in explaining variations in aggregate inefficiency across countries.

Note that the coefficients on the dummy variables can be directly interpreted as the impact on the inefficiency score of a change in country status, holding other things equal; being open reduces the inefficiency score by 0.60 and being a tropical country raises the inefficiency score by 0.57, ceteris paribus. These are substantial intercept effects. In the case of the other two variables we need to consider the estimated coefficient alongside information on the spread of the variable. A doubling of the agricultural share at the mean (9.84% of GDP) and of machinery imports (c. $330,000 per annum) would respectively increase or reduce the inefficiency score by about 0.14, *ceteris paribus*. But the actual spread of the two variables differs. A one standard deviation increase in the agricultural share increases the inefficiency score by 0.18, while a one standard deviation increase in machinery imports reduces the inefficiency score by 0.37.

Table 5.4: The Ten Most Efficient & Inefficient Countries 1970-95

1970				1980				1990				1995			
Efficient	Score	**Inefficient**	Score	**Efficient**	Score	**Inefficient**	Score	**Efficient**	Score	**Inefficient**	Score	**Efficient**	Score	**Inefficient**	Score
Korea	0.99	Honduras	0.34	Mexico	0.971	Niger	0.30	Hong Kong	0.97	Malawi	0.55	Iran	0.98	Rwanda	0.39
Mexico	0.982	Zambia	0.40	Jordan	0.97	Malawi	0.33	Korea	0.96	Niger	0.55	Singapore	0.97	Malawi	0.76
Algeria	0.981	Jamaica	0.45	Hong Kong	0.96	Gambia	0.34	Syria	0.96	Rwanda	0.60	Chile	0.97	Togo	0.78
Singapore	0.97	Ecuador	0.47	Tunisia	0.95	Mali	0.47	Malaysia	0.96	Mozambique	0.60	Egypt	0.97	Algeria	0.80
Uruguay	0.962	Nicaragua	0.48	Korea	0.95	Bangladesh	0.51	Singapore	0.95	Gambia	0.67	Ecuador	0.96	Mozambique	0.71
Dem. Rep. of Congo	0.961	Sri Lanka	0.49	Singapore	0.95	Zambia	0.52	Colombia	0.95	Togo	0.68	Thailand	0.96	Cameroon	0.80
Venezuela	0.96	Papua New Guinea	0.56	Uruguay	0.94	Togo	0.53	India	0.95	Papua New Guinea	0.70	Costa Rica	0.96	Niger	0.82
India	0.941	Dom. Repub.	0.59	Peru	0.94	Honduras	0.54	Chile	0.95	Benin	0.71	Brazil	0.96	Dem. Rep. of Congo	0.83
Peru	0.94	Thailand	0.59	Dem. Rep. of Congo	0.94	Mozambique	0.56	Thailand	0.95	Congo Rep.	0.71	Argentina	0.96	Zimbabwe	0.84
Tunisia	0.87	Paraguay	0.65	Colombia	0.93	Jamaica	0.57	Philippines	0.95	Mali	0.72	Venezuela	0.962	Congo Rep.	0.86

The results point to a strong influence of international trade on the absorption and efficiency with which foreign technology is utilised. Specifically, a greater orientation towards trade and policy openness as well as increases in actual levels of machinery imports are shown (as expected) to increase national efficiency scores. This result is consistent with those of Griffith et al. (2000), Kneller (2002) and Kneller and Stevens (2002) for OECD countries and Mastromarco (2002) for developing countries.

In terms of the impact of climate and associated factors on inefficiency, our estimation shows that tropical countries are more technically inefficient relative to non-tropical countries. This finding thus lends support to those researchers that argue that aspects of geography and their correlates negatively affect output growth in particular groups of countries. It also mirrors earlier findings by Bloom et al. (2002) and Hall and Jones (1999) of the importance of geography in determining the level of productivity. More interesting in our case is the significance of this variable despite controlling for the share of agriculture in GDP. This result indicates that the TROP variable is not solely capturing the effects on agricultural productivity.

In order to check on the robustness of this finding we experimented with the use of an input-based measure (share of the agricultural labour force in the total labour force). Similar positive and significant coefficients were obtained on both the tropical and agricultural intensity variables. Finally, the positive correlation between the share of agriculture in GDP and the inefficiency variable indicates that increases in the former is associated with higher levels of technical inefficiency. This finding is possibly an indication that the agricultural sector in many developing countries is characterised by both constrained and unconstrained slack in the use of the available technology.

5.5 CONCLUSIONS

We use stochastic frontier analysis, to examine the role played by international trade both in determining the position of the technical frontier (through technology transfer), and in explaining deviations from the frontier. The latter role of international trade is also equally important in light of the fact that countries differ in the efficiency with which they use the available technology. This analysis is undertaken for a sample of 57 developing countries over the period 1970-98.

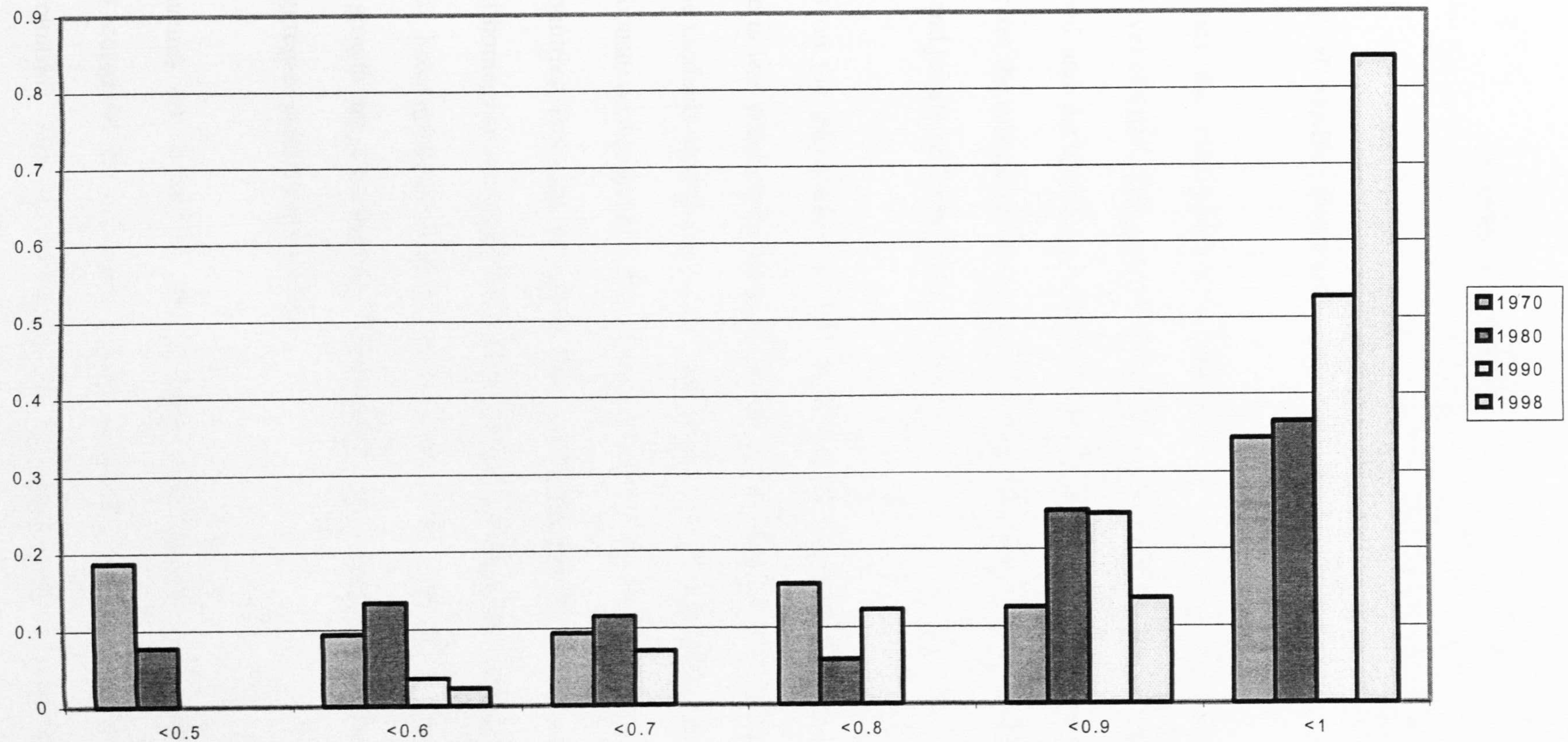
Trade is shown to contribute positively to both technology transfer, technology absorption and efficiency. There is also evidence that differences in efficiency levels between the developing countries in our sample have narrowed considerably over time; the narrowing of the efficiency gap coinciding with improvements in the policy environment and trade liberalisation.

In terms of the other traditional inputs determining the technical frontier, human capital is shown not to impact output positively for all countries (notably the SSA countries). Consequently, this possibility should be recognised rather than omitting it from the production function. This finding with respect to human capital suggests support for the interpretation of Pritchett (2001) regarding the role played by this factor in the economic development of developing countries.

With respect to factors other than trade that explains distance from the frontier, geography (specifically climate) as well as the proportion of domestic output contributed by the agricultural sector have been found to be significant explanatory factors.

Finally, our findings clearly demonstrate that studies which consider only technology transfer or efficiency in explaining productivity differences, are likely to be mis-specified.

Figure 5.1: Percentage of Countries Within Each Efficiency Decile, 1970-1998



CHAPTER 6

CONCLUSIONS

6.1 SUMMARY OF MAIN FINDINGS

This thesis examines the role played by international trade in cross-country differences in the level of GDP, TFP growth and efficiency levels for a broad cross-section of developed and developing countries. In addition to trade openness, the thesis also investigates the role played by geography, institutional quality and foreign R&D, both singly and jointly with trade openness.

Despite consensus on the importance of TFP to sustained economic growth and development, there is less consensus among academic researchers on its theoretical conceptions and the methods used to measure it at both the micro and economy-wide levels. Chapter 2 focuses on economy-wide measures of TFP in the context of a large cross-section of countries. Drawing on some of the competing arguments regarding the performance of homogeneous estimators vis-à-vis heterogeneous type estimators in the presence of heterogeneous cross-sectional units, three alternative sets of estimates of TFP growth are generated for 93 countries following the econometric estimation of an aggregate production function.

Two of the measures are based on the 'extreme' assumptions of complete heterogeneity and complete homogeneity of the parameters of the production function across countries. The latter measure, i.e. the completely homogeneous measure, also controls for the possible endogeneity of the factor inputs. The third measure is an intermediate (augmented mean group) measure that combines elements of both the heterogeneity and homogeneity assumptions. The estimates of TFP growth derived using these measures are then compared among themselves as well as with estimates derived by other researchers. The main findings of the chapter are: first, the three stochastic measures of TFP are highly correlated among themselves and with other stochastic and non-stochastic measures that rely on different assumptions and imply different calculations. For example, the completely heterogeneous measure which admits the assumption of constant returns to scale is highly correlated with the GMM panel measure that assumes variable returns to scale and parameter homogeneity across countries. This general finding is consistent with Van Biesebroeck (2003) for Colombian plant level data and Fischer (1993) for cross-country macroeconomic data.

Second, on cardinal grounds, estimates of TFP growth for randomly selected countries derived using our preferred intermediate measure are reasonably close to estimates generated for these countries by other researchers. For example, based on the augmented mean group measure the average annual rate of TFP growth for Korea for the period 1960-1990 is estimated to be 2.7%. This compares to 2.4% for the same period in Nehru and Dhareshwar (1994), based on a non-residual measure derived from a fixed effects estimation of an aggregate production function. Similarly in ordinal terms the rank ordering of countries is very close. On the latter point, the rank ordering between the intermediate measure and the completely homogeneous measure that controls for endogeneity is also quite close. The magnitude of the estimates derived using this latter measure however are greater than those from the intermediate measure. On cardinal grounds at least, there are differences between the two sets of estimates. Thus, as expected, correcting for endogeneity results in a bigger share of observed output growth being assigned to TFP.

Third, while parameter heterogeneity is clearly an important issue in cross-country empirical work as shown in the recent study of Durlauf et. al (2001), running individual country regressions as a means of capturing this heterogeneity as suggested by time series econometricians may be a bit premature in the cross-country context. This may be due to the quality of the data, particularly for developing countries whose data collection procedures are generally not uniform, and the limited current time span of the existing data. It seems that a balance needs to be struck between the theoretical and the empirical literatures. For example, assuming complete heterogeneity in the technology parameters of the production function across countries, together with the assumption of variable returns to scale yields highly implausible TFP growth estimates for some countries and regions. This would appear to be because the generated parameter estimates for some countries are theoretically implausible. This argument is similar in spirit to that made by Baltagi and others (see Baltagi and Griffin, 1997; Baltagi et al., 2000) in the context of a dynamic demand function.

Chapter 3 revisits the issue of robustness in the openness-growth relationship. Whereas previous studies that examined this issue focused on the right hand side variables, primarily the measures of openness and other growth determinants, this chapter switches emphasis and focuses on the left hand side variable: TFP growth. Using the three alternative measures of TFP growth derived in Chapter 2, we test the robustness of Rodrik and Rodriguez's (2000) results based on their critique of Edwards (1998), using cross-sectional data. We then explore the sensitivity of the openness-growth relationship based on panel estimations using both annual and five yearly data. Across both types of estimations (cross-section and panel), the chapter also explores the robustness issue based on whether the openness measures are assumed to be exogenous or endogenous.

From our cross-section estimations we find that while most of the measures of trade openness used in Edwards (1998) and those constructed by Rodriguez and Rodrik are robust to the three alternative measures of TFP growth derived in Chapter 2, some of the openness measures are definitely sensitive to the way TFP is measured. These include the Sachs-Warner openness index, the average black market premium and the individual components that comprise the collected taxes ratio constructed by Rodriguez and Rodrik (2000). The fact that most of the openness measures found to be sensitive are significantly correlated with TFP growth, both for our preferred and two alternative measures of TFP, means that we find support for a positive and significant effect from trade liberalisation on TFP growth for more of the proxies of trade policy openness compared to Rodriguez and Rodrik (2000). Consequently, some of the latter authors' analysis and conclusions are sensitive to how TFP growth is measured.

Based on the panel estimations, the Sachs-Warner openness index is the only openness measure that is robust to alternative measures of TFP growth in both five year and annual panels. Additionally, it is also robust to the alternative assumptions about the direction of causality between itself and TFP growth. These findings are in direct contrast to the results obtained using cross-section estimations. On the other hand, while the trade intensity measure is also robust to alternative measures of TFP growth based on both five year and annual panel estimations, it is sensitive to whether we assume it to be an exogenous or an endogenous variable. If it is the former, it is significantly correlated with TFP growth for all three measures of TFP. If it is the latter, it loses statistical significance in all three TFP growth regressions. Finally, while the measure of local price deviation from PPP (PRIDEV) is not robust to alternative measures of TFP and also to whether one assumes the measure to be exogenous or endogenous in the five year panel estimations, it is robust in both dimensions when annual data are used.

Overall, we conclude that the precise openness-productivity growth relationship identified in cross-country analysis is sensitive to how both openness and TFP growth are measured, to whether the model is estimated by cross-section or panel methods, whether one uses annual or period data and to whether openness is treated as an exogenous or endogenous variable. Our own preference however, is to use panel estimation methods and to include several alternative dimensions of trade openness and distortion simultaneously (some of which are more likely to be endogenous than others).

Chapter 4 explored the issue of heterogeneity in the openness-productivity growth relationship by searching for contingent relationships between natural barriers to trade and trade openness (distortions) on the one hand, and institutional quality and trade openness (distortions) on the other. Specifically, it seeks to determine whether there exists some threshold level (s) of natural barriers and institutional quality above and below which there are differentiated effects from openness on productivity growth. Three methods are used to determine the existence (or non-existence) of threshold effects. The first two, described as traditional approaches, involves an exogenous splitting of the sample (based on arbitrarily chosen values of institutional quality and natural barriers) in one instance, and the imposition of linear interaction terms - openness interacted with institutional quality (natural barriers) – in the other. The third method, described as the formal threshold model, employs an endogenous threshold regression model based on Hansen (2000) where a break or threshold is determined from the data itself rather than it being imposed by the researcher.

On the basis of both econometric theory and the pattern of results obtained from the different approaches, we argue that the endogenous threshold methodology best captures heterogeneity in the openness-growth relationship. Our main results using this method can be summarised as follows. First, there is support for the hypothesis that there exists a critical level of natural barriers above and below which the contribution to TFP growth from openness differs. However, this relationship depends on the measure of openness used. For example, when trade share as a percentage of GDP is used as the measure of openness we find that 'high' natural barriers countries receive lower or insignificant TFP growth benefits from increased openness relative to countries below this upper threshold. By contrast, using the policy-based (trade tax) measure of openness/liberalisation, 'high' natural barrier countries are predicted to experience TFP growth benefits linked to reductions in trade taxes as a proportion of GDP, while countries below the threshold are predicted to experience no significant TFP growth effects. Second, the 'high' natural barriers group comprises a mix of coastal countries, island economies and landlocked countries.

This finding suggests that factors other than geography, for example being landlocked, contribute to high transport costs. Moreover, it is consistent with other researchers and agencies who argue that factors such as the quality of the regulatory and institutional environment (e.g. transparency of customs procedures, efficiency of the bureaucracy etc.) governing international trade are also key determinants of transport costs (see Anderson and Marcouiller 1999; IDB, 2000).

This pattern of results are, in our view, important from two standpoints. First, they contribute to a deeper understanding of why other researchers (e.g. Block, 2001) have found that being closed to trade is more costly to growth in Africa than elsewhere. Africa is a region with relatively high 'natural barriers'. These differences in the nature of the threshold effects may account for differences in the nature of the productivity growth-openness relationship when trade performance and policy-based indicators of openness have been used in the previous literature. Second, is the implications for government policy. For example, when the trade share measure of openness is used, of the 18 countries (all developing countries) above the threshold level of natural barriers (transport costs) and shown to receive no productivity growth benefits from increased openness, 11 are from Sub-Saharan Africa. Further, of this number, 9 are landlocked. As argued by Limão and Venables (2001), in addition to distance, infrastructure is also an important determinant of transport costs, particularly for landlocked countries. Moreover, they demonstrate that improvements in a country's own infrastructure as well as that of transit countries overcome more than half of the disadvantage of being landlocked. Consistent with Limão and Venables (2001), the implication for government policy from our finding is that improvements in physical infrastructure (road, rail, port etc.) can facilitate greater integration into the world economy by lowering transport costs with a consequent increase in the productivity growth payoffs associated with this integration. Moreover, it emphasises the fact that "geography is not destiny".

Further, in light of the second finding that other than landlocked countries, the 'high' natural barriers group also comprises a mix of coastal countries and island economies suggest that policies other than improvements are also required and may need to be complemented with efforts aimed at improving efficiency in the regulatory and institutional environments that govern international trade.

Although when institutional quality is used as the threshold variable the evidence that it affects the correlation between productivity growth and openness is not as strong as it is for natural barriers, the results indicate that increased policy openness/liberalisation increases TFP growth for countries below the threshold level of institutional quality rather than for countries above it.

Finally, the evidence of heterogeneity in the trade-growth relationship means that the conventional assumption of a simple linear relationship between the two variables in previous cross-country studies is not supported by the data and therefore appears to be misplaced. It thus suggests that future empirical work in this area should begin from the standpoint that the openness-growth relationship is characterised by non-linearities as argued by Baldwin and Sbergami (2000).

Chapter 5 uses the methodology of stochastic frontier analysis (SFA) along with a flexible functional form of the production technology to simultaneously examine the role of international trade in determining the position of the technical frontier for 57 developing countries, and in explaining deviations from it. In terms of the first role, the chapter specifically considers the part played by trade (machinery imports) as a conduit for the diffusion of foreign technology (embodied in the capital goods) from industrial countries to developing countries.

We find evidence that trade has contributed positively to both technology transfer, and technology absorption and efficiency. Additionally, there is evidence of some convergence in efficiency levels among the developing countries in our sample over the period (1970-1998); the narrowing of the efficiency gap coinciding with improvements in the policy environment and trade liberalisation. In terms of factors other trade that explains distance from the frontier, we find geography (specifically climate) as well as the proportion of domestic output contributed by the agricultural sector to be significant explanatory factors.

Finally, among the traditional inputs determining the technical frontier, we found human capital not impacting positively on the level of GDP for all countries in the sample (notably the SSA countries). This finding suggests support for the interpretation of Pritchett (2001) regarding the role played by this factor in the economic development of developing countries.

6.2 LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Whilst we have made progress in exploring parameter heterogeneity in the cross-country context on the basis of single country regressions, the fairly short current time span of the data to fully explore this issue is a limitation to the analysis in Chapter 2. This fact, coupled with the problem of data quality for variables such as stock of physical and human capital from developing countries, make individual country regressions more susceptible to short-run business cycle effects and possibly amplify the problems posed by measurement error in the data.

Another possible limitation is the imposition of constant returns to scale on the parameters of the production function to obtain the estimates used to derive our preferred measure of TFP growth. This assumption may be violated by the data. Although there is no clear cut evidence of increasing returns to scale at the economy wide level, we recognise that empirical evidence of increasing returns in some sectors of industrial economies has led to the questioning of the assumption of constant returns at the aggregate level. However, in the absence of the latter assumption, the parameter estimates of the production function for some countries are theoretically implausible and this may be a contributory factor to some of the highly implausible estimates of TFP growth generated for some countries and regions. With longer time series and the availability of better quality data, single country estimations with the assumption of variable returns to scale as a means of capturing parameter heterogeneity represent a useful avenue for future research.

The main limitation of Chapter 4 is the inability to address the issue of possible endogeneity bias resulting from likely endogenous regressors such as trade openness and institutional quality based on the 'first best' solution of instrumental variable estimation. As argued elsewhere in the literature, institutional quality and trade openness are at least partly endogenous determinants of growth. The use of an instrumental variable GMM threshold model based on Caner and Hansen (2001) forms part of future research aimed at addressing legitimate concerns over possible endogeneity problems posed by the relationship of these variables with productivity growth.

One limitation of Chapter 5 is the fact that the technical efficiency we estimate is conditional upon the actual inputs chosen. These may or may not be the allocatively efficient factor mix. Therefore it is possible that some countries we identified as being technically efficient and thus defining the frontier, may not have done so with the allocatively efficient mix. However, in the absence of data on relative factor prices we are unable to comment on allocative efficiency issues. Another source of discomfort is the finding of negative and significant time trends, which suggest technical regression, against the background of positive contribution of foreign R&D over the period. Though previous researchers using the methodology of SFA have also found and offered possible plausible explanations for the occurrence of negative trends, we signal it as a another possible limitation of the study.

Our intention is to build on the work started in Chapter 5 with the aim decomposing the changes in efficiency levels to capture the separate contributions of trade, geography and institutions to these changes. We hope that the results of this research would establish the income 'return' from alternative policies and allow more guided policy prescriptions. On the academic front, we trust that it provides the impetus for further research aimed at both broadening and deepening our understanding of the role played by these three "deeper" determinants of long run growth and development. We hope that this thesis has contributed to this end.

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APPENDIX TO CHAPTER 2

APPENDIX 2.1

The conventionally measured Divisia index of TFP is obtained in the following way.[1] Total factor productivity is first defined as the ratio of aggregate output (Q) to aggregate input (F). Aggregate output (input) is an index of disaggregated outputs (inputs). The Divisia indexes for aggregate output (Q) and input (F) are defined in terms of the proportional rates of growth ($\dot{Q}$ and $\dot{F}$) as:

(A2.1) $$\dot{Q} = \sum_j \frac{P_j Q_j}{R} \dot{Q}_j,$$

where P_j is the price of output j, Q_j the quantity of output j, $\dot{Q}_j$ the proportional rate of growth of output j, $R=\Sigma_j P_j Q_j$ the total revenue, and

(A2.2) $$\dot{F} = \sum_i \frac{w_i X_i}{C} \dot{X}_i$$

where w_i is the price of input i, X_i the quantity of input i, $\dot{X}_i$ is the proportionate rate of input i, and $C=\Sigma_i w_i X_i$ the total cost.

Given that TFP=Q/F, the proportionate rate of growth of total factor productivity ($T\dot{F}P$) is defined by:

(A2.3) $$T\dot{F}P = \dot{Q} - \dot{F}$$

[1] The analysis in this section draws on material from Denny, Fuss and Waverman (1981).

The formulas (A2.1) - (A2.3) are in terms of instantaneous changes. For data obtainable at yearly intervals, the most commonly used discrete approximation to the continuous formulas (A2.1) and (A2.2) is given by the Törnqvist approximations:

(A2.4) $$\Delta \log Q = \log\left(\frac{Q_t}{Q_{t-1}}\right) = 1/2\sum_j \left(r_{j,t} + r_{j,t-1}\right)\log\left(\frac{Q_{jt}}{Q_{j,t-1}}\right)$$

where Q_{jt} is the quantity of output Q_j produced in period t, $r_{jt}=P_{jt}Q_{jt}/\Sigma_j P_{jt}Q_{jt}$ the revenue share of output Q_j in total revenue during period t, and

(A2.5) $$\Delta \log F = \log\left(\frac{F_t}{F_{t-1}}\right) = 1/2\sum_i \left(s_{it} + s_{i,t-1}\right)\log\left(\frac{X_{it}}{X_{i,t-1}}\right)$$

where X_{it} is the quantity of input X_i used in period t and $s_{it}=w_iX_i/\Sigma w_iX_i$ the cost share of input X_i in total cost during period t.

Finally, the corresponding discrete approximation to (A2.3) is provided by:[2]

(A2.6) $$\Delta TFP = \Delta \log Q - \Delta \log F$$

The functions defining the output and input aggregates in (A2.4) and (A2.5) are assumed to be of the translog form. Diewert (1976) shows that (A2.6) can be derived from a homogeneous translog transformation function that is separable in outputs and inputs and exhibits neutral differences in productivity (i.e. neutral technical change). However, Caves, Christensen and Diewert (1982) have shown that separability and neutrality are not required to derive (A2.6) from a homogeneous translog transformation function.

[2] Q_j and X_i can be quantity and input indexes respectively.

APPENDIX 2.2

Time Series Growth Accounting: Relative Form

A detailed exposition of the *relative form* of the time-series approach to international TFP comparison initiated by Jorgenson and Nishimizu (1978) is shown below. It is based on the methodology used in Christensen, Cummings and Jorgenson (1981) for the sample of countries that were used in the *absolute form* study of Christensen, Cummings and Jorgenson (1980). To consider the data in relative form, Christensen et al (1981) utilised the following translog production function :

(A2.7)

$$\begin{aligned} Y = \exp[&\alpha_0 + \alpha_K \ln K + \alpha_L \ln L + \alpha_T T + \sum \alpha_C D_C \\ &+ \frac{1}{2}\beta_{KK} (\ln K)^2 + \beta_{KL} \ln K \ln L + \beta_{KT} T \ln K + \sum \beta_{KC} D_C \ln K \\ &+ \frac{1}{2}\beta_{LL} (\ln L)^2 + \beta_{LT} T \ln L + \sum \beta_{LC} D_C \ln L \\ &+ \frac{1}{2}\beta_{TT} T^2 + \frac{1}{2}\sum \beta_{TC} T D_C + \frac{1}{2}\beta_{CC} {D_C}^2] \end{aligned}$$

where Y is output, K is capital, L is labour, T is time, D_C is a dummy variable for country C. This is the identical production function used by Jorgenson et al (1980) for their growth accounting exercise in *absolute* form except for the inclusion of country dummies in (A7). The U.S. is taken as the reference country, and hence the dummy for the U.S. is dropped. In this framework, the rate of TFP is given by

(A2.8)

$$v_T = \frac{\partial \ln Y}{\partial T} = \alpha_T + \beta_{KT} \ln K + \beta_{LT} \ln L + \beta_{TT} T + \beta_{TC} D_C$$

which is approximated by the following *translog index of productivity growth*:

(A2.9)

$$\bar{v}_T = \ln Y(T) - \ln Y(T-1) - \bar{v}_K(\ln K(T) - \ln K(T-1)) - \bar{v}_L(\ln L(T) - \ln L(T-1))$$

where

$$\bar{v}_K = \frac{1}{2}[v_K(T) + v_K(T-1)]$$

with

$$v_K = \frac{\partial \ln Y}{\partial \ln K}$$

Similar definitions apply for

$$\bar{v}_L \qquad \bar{v}_T$$

This approach is novel in the sense that it allows having an expression for difference in TFP levels. The difference between any country C and the U.S. is expressed as follows:

(A2.10)

$$v_C = \frac{\partial \ln Y}{\partial D_C} = \alpha_C + \beta_{KC} \ln K + \beta_{LC} \ln L + \beta_{TC} T + \beta_{CC} D_C$$

This is approximated by the following translog multilateral index of differences of productivity:

(A2.11)

$$\hat{v}_C = \ln Y(C) - \ln Y(US) - \hat{v}_K(C)[\ln K(C) - \ln \overline{K}]$$
$$+ \hat{v}_K(US)[\ln K(US) - \ln \overline{K}] - \hat{v}_L(C)[\ln L(C) - \ln \overline{L}]$$
$$+ \hat{v}_L(US)[\ln L(US) - \ln \overline{L}],$$

where,

$$\hat{v}_K(C) = \frac{1}{2}[v_K(C) + \frac{1}{2}\Sigma v_K], \hat{v}_L(C) = \frac{1}{2}[v_L(C) + \frac{1}{2}\Sigma v_L]$$

and

$$\ln \overline{K}, \ln \overline{L}$$

denote averages of ln k and ln L over all countries in the sample. This index is based on Caves, Christensen and Diewert (1982) and is transitive and based country invariant. This framework allowed Christensen et al (1981) to conduct TFP comparison both in terms of growth rates and levels, using the translog indices specified above.

APPENDIX 2.3

COUNTRY SAMPLE

The 93 countries that make up the sample, in their regional groupings are:

EAST ASIA
China
Indonesia
Korea
Malaysia
Philippines
Singapore
Taiwan
Thailand

SOUTH ASIA
Bangladesh
India
Myanmar
Pakistan
Sri Lanka

INDUSTRIAL COUNTRIES
Australia
Austria
Belgium
Canada
Denmark
Finland
France
Germany
Greece
Iceland
Ireland
Italy
Japan
Netherlands
New Zealand
Norway
Portugal
Spain
Sweden
Switzerland
Turkey
United Kingdom
United States

SUB-SAHARAN AFRICA
Angola
Cameroon
Cote d'Ivoire
Ethiopia
Ghana
Kenya
Madagascar
Malawi
Mali
Mauritius
Mozambique
Nigeria
Rwanda
Senegal
Sierra Leone
South Africa
Morocco
Sudan
Tanzania
Uganda
Zaire

Zambia
Zimbabwe

MIDDLE EAST and NORTH AFRICA
Algeria
Cyprus
Egypt
Iran
Iraq
Israel
Jordan
Kuwait
Libya
Malta
Tunisia

LATIN AMERICA and CARRIBEAN

Argentina
Bolivia
Brazil
Chile
Columbia
Costa Rica
Dominican Republic
Ecuador
El Salvador
Guatemala
Guyana
Haiti
Honduras
Jamaica
Mexico
Nicaragua
Panama
Paraguay
Peru
Trinidad and Tobago
Uruguay
Venezuela

APPENDIX 2.4

Table A2.1 : Cobb-Douglas Production Function Estimates for 93 Countries, 1960-90 (unconstrained)

	α	β	Adj. R^2	N		α	β	γ	Adj. R^2	N
1. Angola	-0.17 (-0.20)	-3.76 (-1.15)	-0.017	29		-0.10 (-0.11)	-4.78 (-1.05)	-0.50 (-0.33)	-0.05	27
2. Argentina	0.44 (1.14)	7.64 (1.36)	0.13	30		0.11 (0.22)	9.29 (1.52)	-1.00 (-0.18)	0.04	27
3. Australia	1.02 (2.00)	-0.54 (-0.29)	0.15	30		0.64 (0.97)	-0.28 (-0.14)	-0.74 (-0.73)	0.09	27
4. Austria	0.20 (0.84)	-1.65 (-1.63)	0.24	30		0.38 (1.26)	-1.25 (-1.01)	-0.71 (-0.72)	0.28	27
5. Belgium	0.87 (3.51)	-3.07 (-1.89)	0.32	30		0.78 (1.74)	-3.24 (-1.17)	-0.82 (-0.42)	0.31	27
6. Bangladesh	0.76 (1.29)	0.33 (0.19)	-0.01	29		0.58 (0.93)	-0.13 (-0.06)	3.52 (1.52)	0.04	26
7. Bolivia	0.57 (2.51)	0.68 (0.21)	0.21	30		0.84 (4.01)	2.99 (0.95)	-1.21 (-2.92)	0.48	27
8. Brazil	0.25 (0.55)	7.98 (2.07)	0.31	30		0.35 (0.75)	4.64 (1.00)	-1.70 (-1.27)	0.20	27
9. Canada	-1.40 (-2.17)	1.28 (2.19)	0.21	30		-2.02 (-2.48)	2.42 (2.14)	1.49 (1.17)	0.19	27
10. Switzerland	0.40 (1.29)	1.91 (1.42)	0.25	30		0.88 (1.57)	3.18 (1.74)	1.32 (1.02)	0.26	27
11. Chile	0.65 (0.70)	2.26 (0.40)	-0.05	30		0.82 (0.68)	6.01 (0.89)	0.45 (0.12)	-0.08	27
12. China	0.30 (0.43)	3.69 (0.98)	0.00	30		0.29 (0.30)	3.75 (0.86)	0.07 (0.03)	-0.05	27
13. Côte d' Ivoire	0.66 (2.98)	-1.05 (-0.51)	0.21	29		0.28 (0.94)	-1.89 (-0.91)	0.71 (2.01)	0.17	26
14. Cameroon	0.89 (2.53)	-1.05 (-0.47)	0.14	29		1.41 (2.27)	-1.68 (-0.66)	2.32 (1.76)	0.10	26
15. Colombia	-0.34 (-0.62)	1.20 (0.89)	-0.03	30		0.09 (0.12)	-1.53 (-0.71)	-0.81 (-1.52)	0.01	27
16. Costa Rica	0.56 (1.19)	0.50 (0.27)	0.07	30		0.47 (0.96)	0.69 (0.30)	-1.96 (-1.60)	0.14	27
17. Cyprus	-2.20 (-2.11)	-13.02 (-2.27)	0.19	30		-2.24 (-1.97)	-13.45 (-2.15)	1.45 (0.51)	0.16	27
18. Germany	0.36 (1.65)	-0.32 (-1.63)	0.21	30		0.41 (1.25)	-0.25 (-1.10)	-0.20 (-.27)	0.19	27
19. Denmark	0.24 (1.17)	3.96 (1.54)	0.20	30		0.25 (1.04)	6.05 (1.52)	1.87 (0.68)	0.14	27
20. Dominican Republic	0.35 (0.78)	4.09 (1.02)	0.04	30						
21. Algeria	0.12 (0.20)	0.21 (0.11)	0.07	30		-0.71 (-0.84)	-0.59 (-0.21)	4.09 (1.60)	-0.01	27
22. Ecuador	0.21 (0.34)	5.99 (1.15)	0.03	30		0.41 (0.55)	6.46 (1.15)	-0.39 (-0.18)	-0.01	27
23. Egypt	0.60 (4.70)	-1.15 (-1.04)	0.41	30		0.56 (4.07)	-1.09 (-0.83)	0.79 (0.61)	0.37	27
24. Spain	0.54 (2.37)	-2.19 (-0.97)	0.34	30		-0.69 (-2.51)	-7.73 (-4.02)	-5.76 (-6.02)	0.74	27
25. Ethiopia	0.36 (1.72)	9.20 (1.97)	0.10	30		0.19 (0.64)	7.77 (1.54)	-0.24 (-0.70)	0.04	27
26. Finland	-0.09 (-0.15)	1.32 (0.85)	-0.03	30		-0.79 (-0.81)	3.19 (1.27)	1.63 (0.92)	-0.03	27

27. France	0.69 (5.71)	-0.41 (-0.50)	0.53	30		0.76 (3.32)	0.24 (0.15)	0.06 (0.07)	0.58	27
28. United Kingdom	0.28 (0.83)	0.42 (0.27)	-0.05	30		2.54 (1.54)	7.26 (1.23)	3.87 (1.20)	-0.03	27
29. Ghana	0.07 (0.25)	1.17 (0.54)	-0.06	30		0.11 (0.29)	0.32 (0.12)	-0.03 (-0.04)	-0.12	27
30. Greece	0.78 (4.18)	0.20 (0.14)	0.42	30		0.97 (3.86)	-1.94 (-0.44)	-2.89 (-0.69)	0.42	27
31. Guatemala	0.87 (3.52)	2.60 (1.01)	0.27	30		1.06 (4.12)	2.16 (0.84)	-1.45 (-2.10)	0.38	27
32. Guyana	1.48 (2.88)	-0.13 (-0.09)	0.21	30						
33. Honduras	0.60 (1.69)	0.06 (0.07)	0.04	30		0.56 (1.31)	-0.06 (-0.05)	-0.31 (-0.35)	-0.04	27
34. Haiti	0.40 (1.64)	-1.65 (-0.34)	0.03	29		0.45 (1.60)	5.29 (0.88)	-1.82 (-1.87)	0.08	26
35. Indonesia	0.09 (0.38)	2.81 (1.15)	0.14	30		0.04 (0.15)	0.98 (0.21)	-1.06 (-0.52)	0.09	27
36. India	-1.29 (-1.03)	-4.12 (-1.04)	-0.02	30		-1.25 (-0.98)	-3.68 (-0.90)	-0.52 (-0.42)	-0.07	27
37. Ireland	0.03 (0.08)	-0.10 (-0.01)	-0.07	30		0.22 (0.60)	1.79 (0.94)	2.23 (0.96)	-0.03	27
38. Iran	0.80 (2.79)	10.60 (2.71)	0.24	30		1.17 (2.13)	14.39 (3.55)	0.84 (0.24)	0.36	27
39. Iraq	0.52 (0.77)	-20.97 (-1.89)	0.06	27		0.72 (0.88)	-18.22 (-1.42)	1.75 (0.45)	0.02	27
40. Iceland	-0.63 (-0.97)	8.59 (2.44)	0.12	30		-1.07 (-1.57)	9.28 (2.18)	2.27 (0.71)	0.08	27
41. Israel	0.32 (0.92)	2.36 (2.18)	0.28	30		0.27 (0.64)	3.18 (1.96)	-0.55 (-0.60)	0.22	27
42. Italy	0.49 (2.16)	-2.04 (-1.58)	0.24	30		0.51 (1.49)	-1.96 (-1.18)	0.20 (0.20)	0.20	27
43. Jamaica	0.17 (0.49)	-1.79 (-2.34)	0.27	30		0.28 (0.79)	-0.33 (-0.25)	2.61 (1.26)	0.32	27
44. Jordan	1.06 (2.30)	0.43 (0.40)	0.11	30		0.88 (1.42)	0.02 (0.01)	0.44 (0.56)	0.01	27
45. Japan	0.48 (2.69)	1.44 (1.02)	0.50	30		0.28 (1.01)	3.00 (1.54)	3.35 (1.28)	0.53	27
46. Kenya	0.66 (1.37)	0.80 (0.45)	0.01	30		0.71 (1.32)	1.26 (0.60)	-1.01 (-0.74)	-0.02	27
47. Korea	0.27 (1.45)	-0.03 (-0.49)	0.01	30		0.23 (1.00)	-0.03 (-0.50)	-0.31 (-0.49)	-0.02	27
48. Kuwait	-0.46 (-0.74)	1.67 (1.22)	-0.02	29						
49. Libya	1.14 (4.42)	-11.14 (-1.80)	0.49	29						
50. Sri Lanka	0.14 (0.81)	-0.10 (-0.10)	-0.05	30		0.09 (0.43)	-0.49 (-0.39)	-0.74 (-0.56)	-0.08	27
51. Luxemb.	0.25 (0.50)	-1.23 (-0.60)	-0.05	30						
52. Morocco	0.05 (0.12)	-1.59 (-0.85)	-0.04	30		0.77 (1.36)	-9.44 (-2.31)	-1.85 (-2.15)	0.09	27
53. Madagascar	0.57 (0.93)	-1.60 (-0.58)	0.04	29		0.20 (0.27)	-3.46 (-1.00)	-0.10 (-0.14)	0.02	26
54. Mexico	1.05 (4.71)	-4.08 (-2.31)	0.43	30		1.11 (3.35)	-3.16 (-1.33)	-0.51 (-0.48)	0.40	27
55. Mali	-0.28 (-0.25)	1.74 (0.56)	-0.06	29		-0.49 (-0.40)	7.65 (1.42)	0.80 (1.32)	-0.03	26
56. Malta	-0.93 (-1.82)	2.52 (4.25)	0.42	29						
57. Myanmar	0.53 (0.97)	-6.48 (-1.41)	0.05	30		0.29 (0.55)	-6.29 (-1.33)	1.33 (1.34)	0.01	27
58. Mozamb.	1.19 (2.24)	2.22 (0.51)	0.17	30		2.13 (3.72)	14.47 (2.40)	1.84 (2.60)	0.38	27

59. Mauritius	1.26 (2.24)	-1.38 (-0.95)	0.11	30		1.61 (2.18)	-2.06 (-1.15)	0.59 (0.44)	0.08	27
60. Malawi	0.35 (1.75)	0.08 (0.04)	0.06	30		0.50 (1.78)	0.80 (0.33)	0.86 (0.43)	0.05	27
61. Malaysia	0.06 (0.26)	2.56 (1.36)	0.01	30		0.47 (1.77)	4.60 (2.52)	0.72 (1.01)	0.23	27
62. Nigeria	-0.28 (-0.92)	-5.26 (-1.97)	0.06	30		-0.53 (-1.01)	-7.24 (-2.19)	-1.15 (-1.08)	0.09	26
63. Nicaragua	1.58 (3.39)	0.15 (0.03)	0.26	30						
64. Netherlands	0.88 (4.12)	-1.43 (-1.10)	0.37	30		0.88 (3.36)	0.17 (0.06)	0.38 (0.17)	0.38	27
65. Norway	1.07 (3.01)	4.62 (1.47)	0.25	30		0.45 (1.11)	-0.48 (-0.08)	-1.04 (-0.53)	-0.03	27
66. New Zealand	-0.41 (-0.55)	3.42 (2.62)	0.21	30		-0.36 (-0.44)	2.62 (1.41)	-2.03 (-0.69)	0.16	27
67. Pakistan	-0.32 (-2.08)	-4.34 (-3.33)	0.28	30		-0.38 (-2.29)	-4.95 (-3.55)	-0.74 (-0.91)	0.32	27
68. Panama	0.68 (2.83)	-3.71 (-0.93)	0.18	30		0.39 (1.54)	-4.46 (-1.57)	2.53 (0.82)	0.10	27
69. Peru	1.22 (1.95)	-0.50 (-0.11)	0.06	30		0.23 (0.41)	0.74 (0.17)	-8.91 (-1.90)	0.07	27
70. Philippines	0.37 (1.32)	3.61 (2.80)	0.18	30		0.71 (2.32)	5.55 (3.99)	2.19 (1.81)	0.37	27
71. Portugal	0.86 (2.48)	0.47 (0.42)	0.16	30		1.51 (3.43)	4.85 (2.12)	2.14 (2.19)	0.28	27
72. Paraguay	0.51 (2.27)	-0.51 (-0.32)	0.16	30		0.49 (2.05)	-1.56 (-0.80)	-1.76 (-1.12)	0.18	27
73. Rwanda	0.49 (0.83)	-4.86 (-1.16)	-0.02	29		-1.40 (-1.91)	-2.86 (-0.66)	-4.23 (-3.52)	0.28	26
74. Sudan	0.80 (2.28)	6.49 (1.77)	0.12	30		0.88 (2.06)	6.94 (1.87)	-1.51 (-0.87)	0.14	27
75. Senegal	-0.36 (-0.30)	0.07 (0.03)	-0.07	29		-0.26 (-0.18)	0.02 (0.01)	-0.09 (-0.16)	-0.13	26
76. Singapore	-0.09 (-0.36)	3.22 (1.79)	0.08	29		-0.19 (-0.49)	5.17 (2.54)	0.71 (0.91)	0.21	26
77. Sierra Leone	0.37 (0.45)	-2.03 (-0.43)	-0.04	29		0.36 (0.39)	-1.86 (-0.36)	-0.79 (-0.31)	-0.09	26
78. El Salvador	0.54 (2.03)	1.96 (2.25)	0.33	30		0.55 (1.75)	1.48 (1.41)	-2.06 (-1.00)	0.32	27
79. Sweden	0.50 (2.22)	2.51 (1.92)	0.37	30		0.10 (0.29)	1.59 (0.85)	-1.81 (-1.17)	0.40	27
80. Thailand	0.14 (0.70)	-0.60 (-0.76)	-0.03	30		0.28 (1.41)	0.58 (0.56)	0.89 (0.36)	0.01	27
81.Trinidad & Tobago	0.64 (1.61)	2.55 (1.44)	0.21	30						
82. Tunisia	0.15 (0.36)	0.06 (0.07)	-0.07	29		-0.25 (-0.42)	0.38 (0.37)	1.21 (1.85)	0.02	25
83. Turkey	0.34 (1.04)	1.20 (1.02)	-0.00	30		0.48 (0.98)	0.93 (0.61)	-0.55 (-0.35)	-0.04	27
84. Taiwan	0.03 (0.14)	0.91 (2.31)	0.12	30						
85. Tanzania	0.07 (0.21)	-2.43 (-0.77)	-0.05	28		0.70 (2.23)	-3.02 (-1.20)	1.02 (4.01)	0.35	27
86. Uganda	-0.04 (-0.03)	3.53 (0.77)	-0.03	30		0.07 (0.05)	1.27 (0.24)	-6.19 (-0.81)	-0.05	27
87. Uruguay	-0.10 (-0.26)	-2.10 (-0.90)	-0.04	30		-0.15 (-0.34)	-5.30 (-1.13)	-3.61 (-0.82)	-0.07	27
88. USA	1.10 (1.19)	-0.30 (-0.25)	-0.02	30		0.87 (0.83)	-2.86 (-1.23)	-2.61 (-1.15)	-0.01	27
89. Venezuela	-0.11 (-0.22)	1.04 (0.44)	-0.06	30		-0.02 (-0.04)	0.13 (0.06)	1.74 (1.73)	0.00	27
90. South Africa	0.63 (2.03)	-2.30 (-0.81)	0.07	30						

91. Zaire	-0.32 (-0.30)	-0.16 (-0.04)	-0.06	29		-0.34 (-0.30)	-0.33 (-0.08)	-0.59 (-0.29)	-0.11	27
92. Zambia	0.18 (0.57)	-0.27 (-0.17)	-0.05	30		0.21 (0.52)	-0.76 (-0.33)	-0.55 (-0.25)	-0.11	27
93. Zimbabwe	0.12 (0.23)	-0.40 (-0.14)	-0.07	30		-0.26 (-0.46)	1.37 (0.42)	2.44 (1.65)	-0.00	27

Note: Table A2.1 provides OLS estimates of the output elasticities of capital (α), labour (β) and human capital (γ) for the following unrestricted Cobb-Douglas production functions: $Y_t = A_t K_t^{\alpha} L_t^{\beta}$ and $Y_t = A_t K_t^{\alpha} L_t^{\beta} H_t^{\gamma}$,where Y is real GDP, K is physical capital stock, L is labour, H is human capital, A is a measure of total factor productivity and t a time index. The figures in parentheses are t-statistics.

Table A2.2 : Cobb-Douglas Production Function Estimates 1960-90 (Constrained)

Country	α	β	RMSE	N	Country	α	β	RMSE	N
1. Angola	0.56 (0.88)	0.44 (0.68)	0.113	29	13. Côte d' Ivoire	0.68 (3.19)	0.32 (1.47)	0.049	29
2. Argentina	0.67 (1.94)	0.33 (0.95)	0.043	30	14. Cameroon	0.88 (2.52)	0.12 (0.36)	0.058	29
3. Australia	0.92 (2.23)	0.08 (0.19)	0.020	30	15. Colombia	-0.32 (-0.63)	1.32 (2.60)	0.018	30
4. Austria	0.59 (4.02)	0.41 (2.82)	0.018	30	16. Costa Rica	0.57 (1.55)	0.43 (1.17)	0.034	30
5. Belgium	0.94 (3.64)	0.06 (0.24)	0.018	30	17. Cyprus	-1.42 (-1.28)	2.42 (2.17)	0.089	30
6. Bangladesh	0.75 (1.67)	0.25 (0.57)	0.045	29	18. Germany	0.88 (7.24)	0.12 (1.00)	0.021	30
7. Bolivia	0.56 (3.46)	0.44 (2.69)	0.028	30	19. Denmark	0.38 (2.20)	0.62 (3.60)	0.022	30
8. Brazil	0.91 (2.69)	0.09 (0.27)	0.041	30	20. Dominican Republic	0.51 (1.25)	0.49 (1.22)	0.060	30
9. Canada	-0.78 (-1.83)	1.78 (4.17)	0.019	30	21. Algeria	0.04 (0.07)	0.96 (1.62)	0.088	30
10. Switzerland	0.58 (2.22)	0.42 (1.58)	0.024	30	22. Ecuador	0.56 (1.04)	0.44 (0.81)	0.052	30
11. Chile	0.49 (0.65)	0.51 (0.68)	0.061	30	23. Egypt	0.61 (4.68)	0.39 (2.97)	0.026	30
12. China	0.49 (0.75)	0.51 (0.77)	0.114	30	24. Spain	0.72 (4.44)	0.28 (1.70)	0.024	30

Table 2.2 Continued: Cobb-Douglas Production Function Estimates 1960-90 (Constrained)

Country	α	β	RMSE	N	Country	α	β	RMSE	N
25. Ethiopia	0.22 (1.09)	0.78 (3.84)	0.031	30	39. Iraq	0.04 (0.06)	0.96 (1.45)	0.174	27
26. Finland	-0.03 (-0.06)	1.03 (2.10)	0.023	30	40. Iceland	-0.06 (-0.10)	1.06 (1.68)	0.043	30
27. France	0.67 (5.67)	0.33 (2.80)	0.012	30	41. Israel	0.55 (1.63)	0.45 (1.32)	0.036	30
28. United Kingdom	0.32 (1.20)	0.68 (2.54)	0.021	30	42. Italy	0.69 (3.39)	0.31 (1.52)	0.021	30
29. Ghana	0.07 (0.27)	0.93 (3.51)	0.053	30	43. Jamaica	0.91 (4.20)	0.09 (0.40)	0.041	30
30. Greece	0.79 (5.38)	0.21 (1.47)	0.027	30	44. Jordan	0.94 (2.90)	0.06 (0.18)	0.079	30
31. Guatemala	0.76 (3.51)	0.24 (1.09)	0.026	30	45. Japan	0.57 (4.61)	0.43 (3.46)	0.023	30
32. Guyana	1.49 (2.95)	-0.49 (-0.98)	0.051	30	46. Kenya	0.65 (1.37)	0.35 (0.75)	0.052	30
33. Honduras	0.67 (2.47)	0.33 (1.24)	0.030	30	47. Korea	0.97 (15.30)	0.03 (0.43)	0.042	30
34. Haiti	0.38 (1.60)	0.62 (2.67)	0.037	29	48. Kuwait	-0.43 (-0.73)	1.43 (2.41)	0.097	29
35. Indonesia	0.25 (1.67)	0.75 (5.14)	0.027	30	49. Libya	1.28 (5.04)	-0.28 (-1.11)	0.107	29
36. India	0.00 (0.00)	1.00 (1.27)	0.034	30	50. Sri Lanka	0.17 (0.99)	0.83 (4.84)	0.027	30
37. Ireland	-0.01 (-0.05)	1.01 (3.09)	0.024	30	51. Luxembourg	0.53 (0.99)	0.47 (0.87)	0.031	30
38. Iran	0.51 (1.75)	0.49 (1.71)	0.088	30	52. Morocco	-0.21 (-0.48)	1.21 (2.79)	0.057	30

Table A2.2 Continued Cobb-Douglas Production Function Estimates 1960-90

Country	α	β	RMSE	N	Country	α	β	RMSE	N
53. Madagascar.	0.87 (2.17)	0.13 (0.34)	0.036	29	67. Pakistan	0.21 (2.34)	0.79 (8.67)	0.024	30
54. Mexico	0.99 (4.13)	0.01 (0.05)	0.029	30	68. Panama	0.67 (2.80)	0.33 (1.36)	0.049	30
55. Mali	-0.25 (-0.23)	1.25 (1.13)	0.048	29	69. Peru	1.23 (2.02)	-0.23 (-0.38)	0.055	30
56. Malta	-1.18 (-3.20)	2.18 (5.91)	0.038	29	70. Philippines	0.15 (0.54)	0.85 (3.08)	0.033	30
57. Myanmar	0.77 (1.42)	0.23 (0.43)	0.053	30	71. Portugal	0.80 (3.42)	0.20 (0.88)	0.029	30
58. Mozambique	0.98 (3.05)	0.02 (0.08)	0.059	30	72. Paraguay	0.43 (2.30)	0.57 (3.09)	0.034	30
59. Mauritius	1.38 (2.60)	-0.38 (-0.72)	0.061	30	73. Rwanda	-0.07 (-0.16)	1.07 (2.40)	0.062	29
60. Malawi	0.38 (2.36)	0.62 (3.83)	0.042	30	74. Sudan	0.50 (1.62)	0.50 (1.64)	0.069	30
61. Malaysia	0.08 (0.31)	0.92 (3.68)	0.027	30	75. Senegal	-0.16 (-0.14)	1.16 (1.02)	0.049	29
62. Nigeria	0.17 (0.64)	0.83 (3.22)	0.079	30	76. Singapore	0.10 (0.47)	0.90 (4.26)	0.040	29
63. Nicaragua	1.56 (3.59)	-0.56 (-1.29)	0.072	30	77. Sierra Leone	0.65 (1.10)	0.35 (0.60)	0.088	29
64. Netherlands	0.76 (3.90)	0.24 (1.21)	0.018	30	78. El Salvador	0.61 (2.20)	0.39 (1.40)	0.038	30
65. Norway	1.03 (2.86)	-0.03 (-0.09)	0.017	30	79. Sweden	0.65 (3.10)	0.35 (1.66)	0.015	30
66. New Zealand	-0.19 (-0.24)	1.19 (1.49)	0.032	30	80. Thailand	0.25 (1.25)	0.75 (3.83)	0.026	30

Table A2.2 Continued Cobb-Douglas Production Function Estimates 1960-90

Country	α	β	RMSE	N	Country	α	β	RMSE	N
81.Trinidad & Tobago	0.82 (2.15)	0.18 (0.48)	0.052	30	92. Zambia	0.30 (1.14)	0.70 (2.70)	0.049	30
82. Tunisia	0.35 (0.85)	0.65 (1.56)	0.039	29	93. Zimbabwe	0.22 (0.49)	0.78 (1.77)	0.056	30
83. Turkey	0.29 (0.96)	0.71 (2.39)	0.029	30					
84. Taiwan	0.03 (0.18)	0.97 (5.25)	0.028	30					
85. Tanzania	0.07 (0.22)	0.93 (2.68)	0.030	28					
86. Uganda	0.45 (0.41)	0.55 (0.51)	0.147	30					
87. Uruguay	0.09 (0.24)	0.91 (2.38)	0.044	30					
88. USA	1.16 (1.39)	-0.16 (-0.19)	0.022	30					
89. Venezuela	-0.12 (-0.33)	1.12 (2.95)	0.042	30					
90. South Africa	0.48 (1.77)	0.52 (1.95)	0.024	30					
91. Zaire	-0.75 (-1.15)	1.75 (2.69)	0.058	29					

Note: Table A2.2 provides OLS estimates of the output elasticities of capital (α), labour (β)for the following restricted Cobb-Douglas production functions: $Y_t = A_t K_t^{\alpha} L_t^{\beta}$ where Y is real GDP, K is physical capital stock, L is labour, A is a measure of total factor productivity and t a time index. The figures in parentheses are t-statistics.

APPENDIX 2.5

Table A2.3 : TFP Growth Estimates and Country Rankings					
Countries	**TFPG-AMG2 (%)** (1)	**TFPG-GMM (%)** (2)	**Rank based on TFPG-AMG2** (3)	**Rank based on TFPG-GMM** (4)	**Difference in Rank** (3)-(4)
1. Angola	-1.05	0.30	80	85	-5
2. Argentina	-0.78	0.79	71	79	-8
3. Australia	0.44	2.25	48	44	4
4. Austria	0.53	2.10	42	48	-6
5. Belgium	1.24	2.34	20	39	-19
6. Bangladesh	0.60	1.93	41	53	-12
7. Bolivia	-0.23	1.48	65	65	0
8. Brazil	0.04	3.12	56	19	37
9. Canada	0.97	2.68	28	28	0
10. Switzerland	-0.18	1.33	64	69	-5
11. Chile	0.53	2.01	43	52	-9
12. China	2.34	4.02	10	8	2
13. Côte d' Ivoire	-0.03	2.47	59	36	23
14. Cameroon	-0.17	1.75	63	60	3
15. Colombia	0.71	2.94	38	22	16
16. Costa Rica	-0.69	2.38	70	38	32
17. Cyprus	4.34	4.31	2	5	-3
18. Germany	0.32	1.79	50	58	-8
19. Denmark	0.21	1.64	52	61	-9
20. Dominican Republic	-1.05	2.31	79	40	39
21. Algeria	0.61	1.82	40	57	-17
22. Ecuador	0.73	3.25	37	17	20
23. Egypt	2.98	3.55	3	13	-10
24. Spain	0.87	2.79	32	26	6
25. Ethiopia	-1.02	0.92	77	77	0
26. Finland	1.23	2.58	21	33	-12
27. France	0.48	2.17	45	47	-2
28. United Kingdom	0.29	1.42	51	67	-16
29. Ghana	-1.12	0.41	81	82	-1
30. Greece	0.91	2.81	31	24	7
31. Guatemala	-0.03	2.23	58	45	13
32. Guyana	-1.32	-0.24	84	90	-6
33. Honduras	-0.24	2.20	66	46	-20
34. Haiti	-2.30	-0.13	92	87	5
35. Indonesia	1.19	3.03	23	20	3
36. India	1.07	2.47	25	37	-12
37. Ireland	1.06	2.67	27	29	-2
38. Iran	0.46	1.54	46	64	-18
39. Iraq	-1.41	-0.24	85	91	-6
40. Iceland	1.09	2.86	24	23	1
41. Israel	2.80	3.85	4	9	-5
42. Italy	1.20	2.61	22	32	-10
43. Jamaica	-0.43	0.84	68	78	-10
44. Jordan	2.74	2.79	5	25	-20
45. Japan	0.74	3.63	36	12	24
46. Kenya	2.25	4.03	12	7	5

Countries	TFPG-AMG2 (%) (1)	TFPG-GMM (%) (2)	Rank based on TFPG-AMG2 (3)	Rank based on TFPG-GMM (4)	Difference in Rank (3)-(4)
47. Korea	2.70	5.04	6	2	4
48. Kuwait	-6.00	-2.63	92	93	-1
49. Libya	0.96	1.84	29	56	-27
50. Sri Lanka	1.07	2.47	26	35	-9
51. Luxembourg	1.31	2.29	17	41	-24
52. Morocco	2.50	3.55	8	14	-6
53. Madagascar	-1.03	0.33	78	84	-6
54. Mexico	-0.57	2.67	69	30	39
55. Mali	0.75	2.04	35	50	-15
56. Malta	5.98	5.75	1	1	0
57. Myanmar	0.13	1.56	54	63	-9
58. Mozambique	-1.53	-0.12	86	86	0
59. Mauritius	2.30	3.69	11	10	1
60. Malawi	-0.12	2.04	61	51	10
61. Malaysia	1.34	3.65	16	11	5
62. Nigeria	-1.28	0.76	83	80	3
63. Nicaragua	-2.74	-0.16	91	88	3
64. Netherlands	0.39	1.91	49	55	-6
65. Norway	1.29	2.54	18	34	-16
66. New Zealand	-0.11	1.29	60	70	-10
67. Pakistan	1.49	3.37	15	16	-1
68. Panama	-0.98	2.26	76	43	33
69. Peru	-0.86	1.10	73	73	0
70. Philippines	-0.02	1.93	57	54	3
71. Portugal	1.26	2.99	19	21	-2
72. Paraguay	-0.98	2.62	75	31	44
73. Rwanda	-1.16	0.95	82	73	9
74. Sudan	-2.27	-0.23	88	89	-1
75. Senegal	0.14	1.43	53	66	-13
76. Singapore	1.61	4.21	14	6	8
77. Sierra Leone	0.09	1.41	55	68	-13
78. El Salvador	-0.76	1.16	74	71	3
79. Sweden	0.63	1.79	39	59	-20
80. Thailand	1.95	4.32	13	4	9
81.Trinidad & Tobago	-2.19	0.41	87	83	4
82. Tunisia	2.47	3.44	9	15	-6
83. Turkey	0.87	3.24	33	18	15
84. Taiwan	2.55	5.03	7	3	4
85. Tanzania	0.50	2.26	44	42	2
86. Uganda	-2.47	-0.90	90	92	-2
87. Uruguay	0.45	0.99	47	75	-28
88. USA	0.84	2.07	34	49	-15
89. Venezuela	-0.82	1.15	72	72	0
90. South Africa	-0.14	1.61	62	62	0
91. Zaire	-0.94	0.58	75	81	-6
92. Zambia	-0.35	1.04	67	74	-7
93. Zimbabwe	0.92	2.77	30	27	3

APPENDIX TO CHAPTER 3

Table A3.1: Summary Statistics of Variables used in Cross-section Estimations (1980-90)					
Variable	**Obs.**	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
GDP65	88	7.612093	.957331	5.638355	9.352621
HUMAN65	79	3.691025	2.487378	0.3010	9.54
TFPG-HET	93	0.0279219	.0238988	.0492461	0.0809289
TFPG-AMG2	93	0.0017369	0.0379327	-0.1365363	0.1194063
TFPG-GMM	93	.0088144	.0260975	-.1396826	.0571727
TFPG (R&R)	93	-.0074066	.0255975	-.1467294	.0321217
SWOPEN	63	.3587302	.4445494	0	1
WDR	38	1.973684	.8849139	1	4
LEAMER	49	-0.3157143	.6307403	2.8	.22
BLACK	87	.3159494	.4766939	0	2.7085
TARIFF	80	.175875	.1763449	.012	1.319
QR	78	.2080128	.2476748	0	.888
HERITAGE	69	5.18e-09	1	-2.176814	.9852949
CTR	51	.0281971	.0255553	.0003102	.1023978
WOLF	62	39.01613	21.71386	1	74
PCF	40	-.0419719	1.201321	-2.148262	3.014643
MDUTY	76	11.40951	8.360691	.0216256	35.9512
XDUTY	52	4.663077	6.601559	0	28.91
DUTY	52	.1870301	.1192577	.0016736	.5705495
HERITAGE 2	80	3.725	1.386873	1	5
PROPERTY	86	2.604651	1.140475	1	5

Notes: The three TFPG variables relate to TFP Growth.

Table A3.2: Summary Statistics of Variables used in Panel Estimations (5-YEAR AVERAGES)					
Variable	Obs.	Mean	Std. Dev.	Minimum	Maximum
GDP^0	546	7.7983	1.0023	5.5491	9.9055
$HUMAN^0$	498	1.2205	0.9015	-2.5903	2.7778
TFPG-HET	557	0.03894	0.0255	-0.0605	0.2033
TFPG-AMG2	557	0.01144	0.0406	-0.1439	0.2059
TFPG-GMM	557	0.01386	0.0308	-0.1550	0.1702
OPEN1	545	3.8464	0.6145	1.8721	5.9302
SWOPEN	498	0.3808	0.4726	0	1
PRIDEV	545	4.0868	0.4360	2.5473	5.658
DUTY	257	2.6439	2.2787	-5.2350	6.5632

Notes: The three TFPG variables relate to TFP Growth. All other variables are in logs except SWOPEN.

Table A3.3: Summary Statistics of Variables used in Panel Estimations (ANNUAL)					
Variable	No. of Obs.	Mean	Std. Deviation	Minimum	Maximum
H	2319	1.2506	0.8738	-2.5903	2.7778
TFPG-HET	2760	0.0384	0.0279	-0.1128	0.2402
TFPG-AMG2	2760	0.0110	0.0640	-1.0012	0.3240
TFPG-GMM	2760	0.0208	0.0552	-0.5459	0.3157
OPEN1	2793	3.8492	0.6253	1.6074	6.0483
SWOPEN	2543	0.3842	0.4865	0	1
PRIDEV	2793	4.0843	0.4605	2.2492	6.6487
DUTY	1145	2.5600	2.2984	-5.6293	8.0215

Notes: Same as in Table A2

APPENDIX TO CHAPTER 4

Appendix 4.1

Technical Notes Explaining The Estimation of the Endogenous Threshold Value

Below we explain the principle by which the threshold value in the endogenous threshold framework based on Equation 4.4 is derived. The procedure also applies to 4.4′ analogously.

First let $S_n(\gamma, \beta(\alpha))$ represent the sum of squared errors for equation (4.4), where n is the sample size, and where the β parameters depend on the threshold values α and α'. Because of this dependence, S(.) is not linear in the parameters but is really a step function, with steps occurring at some distinct values of the threshold variable NATBARR. However, conditional on a threshold value, say α_0, S(.) is linear in γ and β which means that it can be minimised to yield the conditional OLS estimators $\hat{\gamma}(\alpha_0)$ and $\hat{\beta}(\alpha_0)$. We next denote the resulting concentrated sum of squared errors function by $S(\alpha_0)$. Essentially the minimisation problem involves searching over values of α equalling the (at most n) distinct values of $NATBARR_{it}$ in the sample. The estimator of the threshold is the value of α that yields the smallest sum of squared errors. That is:

$$\textbf{(A4.1)} \qquad \hat{\alpha} = \arg\min_{\alpha} S(\alpha).$$

If n is large the optimisation search may be numerically intensive. Hansen (1999) demonstrates that limiting the search to specific quantiles rather than over all values of the threshold variable greatly reduces the number of regressions performed in the search. Moreover, it yields almost identical results to the more numerically intensive search. The minimisation problem in (A4.1) is solved by a grid search over 99 natural barriers (and institutional quality) percentiles, respectively.

Appendix 4.2

Table A4.1: Summary Statistics				
Variable	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
TFPG-AMG2	0.002	0.032	-0.165	0.163
GDP^0	7.921	1.018	5.694	9.905
OPEN1	3.881	0.608	1.934	5.935
OPEN2	0.381	0.470	0	1
OPEN3	-4.108	0.451	-5.750	-2.548
OPEN4	-2.703	2.326	-6.786	6.593
INSTIT	5.655	2.793	0	10
NATBARR	1.113	0.065	1.006	1.667

Table A4.2 : Correlation Matrix								
	TFPG-AMG2	**GDP^0**	**OPEN1**	**OPEN2**	**OPEN3**	**OPEN4**	**INSTIT**	**NATBARR**
TFPG-AMG2	1.00							
GDP^0	0.007	1.00						
OPEN1	0.123	0.176	1.00					
OPEN2	0.291	0.621	0.261	1.00				
OPEN3	0.152	-0.691	-0.132	-0.474	1.00			
OPEN4	0.071	0.672	0.295	0.549	0.558	1.00		
INSTIT	0.135	0.706	0.152	0.605	0.545	-0.605	1.00	
NATBARR	-0.109	-0.559	-0.069	-0.402	-0.417	0.407	-0.403	1.00

APPENDIX 4.3

Table A4.3: Natural Barrier Value by Country and Time

Country	OPEN1 Time Period				OPEN4 Time Period			
	1970-74	1975-79	1980-84	1985-89	1970-74	1975-79	1980-84	1985-89
Switzerland	1.017	1.026	1.020	1.010		1.026	1.020	1.010
Norway	1.026	1.026	1.023	1.030		1.026	1.023	1.030
Austria	1.029	1.032	1.041	1.047	1.029	1.032	1.041	
Canada	1.030	1.026	1.025	1.025	1.030	1.026	1.025	1.025
Belgium	1.042	1.042	1.031	1.031		1.042	1.031	1.031
Ireland	1.050	1.050	1.050	1.050	1.050	1.050	1.050	1.050
Mexico	1.050	1.051	1.048	1.046		1.051	1.048	1.046
Denmark	1.057	1.032	1.046	1.044		1.032	1.046	1.044
Tunisia	1.057	1.063	1.063	1.072		1.063	1.063	1.072
Germany	1.058	1.035	1.031	1.026	1.058	1.035	1.031	1.026
U.S.A.	1.062	1.060	1.047	1.044	1.062	1.060	1.047	1.044
Netherlands	1.063	1.057	1.056	1.056	1.063	1.057	1.056	
Singapore	1.068	1.063	1.060	1.060				
France	1.069	1.043	1.052	1.036		1.043	1.052	1.036
Cameroon	1.069	1.091	1.100	1.100		1.091	1.100	1.100
Finland	1.070	1.049	1.049	1.045		1.049	1.049	1.045
Israel	1.074	1.074	1.077	1.080	1.074	1.074	1.077	1.080
Sweden	1.075	1.064	1.021	1.023	1.075	1.064	1.021	1.023
New Zealand	1.077	1.089	1.082	1.082	1.077	1.089	1.082	1.082
Italy	1.083	1.073	1.069	1.069	1.083	1.073	1.069	1.069
South Africa	1.083	1.075	1.078	1.088		1.075	1.078	1.088
Malaysia	1.083	1.106	1.107	1.105	1.083	1.106	1.107	1.105
Algeria	1.085	1.098	1.099	1.102				
Trinidad & Tobago	1.085	1.072	1.098	1.111		1.072	1.098	
China	1.090	1.090	1.090	1.090				1.090
Australia	1.092	1.094	1.121	1.093	1.092	1.094		1.093
Pakistan	1.096	1.096	1.095	1.095	1.096	1.096	1.095	1.095
Nigeria	1.097	1.108	1.107	1.107		1.108	1.107	1.107
Great Brit.	1.097	1.072	1.068	1.044	1.097	1.072	1.068	1.044
Panama	1.098	1.104	1.115	1.127		1.104	1.115	1.127
Sierra Leone	1.099	1.099	1.125	1.136		1.099	1.125	1.136
Egypt	1.099	1.106	1.111	1.111		1.106	1.111	1.111
El Salvador	1.099	1.085	1.108	1.110				
S. Korea	1.100	1.071	1.072	1.056		1.071	1.072	1.056
Myanmar	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100
Guatemala	1.101	1.099	1.083	1.106		1.099	1.083	
Spain	1.102	1.076	1.058	1.060		1.076	1.058	1.060
Nicaragua	1.106	1.109	1.069	1.115		1.109	1.069	1.115
Morocco	1.106	1.136	1.131	1.099		1.136	1.131	1.099
Guyana	1.107	1.101	1.100	1.100		1.101	1.100	1.100
Sudan	1.107	1.101	1.097	1.066	1.107	1.101	1.097	
Cyprus	1.107	1.109	1.109	1.102		1.109	1.109	1.102
Turkey	1.109	1.053	1.053	1.057	1.109	1.053	1.053	1.057
Thailand	1.110	1.112	1.110	1.108		1.112	1.110	1.108
Uganda	1.110	1.110	1.111	1.110	1.110	1.110	1.111	1.110
Iraq	1.110	1.111	1.110	1.110				

Sri Lanka	1.111	1.111	1.111	1.111		1.111	1.111	1.111
Costa Rica	1.112	1.111	1.109	1.107		1.111	1.109	1.107
Venezuela	1.112	1.119	1.110	1.110	1.112	1.119	1.110	1.110
Honduras	1.114	1.101	1.104	1.148	1.114	1.101	1.104	
Philippines	1.114	1.087	1.075	1.068		1.087	1.075	1.068
Malta	1.115	1.111	1.109	1.111	1.115	1.111	1.109	1.111
Portugal	1.115	1.105	1.102	1.103				
Cote d'Ivoire	1.116	1.173	1.235	1.244			1.235	1.244
Bangladesh	1.117	1.119	1.127	1.109	1.117	1.119	1.127	1.109
Mozambique	1.120	1.120	1.120	1.120				
Indonesia	1.121	1.130	1.120	1.120	1.121	1.130	1.120	1.120
Jordan	1.122	1.123	1.124	1.124	1.122	1.123	1.124	1.124
Brazil	1.127	1.105	1.090	1.094			1.090	1.094
Iceland	1.128	1.100	1.100	1.100		1.100	1.100	1.100
Greece	1.130	1.130	1.130	1.130		1.130	1.130	1.130
Ghana	1.134	1.096	1.069	1.069		1.096	1.069	1.069
Senegal	1.135	1.125	1.144	1.144	1.135	1.125	1.144	
Colombia	1.136	1.110	1.110	1.097	1.136	1.110	1.110	1.097
Kuwait						**1.147**	1.154	1.153
Chile	1.143	1.135	1.086	1.091		1.135	1.086	1.091
Malawi	1.145	1.136	1.135	1.667		1.136	1.135	1.667
Kenya	1.147	1.154	1.157	1.163		1.154	1.157	1.163
Zimbabwe	**1.150**	**1.150**	**1.150**	**1.150**		1.150	1.150	1.150
Ecuador	1.151	1.135	1.152	1.138		1.135	1.152	1.138
India	1.152	1.127	1.117	1.117			1.117	1.117
Tanzania	1.153	1.149	1.176	1.176		1.149	1.176	1.176
Haiti	1.156	1.166	**1.150**	**1.150**		1.166	1.150	1.150
Iran	1.158	1.176	1.160	1.160		1.176	1.160	1.160
Dominican Rep.	1.160	**1.150**	**1.150**	**1.150**	1.160	1.150	1.150	1.150
Jamaica	1.161	1.178	1.142	1.139		1.178	1.142	1.139
Mauritius	1.168	1.193	1.170	1.115		1.193	1.170	1.115
Zaire	1.169	1.159	1.160	1.160				
Japan	1.172	1.114	1.080	1.078		1.114	1.080	1.078
Uruguay	1.177	1.100	1.075	1.048		1.100	1.075	1.048
Paraguay	1.177	1.196	1.163	1.144				
Bolivia	1.182	1.099	1.146	1.161				1.161
Ethiopia	1.192	1.218	1.175	1.186	1.192	1.218	1.175	1.186
Zambia	1.197	1.202	1.277	1.006		1.202	1.277	1.006
Madagascar	1.227	1.257	1.205	1.205		1.257	1.205	1.205
Peru	1.239	1.200	1.200	1.200		1.200	1.200	1.200
Rwanda	1.254	1.342	1.435	1.436		1.342	1.435	1.436
Argentina	1.259	1.106	1.105	1.090			1.105	1.090
Mali	1.259	1.392	1.429	1.429		1.392	1.429	1.429

Source: Girma, Henry, Kneller and Milner (2003); Table B1.

Notes:

1. Light grey squares indicate observations in the lower threshold group
2. Medium grey squares when observations lie in the uncertainty range (the confidence interval)
3. Dark grey squares when observation lie in the upper threshold group; white squares indicate missing data for the openness variable
4. Bold numbers indicate the location of the estimated threshold value.

APPENDIX TO CHAPTER 5

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 based on the perpetual inventory method using the pair of equations immediately below. *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 regarding 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 we set equal to 10 per cent.

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

Data on physical capital investment for the developing countries in our sample were obtained from World Bank's World Development Indicators CD ROM 2000.

Estimates of the stock of machinery R&D (R_{it}) in OECD countries necessary to measure technology transfer were calculated in a similar manner (i.e. based on the perpetual inventory method) to the stock of physical capital. The corresponding pair of equations for computing the R&D stock is shown below:

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

In this instance, R refers to the machinery R&D stock, Δ to the depreciation rate (again set at 10%), RD machinery R&D investments and g^{RD} is the average annual growth rate of R&D over the period. Initial R&D stock was also computed in a manner analogous to initial physical capital.

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. These data were available for most countries for the period 1970/3 to 1995. This 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 cumulative R&D stock was then weighted by the ratio of the developing countries' machinery imports from developed countries to the GDP of the 15 OECD countries.

Capital Goods Imports

Capital goods import data, Machinery and Transport Equipment (SITC Rev. 2, Sec 7) imports, for 89 developing countries were extracted from the United Nations COMTRADE Database. The data cover the period 1970-2001. The machinery data are also disaggregated by type (e.g. Agricultural; Textile and Leather Making; Metalworking etc.) and are in current US $.

Human Capital

Data on human capital measured as average years of schooling for the population twenty-five and over were obtained from Barro and Lee (2000).

Table A5.1: Summary Statistics of Variables used in Estimation of Stochastic Production Frontier					
Variable	**Obs.**	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
GDP	1414	23.302	1.695	19.088	27.526
K	1414	23.803	1.719	17.906	28.130
L	1414	15.402	1.510	12.560	20.426
H	1414	1.150	0.637	-1.073	2.326
RD^m (foreign R&D stock weighted by machinery imports)	1414	15.985	1.789	10.134	20.706
KM (Machinery Imports)	1414	12.706	1.759	7.055	17.166
SWOPEN	1414	0.383	0.486	0	1
TROP	1414	0.708	0.455	0	1
AY (Share of Agriculture in GDP)	1414	2.826	0.914	-2.149	4.192

Note: All variables are in logs except SWOPEN and TROP.

Table B5.3: Average efficiency scores and Standard Deviation by Country and Year[1] (1970-1998)

	1970	1980	1990	1995	mean	Std. Dev.	obs
Algeria	0.98	0.91	0.83	0.80	0.890	0.060	29
Argentina	0.89	0.90	0.88	0.96	0.915	0.039	29
Bangladesh		0.51	0.81	0.95	0.783	0.157	19
Bolivia			0.87	0.95	0.878	0.075	13
Brazil	0.76	0.93	0.93	0.96	0.913	0.046	29
Cameroon		0.85	0.84	0.80	0.883	0.051	24
Sri Lanka	0.49	0.58	0.78	0.95	0.700	0.153	29
Chile	0.74	0.89	0.95	0.97	0.877	0.091	29
China		0.89	0.95	0.95	0.937	0.020	24
Colombia	0.89	0.93	0.95	0.94	0.923	0.021	29
Congo, Rep.			0.71	0.86	0.773	0.130	14
Congo, Dem. Rep.	0.96	0.94	0.84	0.83	0.913	0.052	28
Costa Rica	0.76	0.84	0.91	0.96	0.866	0.059	29
Benin			0.71	0.87	0.706	0.184	17
Dominican Republic	0.59	0.75	0.83	0.94	0.805	0.105	29
Ecuador	0.47	0.69	0.90	0.96	0.769	0.147	29
El Salvador	0.88	0.87	0.87	0.94	0.869	0.069	29
Gambia, The		0.34	0.67	0.93	0.592	0.218	24
Ghana	0.72	0.69	0.86	0.94	0.775	0.118	29
Guatemala	0.66	0.83	0.92	0.94	0.833	0.085	29
Honduras	0.34	0.54	0.88	0.92	0.670	0.205	28
Hong Kong		0.96	0.97	0.94	0.956	0.016	18
India	0.94	0.92	0.95	0.94	0.933	0.015	29
Indonesia		0.90	0.95	0.95	0.925	0.041	19
Iran, Islamic Rep.		0.85	0.92	0.98	0.908	0.050	20
Jamaica	0.45	0.57	0.90	0.95	0.710	0.182	29
Jordan		0.97	0.93	0.91	0.933	0.046	23
Kenya		0.64	0.85	0.93	0.815	0.113	20
Korea, Rep.	0.99	0.95	0.96	0.94	0.961	0.016	28
Malawi		0.33	0.55	0.76	0.487	0.214	26
Malaysia	0.79	0.91	0.96	0.94	0.906	0.053	28
Mali		0.47	0.72	0.88	0.701	0.167	20
Mauritius		0.86	0.91	0.93	0.922	0.023	23
Mexico	0.98	0.97	0.93	0.87	0.943	0.043	29
Mozambique		0.56	0.60	0.88	0.640	0.163	18
Nicaragua	0.48	0.62	0.78	0.95	0.705	0.124	27
Niger		0.30	0.55	0.82	0. 558	0.223	19
Pakistan		0.69	0.91	0.95	0.782	0.144	27
Panama		0.82	0.90	0.93	0.890	0.045	19
Papua New Guinea	0.56	0.62	0.70	0.94	0.712	0.107	28
Paraguay	0.65	0.90	0.95	0.94	0.870	0.091	29
Peru	0.94	0.94	0.85	0.94	0.933	0.026	22
Philippines	0.67	0.85	0.95	0.95	0.865	0.078	29
Rwanda	0.93	0.79	0.60	0.39	0.683	0.166	29
Senegal	0.88	0.79	0.85	0.88	0.857	0.034	29
Singapore	0.97	0.95	0.95	0.97	0.957	0.012	28
Zimbabwe		0.92	0.93	0.84	0.874	0.063	24
Syrian Arab Republic		0.87	0.96		0.869	0.078	17
Thailand	0.59	0.81	0.95	0.96	0.832	0.133	28
Togo		0.53	0.68	0.78	0.679	0.106	19

Trinidad &Tobago			0.94	0.93	0.926	0.030	14
Tunisia	0.94	0.95	0.94	0.95	0.945	0.013	29
Uganda			0.83	0.92	0.861	0.050	17
Egypt, Arab Rep.		0.92	0.93	0.97	0.921	0.039	24
Uruguay	0.96	0.94	0.94	0.94	0.927	0.046	29
Venezuela	0.96	0.80	0.93	0.96	0.892	0.077	29
Zambia	0.40	0.52	0.76	0.91	0.656	0.190	29
	0.756	0.774	0.856	0.910	0.830	0.154	1414

1. The mean, standard deviation and number of observations for each country is for the entire period 1970-1998.