Dana Hájková

Measurement of Economic Variables

Dissertation

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CERGE
Center for Economics Research and Graduate Education
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ABSTRACT

The research focuses on the problems and economic consequences connected with the measurement of economic variables. The core of the text consists of three chapters that in succession analyze the issues associated with the measurement of economic growth, multi-factor productivity and capital input into production.

Measurement problems are described for each variable, suggestions about correct measurement are made and the consequences of mismeasurement quantified. The analysis of the measurement of growth in GDP per capita is carried out for a wide international dataset and for three main sources for this variable. Issues related to multi-factor productivity are presented for seven OECD countries. The study of productive capital input measurement concentrates on the Czech Republic and proposes an experimental measure of capital services.

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CONTENTS

GENERAL INTRODUCTION

The basic concern of any empirical work is to employ statistical data that correspond to the notion of the theoretical variables in the model. Economic analysis faces the difficulty that the fit between the theoretical concept and the available statistics is often not perfect. Using any statistical data should always be accompanied by a careful check to determine whether the data describe precisely the phenomenon analysed. Many essential economic variables are unobservable, or desirable statistics are not collected, because of excessive cost. In empirical research, imperfect proxies are often used in place of the theoretical concept. Frequent use of some statistics in research may also develop as they come to be considered as a default for a particular concept. However, without constant and sufficient checking, a risk may arise that they are not used correctly.

Recent decades have seen tremendous improvements in the availability, quality and harmonization of economic statistics, which has been called for by the increased need for cross-country comparability of data in a globalizing world. Statistics are compiled at the supra-national level, comprehensive work is often done to clean them, and a check for internal consistency is undertaken to create user-friendly databases. High quality databases have also emerged thanks to academic work. This facilitates the evaluation of economic policies and institutions, creating benchmarks for best practices, as well as greatly facilitates empirical research in many important areas (economic convergence and factors of growth are the ones touched upon in this dissertation).

Harmonized statistics and ready-made databases have a clear appeal because of their immediate usability. But this comes at a certain cost. Harmonization means that some country-specific information is eliminated. Processing the data and adjusting them in order to improve their comparability may also alter the information in the data. The researcher must then carefully analyze whether such statistics are still the right proxy for the analyzed phenomenon. They may even become unusable for a particular purpose, if the adjustments in the database are correlated with the analysed phenomenon or if an important part of the information was omitted in the process of harmonization. Furthermore, a risk exists that systematic adjustments made to the data may actually create additional patterns; the researcher would then not know whether the phenomenon found in the data is not a sole statistical artefact. It is then the task of the researcher to evaluate whether ready-made statistics fully capture the variation assumed in the model. If it is not the case, one has to be aware of it and interpret the results accordingly.

This dissertation selects three economic variables that are often used in empirical analyses of economic convergence and factors of economic growth. These are economic growth, multi-factor productivity and capital input to production. The analysis points out some immediate problems a researcher faces and should acknowledge when working with these seemingly common and easy statistics. Further, the analysis attempts to quantify the effects of neglecting some important assumptions underlying the use of those data.

The first variable, economic growth, is often approximated by growth in GDP per capita. We take this approximation for granted, but analyze three main sources of international data for GDP per capita growth. These international databases are constructed with different aims, which imply differences in the treatment of the data. The procedures are well-documented in the manuals of those databases. Still, it seems that there is a lot of uninformed choice by users of the databases, which might affect the reliability of empirical results.

Secondly, statistics on multi-factor productivity are usually not readily available from statistical offices or international databases. Growth in multi-factor productivity is, however, widely used as a proxy for the important concept of technological progress. In growth accounting, it is measured as residual growth after the contributions of factors of production (capital and labor) have been accounted for. Rather strong assumptions of the simple model imply that the measure of multi-factor productivity is still to a certain extent obscured by the effects of unmodelled factors. One part of economic research concentrates on stripping the broad measure of factors which should not be a part of it. A researcher using data on multi-factor productivity needs to acknowledge a certain portion of uncertainty, however, especially if country measures are not computed using a single methodology that would correctly account for the variation in relevant variables.

Capital input into production, the third economic variable analysed in this dissertation, is a tricky variable in growth accounting. The theoretical concept is a flow of services of tangible and intangible capital. These flows are hard to measure since only a small part of them is explicitly intermediated by the market. Existing measures of stock of capital do not capture the variation in the contribution of capital well. Description of the latter can be improved on by using the information relevant to the productivity of capital assets and constructing an estimate of flow of capital services. In this dissertation the effects of the measurement of capital input are assessed from an international comparability point of view as well as by constructing an experimental measure of capital services for one country.

The main questions we attempt to answer are:

- Is there any difference between the measures of GDP per capita growth that can be downloaded from three international databases, namely International Financial Statistics, World Development Indicators, and Penn World Table? What is the cause of these differences and does this imply something about the use of the respective measures in a general context? What would be the consequences of incorrect use?
- What is the difference between the theoretical concept of multi-factor productivity and the empirical measures of it? What are the main challenges for measuring multi-factor productivity and the consequences for comparing developments in multi-factor productivity across time and across countries?
- Is it possible to construct a measure of the flow of capital services in the Czech Republic, i.e. the correct measure of capital input to production if contributions of economic growth factors are to be disentangled, from publicly available data? What is the impact of moving towards a better measure of capital input on measured multi-factor productivity in the Czech Republic?

The dissertation consists of three papers that address the issues associated with the measurement of economic growth, the measurement of multi-factor productivity growth, and the measurement of capital input into production. In each of the papers, the theoretical concept for the variable considered is presented and the analysed measurement problems outlined. The emphasis is on showing the consequences of inaccurate measurement. In the first two papers, the analyses are performed using evidence from a cross-country comparison. The analysis of the measurement of GDP per capita growth is carried out for a wide international dataset and three main international databases containing information on this variable. The issues related to multi-factor productivity are presented for seven OECD countries. The study of productive capital input measurement concentrates on the Czech Republic and proposes an experimental measure of capital services.

Motivation

The analysis of the measures of GDP per capita growth was motivated by the fact that relevant data downloaded from different databases appear to be systematically different, yet discussion of the choice of database for GDP per capita growth is missing in most papers using those measures. When examined, the three most commonly used international sources for GDP per capita growth, i.e. the International Financial Statistics (IFS) of the International Monetary Fund, the World Development Indicators (WDI) of the World Bank and the Penn World Table (PWT) of the Center for International Comparisons at the University of Pennsylvania, do not imply matching growth rates for this variable. Behind these differences lie the different aspirations as to what the published numbers should describe and the corresponding treatment of the data. In particular, the aim of Penn World Table is to provide a set of internationally comparable statistics. For this purpose, a set of international prices instead of national prices is used as weights in the aggregation across expenditure categories. The literature points out some possible effects, like a Gerschenkron effect or a spurious correlation effect that such treatment can have on subsequent analysis. The treatment of the GDP data thus predetermines its optimal use. The aim of this research is thus to evaluate the differences among those databases and their possible impacts on empirical results.

Issues related to multi-factor productivity measurement are analysed because of the complexity of this seemingly simple measure. In growth accounting, it is quantified as a residuum, and as such, its value and variation is influenced by model specification and its quality impaired by errors of measurement at the level of all other variables. For instance, it has been long established that the variability of each production input should be taken into account when computing the growth of multi-factor productivity. This is, however, often neglected and production factors are regarded as homogeneous. If simplifying assumptions of some sort are made, often because of practical problems with measurement, their consequences must be acknowledged and taken into account when interpreting the resulting measures. This holds for analysing one country in time and, similarly, for any meaningful comparison among countries. The present research thus investigates several selected issues that should be considered when multi-factor productivity growth is analysed.

Based on previous research, it is clear that if a correct account of capital contribution to changes in aggregate production is to be made, one cannot measure it as the changes in capital stock. Instead, a measure of the changes in the flow of capital services that derive from the existing capital stock should be used. In the Czech Republic, like in many other countries, the measure of the flow of capital services is not available from the national statistical office. This means that the estimates of the economic variables that should in theory use the capital contribution to aggregate production, like multi-factor productivity, for instance, are biased. Given the public availability of statistical data, it is worth constructing an experimental measure of capital services; this is done in the final paper.

Main findings and conclusions

We establish that important differences exist among the annual GDP per capita growth rates as implied by IFS, PWT and also WDI. This is mainly due to the adjustments or construction of the underlying variables in PWT and WDI, which reflect the different aims the measures are to serve. In the case of PWT, the aim of which is to better reflect cross-country variability in levels, the time variation is altered; as a consequence, it is different from that implied by national accounts. Based on theory, the most appropriate variable to measure economic growth in time series as well as cross-section is the growth of real GDP from the IFS, since this variable contains the national price structure that actually influenced the decisions of the agents in the economy. This variable should be combined with purchasing-power-parity adjusted initial economic income levels in the analyses of economic convergence.

We find that the difference between IFS and PWT implied GDP per capita growth corresponds to the pattern of a country's development and time. No evidence of the Gerschenkron effect or spurious correlation is found in the PWT data, but we find some support for the effect of imposed price structure on measured growth, which is consistent with convergence under non-decreasing prices. We find that the results of selected studies are sensitive to replacing the study's original dependent variable (GDP per capita or per worker from PWT or WDI) with our preferred measure based on IFS with the PPP-adjusted initial income variable based on PWT.

When analyzing the measurement of multi-factor productivity in growth accounting, we keep in mind that this measure contains effects of technological progress as well as the effects of imperfect competition, non-constant returns to scale and other factors not captured in the growth accounting. We emphasize that it may also be influenced by the specification of the underlying model as well as by various measurement errors.

Several measurement problems persist in the literature that have been long recognized but remain an obstacle to transparent cross-country and time comparisons of multi-factor productivity. We attempt to assess some of them, primarily those related to the contributions of labor and capital inputs to production. We find that a substantial impact on the measured multi-factor productivity growth can originate from inaccurately accounting for the quantity of labor contribution by total employment instead of total hours worked. Important effects are also observed when changes in capital composition are not fully accounted for and when different assumptions concerning the marginal productivity of factors of production are made.

In the last paper, we concentrate in detail on the measure of capital services, which is expected to better account for productive capital input than a simple measure of net capital stock that is often incorrectly used for this purpose. We construct two experimental measures of capital services for the Czech Republic, both indicating consistently higher contributions of capital to economic growth than would be measured by changes in net capital stock.

The analysis in this dissertation uses several specific examples to show the importance of care in preparing data for empirical work. While this seems obvious, discrepancies between the analysed data and the analysed theoretical concept are sometimes not given enough attention. This may be caused by a desire to maintain continuity and comparability with previous research, but the reliability of results is at risk if researchers do not critically scrutinize the underlying data.

Choices and decisions regarding empirical data are rarely straightforward; often one has to face a trade-off among important characteristics of the data, like coverage, detail, timeliness, actual proximity to the theoretical concept, etc. Sometimes, one has to resort to crude proxies. Decisions can still be valid, if they are based on a process that includes weighing the pros and cons. A good understanding of the aims and assumptions underlying statistics used in research is a prerequisite for accurately interpreting any results based on them.

CHAPTER I: MEASUREMENT OF ECONOMIC GROWTH: ADDITIONAL EVIDENCE ON THE LEFT-HAND-SIDE VARIABLES IN GROWTH REGRESSIONS

(with Jan Hanousek and Randall K. Filer)

Abstract

There are observable differences among the growth rates of GDP per capita based on data from the three most commonly used databases, namely International Financial Statistics (IFS), World Development Indicators (WDI) and Penn World Table (PWT). Using a wide international dataset, we find significant differences in the growth rates that are mainly due to the adjustment for cross-country comparability of GDP per capita levels. Importantly, these differences are correlated with the level of development. We replicate six recent studies of growth determinants and find their results sensitive to the choice of data.

1. Introduction

What drives economic growth has been a persistent question for economists ever since they began aggregating economic variables and began to analyse the economy as a whole. The most recent wave of interest in this question came as a response to the work of Baumol (1986), Romer (1986) and Lucas (1988).

Despite its well-known drawbacks,[1] the level of GDP per capita is nevertheless used almost exclusively to compare standards of living among countries, and the growth of GDP per capita is seen as evidence of a country's increasing wealth. The income dispersion among countries measured by GDP per capita is large and persistent, and thus GDP growth is considered to be the key channel in achieving some level of convergence among countries in the world economy. The attention of many development economists is thus turned towards the determinants of economic growth and towards policies that may enhance it.

The size of the growth literature is overwhelming; typing "economic growth" into the Econlit database gives us nearly 30 thousand entries. Without close scrutiny, a researcher can be rather confused to learn that different studies of the same phenomenon show different results.[2] Levine and Renelt (1992), Sala-i-Martin (1997), Kalaitzidakis et al. (2000) or Islam (2003) find that results are often sensitive to specification, time span or country coverage. A significant part of this inconsistency naturally stems from the improvement of analytical methods and improvements in variable measurement.

Nevertheless, one very important factor influencing the results may be the choice of a statistical database and of the particular measure of economic growth itself. The sources for data on economic growth have generally been three databases: IFS, WDI and PWT (or the Summers and Heston dataset). The development of these databases has greatly contributed to the expansion of economic growth research. However, it can be said that each of them has a slightly different purpose which is also reflected in how their data is

[1] See e.g. World Bank (1997 and 2005).

[2] Compare, for instance, Temple (1999, Figure 1) and Nuxoll (1994, Figure 1).

treated. Seemingly identical data from different databases may thus be suitable for different purposes. Although this is well documented in the manuals to each of these databases, the caveats are sometimes ignored.

This study explores to what extent ignoring such caveats regarding the measures of economic growth (i.e. the dependent variable in growth regressions) may undermine the reliability of the research results. This analysis is based on the work of Filer et al. (2004) and Hanousek et al. (2007). It describes the databases of economic data typically used by economists for the choice of left-hand-side variables when analyzing determinants of growth. A wide sensitivity analysis is presented that examines the robustness of several growth studies to the choice of database for the dependent variable.

Another important decision facing an economist is whether the dependent variable should reflect the concept of gross domestic income or gross domestic product, or whether "national" variables should be used. Interpreting the results of economic studies may thus be complicated by the potentially different quality of the underlying data, perhaps related to different income levels. These issues, though central to any economic research, are beyond the scope of the present study and are left for further research.

Naturally, there has been previous work emphasizing the importance of prudence when choosing data for hypothesis testing. Levine and Renelt (1992) and Sala-i-Martin (1997) report sensitivity analyses regarding the inclusion of variables in growth regressions. Atkinson and Brandolini (2001) analyze the "promises and pitfalls" of the secondary data on inequality from three different databases. Implications resulting from differing price levels for measuring income levels and growth are discussed in Nuxoll (1994) and Temple (1999); the latter study also discusses a broader range of growth regression problems. Nordhaus (2007) discusses the suitability of alternative measures of output for different modelling frameworks and comes up with the same conclusion about the preferred combination of data for calculating convergence among countries as is presented in this paper.

2. Data

In the empirical work on growth determinants done since 1990, three databases have served as workhorses supplying data for wide cross-section or cross-section time-series comparisons: the IFS compiled by the International Monetary Fund, the WDI collected by the World Bank and the PWT compiled originally by Robert Summers and Alan Heston (1988 and 1991).[3] The aggregate economic output variable from PWT is used by Barro (1991) as well as Sala-i-Martin (2002); Rousseau and Wachtel (2000) use WDI, and Levine et al. (2000) combine information from both these databases. Filer et al. (2004) report that in a sample of seventy-five recent studies that could be included in the reading list for a graduate-level course on growth determinants, three-quarters use the PWT data, 15 % the WDI data and 10 % the IFS data.

The analysis in this paper concentrates on the variable GDP per capita growth. GDP per capita is either directly extracted from the database concerned, or is calculated based on other variables from the database. While calculating yearly growth rates of per capita real GDP in local currency is rather straightforward, calculating the average growth rates for a certain period may be tricky, if breaks in comparability are present in the time series. This

[3] The current version of PWT: Alan Heston, Robert Summers and Bettina Aten, Penn World Table Version 6.1, Center for International Comparisons at the University of Pennsylvania (CICUP), October 2002.

paper thus also devotes attention to this issue and where relevant presents a sensitivity analysis.

Details on the analysed databases, including methodology, time coverage, and variable availability, are provided below.

International Financial Statistics

International Financial Statistics is based on the System of National Accounts (SNA) and provides data for member countries of the International Monetary Fund, i.e. 175 countries since 1945. Many of the time series are much shorter, however. The number of variables available for each country depends on the dissemination method of each country. Basically, no adjustment is done to the data; only the methodology changes or other breaks in the series are indicated. GDP is generally presented as the sum of final expenditures; the definition of the aggregates may differ according to the dissemination standards adopted by each country. Statistical discrepancies between aggregate GDP based on expenditure flows and GDP measures based on production or income accounts are not explicitly presented. Real values of GDP are provided either as volume at reference year price levels or as volume indexes derived from the GDP volume series reported by national compilers. The IFS database (as the only one of the three compared) also contains a description of possible problematic points in the data (this is indicated by the blue-colored numbers and comments explaining the reason for the warning).[4] For the real GDP variable, there are three possible caveats: break in comparability, splice of series, and new or changed data.

World Development Indicators

The WDI contains data for 207 countries starting from the year 1960. National accounts data come from two sources: data obtained from official sources and current reports collected by the World Bank. The WDI manual reports some adjustments made in the balance of payments to account for differences between fiscal and calendar year. Gross domestic product is obtained by summing the gross value added by all resident producers in the economy plus product taxes minus subsidies. Real GDP is reported in constant local currency units, constant US dollars and constant international dollars (PPP measure).

Penn World Table

The Heston-Summers-Aten dataset, or Penn World Table??, is aimed at providing valid cross-country comparability of national accounts data. The dataset is processed by the Center for International Comparisons at the University of Pennsylvania. The characteristics of the data have been discussed most recently by Heston and Summers (1996), and the dataset is described in more detail in Summers and Heston (1988, 1991). The Penn World Table is based on data from the System of National Accounts[5] and on benchmark price studies. These benchmark studies compare internationally the prices of standardized goods and create indexes based on these prices that are applied to entries in the countries' SNAs. The original dataset of this database covered 152 countries for the period 1950-1988; version 6.1 used in this analysis covers 168 countries and extends to the year 2000. By definition, the growth rates of GDP in the PWT differ from those implied by the national accounts of each country because in the PWT international price weights are used for the growth rates of the aggregates (private consumption, private and public gross domestic

[4] Unfortunately, the text of the warning is available only when working with the database and does not carry through to the downloaded dataset, unlike the color.

[5] It draws from WDI and from the OECD for developed countries.

capital formation and public consumption) and these are likely to differ from those used by countries in their national accounts.

A summary of the available data is given in Table 1. The analysis presented below was carried out using a dataset constructed in January 2006, which contains 135 countries available from all three described databases and covers the years 1960-2000. The full list of countries and details of how the dataset was constructed can be found in Appendix 1. In the analysis, attention was also paid to the possible interaction of the differences among the databases with the level of income, which could have important implications for their use in growth regressions. A description of the income groups and the structure of the sample are presented in Table A1. 4.

Table 1: Description of databases

	IFS	WDI	PWT 6.1
Time span	1945-2004	1960-2004	1960-2000
Number of countries	176	207	168
Number of variables	Approx. 200	559	25
Variables for economic develop-ment	**GDP** **GDP volume** (constant prices) **GDP volume index** (given year=100)	**GDP** (current LCU, constant LCU, current US$, constant 1995 US$, PPP) **GDP per capita** (based on aggregate values divided by mid-year population) **GDP growth** (growth of GDP at market prices based on constant local currency. Aggregates are based on constant 1995 US$) **GNI** (current LCU, constant LCU, constant 1995 US$, current US$-Atlas method) **GNI per capita** (constant 1995 US$, PPP, Atlas method) **GNP (per capita) growth** (growth of GNP at market prices based on constant local currency. Aggregates are based on constant 1995 US$)	**Real GDP per capita** (based on current price entries using price parities and domestic currency expenditures for C,I,G) **Real GDP per capita** – Laspeyres (based on constant price entries; fixed base index with reference year 1996) **Real GDP per capita** – Chain (based on constant price entries; a chain index based on components' growth rates and their current price shares) **Growth rate of real GDP per capita** – Chain

A closer look at WDI adjustments

The great advantage of the WDI database and its appeal to development economists consists in its extensive coverage of countries and in the wide range of variables that describe development. However, with respect to the economic growth variable, some data adjustment is done before presenting the data to the public that is not widely recognized. A critical look at WDI shows that the data shows certain characteristics that would not be observed in reality.

For working with this database, it is important to note that computing real growth rates based on GDP in domestic currency and in constant and international dollars provides almost the same result. This is because conversions from local currency units to dollars (both expressions) are made with a single exchange rate relating to the base year. The resulting growth rates are, consequently, identical, or almost identical, to the single measure of GDP growth rate available from the database (Table 2).[6]

Table 2: WDI: Summary statistics of the difference from reported GDP growth of measures calculated based on real GDP level measures

Variable	Number of observations	Mean	Standard deviation	Minimum	Maximum
Constant local currency units	6128	2.29E-09	1.97E-07	-3.21E-06	2.91E-06
Constant 1995 USD	5933	1.93E-09	1.90E-07	-3.21E-06	2.91E-06
Constant 1995 international dollars (PPP)	3976	0.003385	1.649915	-39.65377	81.90303

The WDI database also contains a measure of gross national income (former gross national product), which is by some economists considered a better measure of a country's wealth than GDP.[7] The measure is obtained by summing the gross value added by all resident producers plus product taxes (less subsidies) plus net receipts of income from abroad. In order to obtain the value in PPP terms, gross national income is converted to international dollars (of the same purchasing power over GNI as the U.S. dollar in the United States) using purchasing power parity rates. Gross national income per capita is the gross national income, converted to U.S. dollars using the World Bank Atlas method[8], divided by the mid-year population.

Still, using the spatially comparable variable from WDI requires awareness of some manipulation with the data. To smooth fluctuations in prices and exchange rates, a special Atlas method of conversion is used by the World Bank to compute GNI and GNI per capita in international U.S. dollars. This applies a conversion factor that averages the exchange rate for a given year and the two preceding years, adjusted for differences in rates of inflation between the country and the G-5 countries (France, Germany, Japan, the United Kingdom, and the United States).[9] While a country's inflation is measured by the change in its GNI deflator, inflation for the G-5 countries is represented by the change in the SDR deflator that is computed as the weighted average of the G-5 deflators in SDR terms, using the weights of a country's currency in SDR (see Table 2). The fact that the G-5 deflators are computed in SDR terms leads to the weights varying in time.

Atlas conversion factor is then computed in the following way:

[6] This comparison covers all countries for which the data are available in the WDI database.

[7] PWT contains a measure of real gross domestic income that is a Laspeyres fixed-base real GDP adjusted for changes in terms of trade.

[8] This method is described below.

[9] World Development Indicators, 2000, pp. 361-362.

$$e_t^* = \frac{1}{3}\left(e_{t-2}\frac{\frac{p_t}{p_{t-2}}}{\frac{p_t^{S\$}}{p_{t-2}^{S\$}}} + e_{t-1}\frac{\frac{p_t}{p_{t-1}}}{\frac{p_t^{S\$}}{p_{t-1}^{S\$}}} + e_t\right),$$

where e_t* is the Atlas conversion factor for year t, e_t stands for the domestic currency to U.S. dollar exchange rate for year t, p_t is the GNP deflator for year t, and $p_t^{S\$}$ is the SDR deflator in U.S. dollar terms for year t. The development of the weights of G-5 currencies in the SDR basket is shown in Table 3.

Table 3: Currency weights in SDR basket

	1981-85	1986-90	1991-1995	1996-2000	2001-2005	2006-
USD	42	42	40	39	45	44
EURO					29	34
DEM	19	19	21	21		
FRF	13	12	11	11		
JPY	13	15	17	18	15	11
GBP	13	12	11	11	11	11

Source: IMF (2005).

Although the purpose of this adjustment can be some kind of correction for non-equilibrium exchange rate developments, it is also obvious that there is a moving average process applied to the data that possibly contains an autoregressive process. This data adjustment may therefore undermine the integrity of the information on economic growth in the database. Moreover, the exchange rate that is used for computing the Atlas conversion factor as well as for conversion of GDP in local currencies to U.S. dollars may be changed ad hoc if it is not deemed to correctly reflect reality. Thus a certain noise may be introduced into the data.[10] Such adjustments are reported in the *Primary data documentation* and are reproduced in Table A1. 5. In the period 1960-2000, 9.4 % of the total sample of exchange rates in the WDI database were adjusted, and for the period 1980-2000, 12.2%. Despite the improving effectiveness of international financial markets, the number of such adjustments has not been falling over time. The impact of these exchange rate adjustments on our analysed sample is summarized in Table 4.

Table 4: Shares of WDI ER adjustments in the analyzed sample in %

	All countries	High income countries	Upper middle income countries	Lower middle income countries	Low income countries
1960-2000	9.4	0	2.4	12.8	19.6
1970-2000	11.3	0	3.1	15.5	23.1
1980-2000	12.2	0	3.2	18.1	23.9
1990-2000	11.2	0	4.7	12.0	24.7

[10] The alternative rate is used when “the official exchange rate is judged to diverge by an exceptionally large margin from the rate actually applied in international transactions. This applies to only a small number of countries…” World Development Indicators, 2000, p. 362.

A closer look at Penn World Table adjustments

The Penn World Table has the ambition of introducing sensible real cross-sectional comparability in the national accounts data while preserving the time-series dimension. The process includes converting the disaggregated country's current price expenditures to a common currency unit with the help of price parities based on the set of benchmark studies of the United Nations International Comparison Program (ICP).

PWT 6.1 contains 117 benchmark countries, i.e. countries included in the ICP, and 50 non-benchmark countries. The input for computing the international prices are national price parities and expenditure shares (reportedly, for about 150 categories). The Geary-Khamis formula is used, which simultaneously calculates the international prices for each product and the countries' relative price levels (Appendix 4). Purchasing power parities for the group of non-benchmark countries are obtained by extrapolation. The relations between nominal and real shares of domestic absorption observed in benchmark countries are extrapolated to the non-benchmark countries with the use of the International Civil Service Commission index[11], Employment Conditions Abroad index, and U.S. State Department index.

This process is always done for the benchmark year; data for the interim years are obtained in the following way. CGDP ("real gross domestic product per capita", current entries) estimates in current year international prices are obtained using Geary aggregations with national expenditures on private consumption, investment and public consumption, and extrapolated price levels. For the constant price entries, the national growth rates are applied to the benchmark-year constant-price value of components, and either a fixed-base Laspeyres index or a chained index is constructed. A reconciliation process takes place which puts the estimates from the last benchmark years in line with the estimates based on the previous price studies. This is done by weighting the respective estimates according to the number of times a country participates in the benchmark studies. Constant price entries are hence obtained by summing the sub-aggregates extrapolated from the benchmark year value using the national growth rates.[12] Thus the GDP components are given a different weight than in national accounts. Implicitly, this means assuming different national relative prices than those economic agents have in fact faced.[13]

It is well-established in economic theory that the selection of a set of base prices (be it a base year or international set of prices) to compute real GDP growth rates influences the results (Gerschenkron, 1951,[14] later in the literature this effect is referred to as the "Gerschenkron effect").

The comparison of two GDP levels using one set of prices (A) can be expressed as follows:

$$\frac{GDP_{B(A)}}{GDP_{A(A)}} = \frac{\sum_i p_{iA} q_{iB}}{\sum_i p_{iA} q_{iA}} = \sum_i \frac{q_{iB}}{q_{iA}} \frac{p_{iA} q_{iA}}{\sum_i p_{iA} q_{iA}},$$

[11] United Nations, capital city price surveys.

[12] Both a fixed-base Laspeyres index as well as a chain index are constructed.

[13] Still, it can be said that the PWT's real GDP variables are, from the point of preserving time-series information, better designed than the Atlas conversion factor-based variables in the WDI. While the PWT variables preserve the growth rates of GDP components before aggregation, the design of the Atlas conversion factor impairs the time-series information and possibly brings into the process new dependencies.

[14] Gerschenkron was a Russian economist who first described this phenomenon on data from the Soviet economy in the 1930s.

A and B can be understood as labeling different countries or years; $p_{1A}....p_{IA}$ is a set of prices of A for a set of items i and q_{iA} and q_{iB} are quantities in A and B. Contributions to the measured difference between GDP_A and GDP_B will depend on the differences between individual quantities weighted by their share in expenditure basket A. The Gerschenkron effect occurs if relative prices and relative quantities move in opposite directions, i.e.

$\frac{p_{iA}}{p_{jA}} > \frac{p_{iB}}{p_{jB}}$ *if and only if* $\frac{q_{iA}}{q_{jA}} < \frac{q_{iB}}{q_{jB}}$ and implies that if the price level of an earlier year or a less developed country is used, the measured growth rate will be higher than if the price level of a later year or a more developed country is used.

The Gerschenkron effect is caused by technological development, which decreases prices. If falling prices of certain goods because of higher productivity lead to a relatively higher growth of output of these goods vis-à-vis other output, i.e. $\frac{q_{iB}}{q_{iA}} > \frac{q_{jB}}{q_{jA}}$, this may lead to underestimation of the real growth rate if a fixed-price base from later years or more developed countries A (when the relative price of these goods is lower and hence their weight in the index) is imposed, i.e.

$\frac{p_{iA}q_{iA}}{\sum_i p_{iA}q_{iA}} < \frac{p_{iB}q_{iB}}{\sum_i p_{iB}q_{iB}}$. An index with a later base year assigns less importance to those sectors where prices were falling, which may be the most rapidly expanding sectors.

Nuxoll (1994) analyses the impact of imposing a common currency unit and price structure on the levels and growth rates of countries' GDP in the Penn World Table database. He distinguishes a so-called "level effect" of base prices on the measured income gap between countries from a "spurious correlation effect" on the relation between the country's level of income. Nuxoll finds that with ICP3[15] the price structure assumed is that of a middle-income country like Hungary and Yugoslavia. More developed countries will, in the presence of opposite movements of prices and quantities, have higher growth rates and their level of "comparable income" will be relatively overstated with increasing trend in time. The level of income of less developed countries will be underestimated, with implications for growth rate as well. This is called by Nuxoll the spurious correlation effect.[16]

Nuxoll maintains that the above statements hold under the (sufficient) condition that as a country develops, relative prices of goods decrease and quantities consumed increase. While he finds some evidence of the Gerschenkron effect in the ICP3 data,[17] he reports that the difference of growth rates of countries' GDP reported by national accounts data and the Penn World Table, i.e. the domestic and the "international"[18] growth rates, is not significantly correlated with the level of income. The spurious correlation effect is thus not found in the PWT data. Nuxoll argues that this is because the sufficient condition of the

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[15] ICP3 is the benchmark study in 1975 (Kravis et al., 1982). It provides both Geary-Khamis indexes as well as bilateral indexes comparing income in two countries using the price indexes of both countries.

[16] Figure 1 in Nuxoll (1994) and a corresponding regression show a significantly positive relationship between initial income and subsequent growth when measured by the PWT data.

[17] In PWT, the Gerschenkron effect is probably less severe if the real data based on chaining method is used. This method constantly updates the weights (in time) so that the Gerschenkron effect at least is not increasing with the time dimension.

[18] International growth rate is the growth rate in international currency units, while the domestic growth rate is the growth rate implied by national accounts data.

opposite movement of relative prices and quantities is not met and that this can be partly due to the very high level of aggregation of the data in the PWT. However, regression of the international growth rate of per capita income on the domestic growth rate has a significantly positive constant and a coefficient that is significantly less than 1, meaning that when using international growth rates, these will be overstated for slowly-growing countries and understated for fast-growing countries.

Nuxoll's results only confirm the suggestions of Summers and Heston (1991) that the PWT data on level of income should preferably be used only for cross-country comparisons, while national accounts data should be used as a source for output growth rates. Heston and Summers (1996) re-emphasize this warning when pointing out the pitfalls of using benchmark price studies and PWT data in particular.[19] The consequences for output data of differences in price levels are also discussed by Temple (1999) in his review of "the new growth evidence". The author calls attention to the fact that after many years of methodological discussions about the applicability of the PWT data, many economists still use growth rates based on the PWT.[20] Nordhaus (2007) states again that the as yet best existing combination of data for analysing economic convergence is the PPP-adjusted initial level and national accounts-based economic growth.[21]

Problem of data adjustment: Cross-section versus time-series comparability

While in World Development Indicators and Penn World Table significant work has been done to improve the spatial comparability of the data on income, and data are provided in local currencies as well as in internationally comparable U.S. dollars (serving as a numeraire) using some kind of adjustment for the purchasing power of domestic currencies, this is not a feature of the "raw" data in International Financial Statistics, which offers data as they were submitted by the statistical offices of the respective countries. IFS provides the user with nominal data in local currencies, accompanied by data in constant prices and the exchange rate. As the exchange rates diverge from price level parities, sensible cross-sectional analysis of output or income levels is limited. In contrast, GDP data from the IFS are suitable for computing economic output growth rates since they preserve the price structure and corresponding incentives facing the economic agents (Nuxoll, 1994). Therefore, it is correct to use them for time-series analysis. There are some limitations for the automatic use of GDP data from the IFS in empirical analysis, however, e.g. for computing expenditure shares of other variables denominated in local currency.[22] The important advantage of the IFS data lies in the fact that no adjustments have been made to them and a user of the data is thus fully responsible for any changes.

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[19] The indicated measurement problems related to the ICP benchmark estimates include the quality of underlying price and quantity data, matching problems because of heterogeneity among countries, choice of aggregation method and the fact that the estimates relate only to the expenditure side. An added remark connected with PWT is the clearly distinct quality of the estimates for benchmark and non-benchmark countries and the difference between the real economic growth rates based on the PWT and the countries' national accounts.

[20] From this point of view, it is really surprising that the authors of the PWT database have decided to include in the list of variables an explicitly computed growth rate based entirely on the variable RGDPCH.

[21] Nordhaus points out that the assumptions in the national accounts of a "representative consumer" and of homotheticity of preferences (independence of relative preferences of income and output) are often rejected by the data.

[22] Nominal shares in GDP may not capture some economic phenomena. Summers and Heston (1996) use the example of investment share to show that real (based on real international prices) and nominal I/GDP shares behave very differently, the earlier being in line with theory-based expectations.

As both cross-sectional and time-series variation (panel data) are so often used, an important question is what the characteristics of the data used for this type of analysis should be, given the above discussion, since in this tupe of analysis, the reasearcher pays attention to both cross-sectional as well as time variation.

The answer depends on the type of variation of interest. One possibility is that the best model specification is fixed effects, for instance, for a type of policy analysis, where one is interested in the effect of institutions or policies on a country's income or growth. This specification uses within-group heterogeneity, i.e. the deviations of variables from their country mean, it is the variation for one country in time that matters. The possible differences between countries' income levels are taken care of by the fixed effects. The correct variation in data should thus reflect this pattern, and data maintaining country growth rates should be used. This implies using the IFS data.

For a model assuming random effects, which means the same effects coming from the within-group and between-group variation, however, the data should correctly reflect the real differences across countries and over time. None of the datasets available can satisfy this assumption, since apparently, the PPP-based exchange rates also change over time and thus one does not have enough degrees of freedom to impose the correct variation in both cross-sectional and times-series dimensions.[23]

3. Comparison of WDI, PWT and IFS

Simple statistical and econometric methods are employed to compare the real GDP per capita growth data in the three databases as described in Appendix 1. It is important to recall that (unlike PWT and WDI) IFS contains "raw" data and breaks in the series are indicated. Prior to analysis, cleaning of the IFS data was carried out. This is also described in detail in Appendix 1. The variables are labelled simply IFS, PWT and WDI according to the database they come from. We suspect that certain countries with common characteristics will be affected by data adjustments; we hypothesize that the level of development of each country may provide significant information regarding the differences and, therefore, we use the classification of the World Bank according to 2005 Gross National Income per capita (Table A1. 4).

The first step is to compare the summary statistics of the variables and simple correlations (Table 5). The comparison is presented both for all available data (Pane B) and for observations that have a non-missing value for real GDP per capita growth in all three databases (Pane A). It appears that the mean growth rates are very similar. However, their differing range signals some methodological issues, if not errors in the data. It also stands out that the correlations among the variables are markedly lower than one.

[23] Also Nordhaus (2007) notes that to account correctly for spatial as well as time variation if one analyses economic convergence, "index-number calculations across space and time should be based on similar techniques" (page 362).

Table 5: Annual real GDP per capita growth (%) – comparison across databases

A. Full-row observations

	Number of Obs.	Mean	Standard Deviation	Minimum	Maximum	Correlation with IFS growth	Correlation with PWT growth	Correlation with WDI growth
IFS	3583	2.1	5.0	-46.4	98.0	1		
PWT	3583	2.2	5.8	-41.9	77.7	0.68	1	
WDI	3583	2.1	4.8	-34.1	66.7	0.88	0.74	1

B. All available observations

	Number of Obs.	Mean	Standard Deviation	Minimum	Maximum	Correlation with IFS growth	Correlation with PWT growth	Correlation with WDI growth
IFS	3788	2.1	5.2	-46.4	98.0	1		
PWT	4594	2.1	6.5	-41.9	77.7	0.68	1	
WDI	4521	2.0	5.6	-41.2	138.9	0.88	0.70	1

An overall picture of relations among the growth rates from these analysed databases is provided in Figure 1-3. The simple regression coefficients are given. In all cases, the intercepts are significantly different from zero; the slopes are in line with the evidence above.

Figure 1: Comparison of growth rates in PWT and IFS

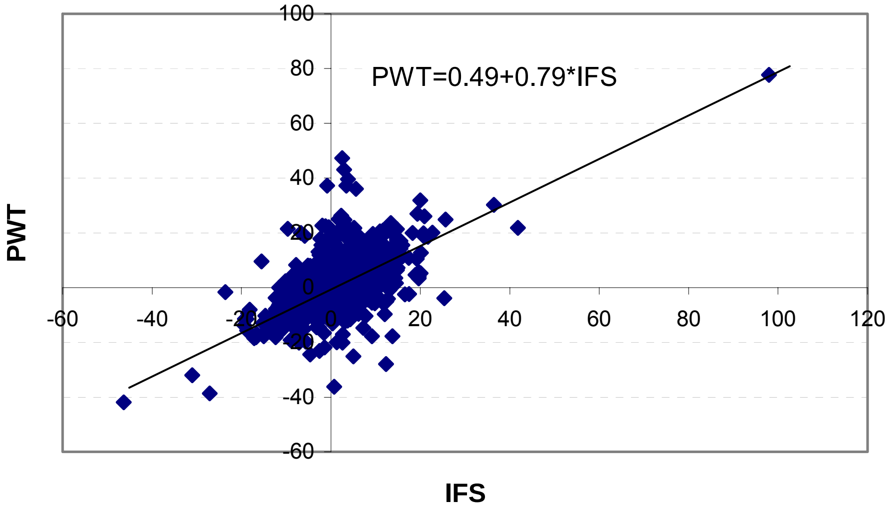


Figure 2: Comparison of growth rates in WDI and IFS

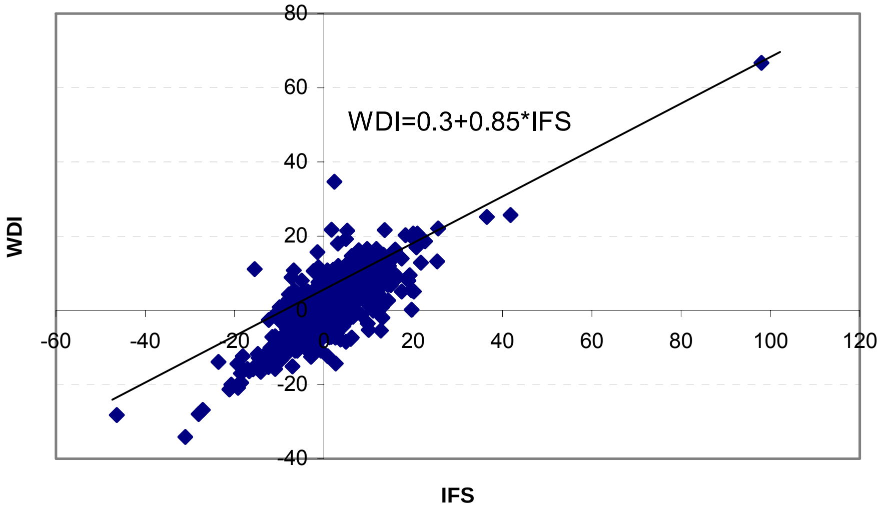
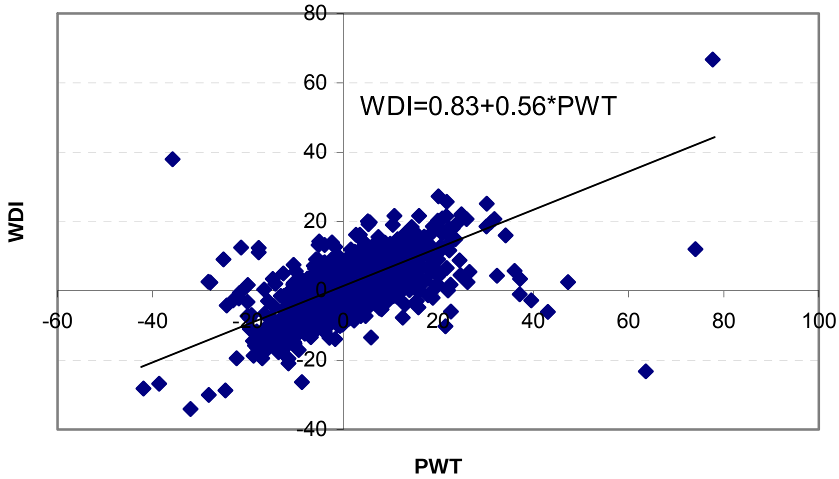


Figure 3: Comparison of growth rates in WDI and PWT



Next, in order to disentangle the differences between the implied rates of economic growth as defined and reported by IFS, WDI and PWT we look at the simple correlation of these growth rates across time and income groups.

The above discussion of the implication of price structure in the PWT data can be qualified by Table 6 (below), which presents the mean differences and correlation coefficients of the growth rates within four income groups. If the Gerschenkron effect held, countries with a lower price level than the reference country would see their growth rates based on IFS (and hence domestic prices) higher than those based on PWT (international prices). The table shows that IFS growth for low-income countries is on average 0.20 percentage points lower than PWT growth, while WDI growth for this group is 0.15 percentage points lower than PWT, i.e. the opposite of what one would expect from the Gerschenkron effect. In contrast, the data show the tendency that the correlation of PWT and WDI implied growth with IFS growth is higher for the lower middle income countries than for low income countries and upper middle income countries, which for PWT could be an artefact of the imposed price structure. However, the same phenomenon is observed in the WDI data, too, and these data are not expressed in PPP terms. Also, the highest correlations are observed for the upper income countries for all three comparisons. An unambiguous case for the Gerschenkron effect is thus not observed.

The reason may be that the sufficient condition is not fulfilled. In fact, since we measure economic growth starting from 1960, the underlying structural changes may be different than those observed by Gerschenkron in the 1930s. The period since 1960s saw rapid development in the service sector in industrialized countries and a substantial reallocation of resources towards tertiary sector. Average productivity gains in the service sector are smaller relative to manufacturing,[24] and thus prices do not have to move in the opposite direction to output.[25] It is a stylized fact that relative prices of services are lower in poorer countries than in richer ones (e.g. Kravis et al., 1981). If prices increase along with quantities, the share of this sector in total output increases. The contribution of services to growth will thus be higher if the price set of a later time or a more developed country is used, giving it greater weight. This can work against the Gerschenkron effect, which may be more relevant to the industrialization period and to tradable goods. It can be observed that the average share of value added in services in GDP in countries covered by the WDI database grew between 1960 and 2000 by about 10 percentage points, from a little above 40% to more than 50%.

The results in Table 6, in particular for the relation between IFS and PWT, and except for upper income countries, thus seem to be consistent with a convergence story in the period of gradual growth of the nominal share of the service sector: if a lower middle income country's price structure is taken as a base, then sectors that developed fast in the upper income countries are given less weight (if they were the drivers of growth they gained in importance) and the sectors developing in low income countries (which still have low weight as they have not developed enough yet) are given greater weight. Therefore, PWT could understate the growth in higher income countries and overstate that in low income countries.

Table 6: Growth difference and correlation by income groups

Income Group	Number of Obs.	Difference between			Correlation between		
		IFS growth and PWT growth	IFS growth and WDI growth	PWT growth and WDI growth	IFS growth and PWT growth	IFS growth and WDI growth	PWT growth and WDI growth
Low Income	914	-0.20	-0.04	0.15	0.52	0.83	0.62
Lower Middle Income	931	-0.04	0.06	0.10	0.74	0.92	0.79
Upper Middle Income	771	0.19	0.12	-0.07	0.72	0.87	0.79
Upper Income	1040	-0.10	-0.01	0.09	0.82	0.93	0.83

Table 7 describes the development of growth differences and correlations over time. We can see that there likely is a development in the difference between the growth rates implied by IFS and PWT, which started to be negative, over -0.4 percentage points, in the first part of the analysed sample, but since 1986, started to be positive. The story outlined above of gradual development, growing prices and convergence would hold here, too. As early on countries are at a lower level of development than later on, imposing the price structure of a lower middle income country will on average overestimate the growth rate in the earlier years and underestimate those in later years.[26] There is no such pattern observable in comparing IFS with WDI or WDI and PWT. Correlations between IFS and PWT and WDI and PWT started from very low levels and ended markedly higher, but

[24] Wölfl (2004) argues that a part of this effect can, however, also be due to measurement problems.
[25] The possibility that Gerschenkron's sufficient condition does not have to hold is admitted e.g. in Samuelson (1974).
[26] Development of the correlation within income and time groups reinforces this result (Table A2. 1).

already from the second analysed period (i.e. from 1966) no clear trend is observable. Some steady increase in the correlation coefficient for IFS and WDI can be observed throughout the sample period.

Table 7: Growth difference and correlation by period

Period	Number of Obs.	Difference between			Correlation between		
		IFS growth and PWT growth	IFS growth and WDI growth	PWT growth and WDI growth	IFS growth and PWT growth	IFS growth and WDI growth	PWT growth and WDI growth
1961-1965	246	-0.41	0.19	0.61	0.51	0.81	0.56
1966-1970	310	-0.19	-0.10	0.09	0.65	0.82	0.77
1971-1975	377	0.17	0.07	-0.10	0.69	0.83	0.84
1976-1980	430	-0.15	-0.07	0.08	0.65	0.84	0.75
1981-1985	497	-0.48	-0.02	0.46	0.61	0.87	0.72
1986-1990	546	0.02	-0.06	-0.07	0.73	0.90	0.81
1991-1995	604	0.18	0.12	-0.07	0.69	0.94	0.71
1996-2000	573	0.21	0.10	-0.10	0.76	0.93	0.77

Knowing that the correlations of growth rates across databases are far below one, it is interesting to see to what extent at least the direction of implied growth rates is the same. Table 8 provides information about the occurrences of the same direction of growth. It is clear that the number of cases where the growth rates have opposite signs is also significant; comparing IFS and PWT, we find on average 14 cases out of 100 where the sign of the growth rate is opposite; for IFS and WDI it is 7 cases and for WDI and PWT, 12 cases.[27] Moreover, it is clear that this phenomenon is strongly correlated with income levels, and the occasions of the opposite signs are higher for countries with lower income. This is true for all compared variables.

Table 8: Occurrences of identical direction of growth (%)

Income group	IFS and PWT		IFS and WDI		PWT and WDI	
	same sign	opposite sign	same sign	opposite sign	same sign	opposite sign
Total	86	14	93	7	88	12
Low Income	76	24	87	13	81	19
Lower Middle Income	87	13	95	5	87	13
Upper Middle Income	87	13	94	6	89	11
Upper Income	95	5	96	4	97	3

Finally, we test for the presence of a spurious correlation between the error in growth measurement and income level in our sample as outlined by Nuxoll (1994). Table 9 shows the results of regressions of the (logarithmic) average growth differences over the period 1960 – 2000 between IFS and PWT, and WDI and PWT, at the level of 1960 initial income as defined by PWT. Since the above analysis has shown that the data problem for high income countries is probably not so severe, we also investigate the effect for countries that fall into the groups low, lower middle and upper middle income only. The results refute the presence of the spurious correlation (a result found also by Nuxoll).[28]

[27] Table A2. 2 and Table A2. 3 show details of these results.
[28] An analysis of the period 1980 – 2000 shows similar results.

Table 9: Correlation between initial income and subsequent growth difference

	IFS and PWT		WDI and PWT	
	All	**Without high income countries**	**All**	**Without high income countries**
Initial income	-0.0002 [0.0015]	-0.0024 [0.0026]	-0.0007 [0.0009]	-0.0015 [0.0016]
Constant	-0.0004 [0.0118]	0.0148 [0.0196]	0.0057 [0.0071]	0.0110 [0.0118]
Observations	105	78	105	78

Note: Standard errors in brackets.

4. Sensitivity of selected growth regressions

The importance of choosing the correct dependent variable can be illustrated by investigating the sensitivity of results of published studies on growth. This section describes the exercise of replicating selected studies of growth determinants.[29] The aim is to examine whether the results of the studies are sensitive to the choice of database for the dependent variable and thus might be subject to the problems explained in Section 3. This would be signalled by changes in the coefficients of the explanatory variables and/or the loss of their statistical significance.[30]

One basic equation was selected from each replicated study and the sensitivity of the results was analysed by replacing the dependent variable – economic growth in the form defined by the particular study – with the expression of economic growth calculated according to the same definition but based on data from IFS, PWT and WDI, alternatively. Further, because theory strongly suggests that the appropriate specification for convergence analysis is to use a country's national accounts' economic growth rates and PPP-adjusted initial income levels, we also estimated the replicated studies with a combination of growth rates based on IFS and income levels based on PWT. Since all studies originally used PPP-adjusted initial income levels, the change in the initial income data may include the effects of a change in the original database or data revision.[31]

In such sensitivity analysis, it is necessary to distinguish between the difference in the results originating from the dependent variable itself and from the effect of varying sample due to different sample sizes.[32] The replicated results based on alternative databases are,

[29] Filer et al. (2004) analyze two articles in this way; the number is extended to four in Hanousek et al. (2007).

[30] One referee pointed out that the sensitivity analysis should take into account the likely consistency of the right-hand-side variables used in individual studies with the dependent variables if they come from the same database. It would thus be correct to replace the variables in the tested regressions with a consistent set of dependent and explanatory variables coming from the same database. Because of the specificity of the explanatory variables or their coverage in the databases, this was in fact done only for population. Other variables were missing from at least one database.

[31] The sensitivity analysis was further extended to replace the initial levels of GDP from the same dataset as the dependent variable, since referees justly pointed out that variables in one database may be adjusted to be internally consistent. However, in this case it would mean moving in the wrong direction in terms of theory by knowingly using exchange rates instead of purchasing power parities for level variable on initial income from the IFS.

[32] The maximum sample is always that of the original study. In the replication, the sample may be reduced because of country or time coverage of the analysed databases, or by excluding individual observations from the sample due to breaks in comparability in the data (see Appendix 1 for a detailed description).

therefore, always compared with the results based on the respective study's original data with identical sample, i.e. where observations missing in the alternative database were also excluded from the respective study's original data.

The obtained results are presented according to the following strategy: The selected studies, their basic empirical approach, and relevant replicated results are described in alphabetical order. The first columns of the tables contain the results obtained from the replication of the analysed equations with the original data of each respective study (labelled "study original data"). If not otherwise noted, the results are identical to those in the analysed paper. After that, results based on alternative data sources (labelled "IFS", "PWT", "WDI", respectively) followed by results using the papers' original data on a reduced sample (labelled "study (IFS/PWT/WDI sample)") are presented.

Results of regressions with the combination of growth data from IFS and level data from PWT are reported in Appendix 3, and are labelled "final".

Aghion, Howitt, Mayer-Foulkes (2004) – The Effect of Financial Development on Convergence: Theory and Evidence

Aghion, Howitt, and Mayer-Foulkes (2004), henceforth AHM, test whether there is evidence that a country's long-run growth rate is determined by its level of financial development (by its critical mass) and whether the steady-state per-capita GDP of countries with more financial intermediation than the critical level (positively but with vanishing effect) is influenced by the degree of financial development. They estimate this effect by including the interaction term of the initial income gap and indicator of financial development along with the two other conditioning variables on the right-hand side of a cross-sectional growth regression. Table 1 of the AHM paper presents the estimation of the following equation that approximates the theoretical model:[33]

$$g_i - g_1 = \beta_0 + \beta_f F_i + \beta_y (y_i - y_1) + \beta_{fy} F_i (y_i - y_1) + \beta_x X_i + \varepsilon_i ,$$

where $g_i - g_1$ is the average (1960-1995) growth rate of per capita real GDP relative to the United States (as the technological leader), F_i is average financial development 1960-1995 (four alternative measures are exploited: private credit, liquid liabilities, bank assets and share of deposit-money banks' assets in the sum of deposit-money bank and central bank assets), $y_i - y_1$ is log GDP p.c. in 1960 relative to the United States, and $F_i(y_i - y_1)$ is an interactive term of the (relative) initial income and the financial development variable. For the convergence to depend on financial development, the coefficient β_{fy} must be negative. For the financial development to have a vanishing effect for convergence of the steady-state level of GDP per capita relative to the technology frontier, β_f must be equal to zero. Three specifications are pursued (1. "empty" – where the matrix X_i contains no variable; 2. "policy" - with X_i containing policy variables: average years of schooling in 1960, government size, inflation, black market premium and openness to trade; and 3. "full" – with X_i containing policy variables and variables quantifying revolutions, political assassinations, and ethnic diversity – coefficients of these additional variables are not reported in the paper). The financial development variable *F* and the interaction term may be endogenous and, therefore, the legal origin and legal origin interacted with initial income are used as instrumental variables.

[33] Also estimated are equations where income gap is replaced by technological gap, and equations where other interactions are tested.

The source of data for the AHM paper is Levine, Loayza and Beck (2000). The GDP level in Levine et al. (2000) came from PWT, while the growth measure from WDI, but it is not clear whether the variables were used in the same way in AHM as no explicit remark is made. The alternative dependent variables are the average (1960-1995) real per capita GDP growth rates based on data from IFS, WDI and PWT.[34] The main result of AHM is reported in the first column of Table 1 in their paper. This is the specification where financial development is measured by the value of credits by financial intermediaries to the private sector ("private credit"), divided by GDP, and matrix X_i contains no other variable.

The sensitivity analysis of this result to the choice of the source of the growth measure is provided in Table 10. We see that the main result of the paper, i.e. a negative and significant coefficient of the interaction term of initial income gap and financial development, continues to hold when the dependent variable is replaced by the alternatives. Also, the direct effect of financial development does not become significantly different from zero. However, we can observe the coefficient of the interaction term to be somewhat smaller and less significant than reported by AHM. This result is, however, partly due to the definition of the sample, as some reduction in the coefficients (along with the increase in standard errors) is also observed for the original AHM data with the reduced sample. The effect is most pronounced if the growth measure comes from IFS and the effect of financial intermediation is estimated to be lower by one third; in this case, the coefficient of the initial income gap also ceases to be significantly positive, implying that there would be no critical mass of financial development needed to obtain convergence. The effect on the result is negligible if the growth measure is taken from the newest PWT data. The effect of taking WDI as the source of the measure of growth lies in the middle of those for IFS and PWT.

Table 10: Sensitivity of the impact of financial development on GDP per capita growth

	AHM original data	IFS	AHM (IFS sample)	PWT	AHM (PWT sample)	WDI	AHM (WDI sample)
Private credit	-0.015 [0.016]	-0.007 [0.014]	-0.005 [0.018]	-0.018 [0.014]	-0.017 [0.015]	-0.015 [0.016]	-0.014 [0.015]
Initial income	1.507 [0.480]**	0.84 [0.542]	0.84 [0.669]	1.538 [0.444]**	1.58 [0.472]**	1.513 [0.482]**	1.418 [0.459]**
Interactive term	-0.061 [0.011]**	-0.039 [0.012]**	-0.046 [0.015]**	-0.059 [0.011]**	-0.062 [0.011]**	-0.048 [0.012]**	-0.054 [0.012]**
Observations	71	50	50	67	67	67	67
R-squared	0.50	0.35	0.35	0.46	0.46	0.5	0.48

Note: Standard errors in brackets; * significant at 5%; ** significant at 1%;
In fact, R-squared values do not have a good meaning in 2SLS (IV) estimation since the model sum of squares is computed based on the values of the RHS endogenous variables and not their instruments, and, since the constant-only model may not be nested within the 2SLS model, TSS may be smaller than RSS.

The results of the sensitivity analyses for all results presented in Table 1 of AHM are provided in Tables A3. 1 - A3.15. The conclusion drawn from the full set of results is

[34] The average growth rate was calculated if at least 30 out of 35 possible observations (yearly growth rates) were available. The analysis could not be done for the IFS data if complete availability of data were strictly required, since in this case the average growth rate for the reference country (United States) could not be computed as there is a break in comparability of the population data in this database reported for the year 1960.

similar to that described above. Using the growth rate from the IFS database decreases the coefficient of the interaction variable and it even makes it insignificant in the "policy" specification with liquid liabilities as the financial development indicator. It is also observed that the specification with domestic assets of deposit-money banks relative to GDP ("bank assets") as the indicator of financial development is the most robust one to the selection of the dependent variable.

Results based on the preferred specification of the GDP growth rate from IFS and the GDP level variable from PWT do not change the picture. Although these results are closest to the original AHM results, the coefficients of the interactive term are smaller; the coefficients of initial income are less significant. Moreover, the results are less robust with more variables added to the regressions ("policy" and "full" specifications).

Bosworth and Collins (2003) – The Empirics of Growth: An Update

Bosworth and Collins (2003), henceforth BC, attempt to construct consistent growth accounts to investigate the role of capital accumulation, multi-factor productivity, education quantity and quality for growth in per capita income, and to disentangle the sources of the difference in growth performance before and after 1980. BC run growth regressions for 84 countries for the periods 1960-2000, 1960-1980 and 1980-2000.[35] Their source of data is primarily the WDI for developing countries and the OECD for industrialized countries. The authors also mention that they use some complementary information from national accounts data underlying version 6 of PWT. The dependent variable used is average yearly growth in output per worker (defined as the average annual log change). The measure of labor force comes from the ILO database. BC's data were provided by Bosworth. When constructing the alternative growth measures, the real GDP data from IFS, PWT and WDI and the measure of labor force from ILO were used;[36] real GDP per worker is directly available in PWT but we wanted to eliminate a possible source of discrepancy stemming from different labor force measures.[37] In principle, we were able to replicate BC's results based on the data from the authors with the exception of the period 1980-2000 (we were not able to replicate the coefficients and standard errors precisely, but the size of coefficients and significance were quite close).

The variables on the right-hand side of the growth regressions[38] are divided into two groups. The "initial conditions" include initial income per capita, life expectancy, logarithm of population, Frankel-Romer-Rose trade instrument, geography, and institutional quality. The "policy variables" include budget balance, inflation, and average Sachs-Warner openness. The sensitivity analysis of BC's basic results ("initial conditions" equation for 1960-2000, Table 8, column 8-1 in BC) is presented in Table 11. We can observe that the change of growth measure does not have an important effect on the coefficients by life expectancy, log of population or trade instrument, neither directly nor by changing the sample. The effect is more significant for the coefficient of geography; if the original BC growth measure is replaced by that from the IFS, the coefficient loses

[35] Growth accounting is also a part of their analysis.
[36] Labor force is not available from IFS for the period 1960-2000; the coverage is low also for the period 1980-2000.
[37] An average growth rate for the desired period is computed (as a simple average of the growth rates) if there are no more than three missing yearly growth rates in the time series for 1960-2000, no more than one missing yearly growth rate for 1960-1980 and no more than two missing yearly growth rates for 1980-2000 (these discretionary values were chosen according to the histogram of availability).
[38] Capital contribution and multi-factor productivity also perform as dependent variables in BC's paper.

statistical significance.[39] The coefficient of initial income decreases somewhat for all the alternative measures, but except for the IFS data, results using BC's data show a similar decrease in the reduced sample. In the case of IFS, however, the result possibly implies slower convergence. A decrease in significance can be also observed for the measure of the quality of institutions when IFS data are employed. But this result is mainly due to the reduction of the sample.

Table 11: BC – Sensitivity of the structure of growth regression (initial conditions)

	BC original data	IFS	BC (IFS sample)	WDI	BC (WDI sample)	PWT	BC (PWT sample)
Initial income	-6.29 [0.60]**	-4.74 [0.76]**	-5.39 [0.78]**	-5.74 [0.68]**	-5.64 [0.67]**	-5.66 [0.72]**	-5.83 [0.65]**
Life expectancy	0.07 [0.01]**	0.07 [0.02]**	0.07 [0.02]**	0.07 [0.01]**	0.06 [0.01]**	0.06 [0.01]**	0.06 [0.01]**
Log of population	0.29 [0.06]**	0.25 [0.08]**	0.25 [0.08]**	0.33 [0.07]**	0.32 [0.07]**	0.27 [0.07]**	0.3 [0.06]**
Trade instrument	4.77 [1.15]**	4.41 [1.33]**	4.91 [1.37]**	4.57 [1.23]**	4.46 [1.20]**	5.46 [1.27]**	4.8 [1.15]**
Geography	0.53 [0.13]**	0.25 [0.20]	0.47 [0.20]*	0.54 [0.16]**	0.49 [0.16]**	0.52 [0.15]**	0.5 [0.14]**
Institutions	2.84 [0.63]**	2.12 [0.95]*	2.26 [0.98]*	2.43 [0.71]**	2.67 [0.69]**	2.31 [0.72]**	2.68 [0.65]**
Constant	-7.05 [1.22]**	-6.87 [1.71]**	-6.43 [1.76]**	-7.38 [1.41]**	-7.25 [1.38]**	-6.47 [1.38]**	-6.98 [1.24]**
Observations	84	49	49	71	71	79	79
Adjusted R-squared	0.76	0.69	0.71	0.74	0.74	0.69	0.73

Standard errors in brackets; * significant at 5%; ** significant at 1%

Applying similar sensitivity analysis to other of BC's results (conditioning variables including initial conditions as well as policy variables and for two sub-periods, Table A3. 16 - Table A3. 21), the implications are rather similar. The variables of geography and institutions are not very robust to the choice of growth measure and/or to sample reduction, though the performance of the latter improves for the more recent sub-period. This holds as well for the preferred combination of GDP growth from IFS and GDP level from PWT. These observations are also to a certain extent robust to the alternative definition the IFS, PWT and WDI growth rates, when these are constructed as the difference between the logarithms of the last and initial value in the sample, conditioned on no break in the series.

Forbes (2000) – A Reassessment of the Relationship Between Inequality and Growth

Forbes (2000) investigates the link between income inequality and subsequent growth rates and proposes using improved inequality statistics. The model used in the paper is $y_{it} = \beta X_{it-1} + \alpha_i + \eta_t + u_{it}$, where y_{it} is country *i*'s per capita economic growth rate in period t, X_{it-1} contains inequality, income, male and female education (average years of schooling of population over 25) and market distortions (measured as the price level of investment relative to the U.S.) for country *i* during period *t-1*, α_i are country dummies, η_t are time dummies and u_{it} is the error term. This relationship is analysed in a cross-country time-series model and in a cross-section model. Because of the non-availability of

[39] This is the measure of geography (a composite average of the number of days of frost and area within the tropics), within which BC reportedly obtained the most significant results.

data, only the cross-section analysis is replicated. In the cross-section, the author regresses average annual per capita growth (1970-1995) on the dependent variables listed above. Two inequality measures from Deiningen and Squire (1996) are used: a “low quality” (GINI 1) and a “high quality” (GINI 2), the latter having been corrected for measurement error.

The source of the dependent variable in the paper is the World Bank STARS dataset. In Table 12 below, a replication of column 4 of Table 4 on page 879 with original data is presented, i.e. the OLS estimation with the improved inequality measure. We were able to replicate the results, except that this was using a lower number of observations.[40] The alternative dependent variables are average annual per capita growth (1970-1995) rates as defined by IFS, WDI and PWT.[41] The results are reported under the corresponding column headings. There was no need to do a sensitivity analysis for sample selection as the samples are identical.

Table 12: Forbes – Inequality (high quality measure) and growth

	Forbes original data	IFS	WDI	PWT
Inequality	-0.00049 [0.00028]	-0.00047 [0.00026]	-0.0004 [0.00029]	-0.00048 [0.00028]
Income	-0.00362 [0.00331]	-0.00856 [0.00312]*	-0.00787 [0.00344]*	-0.0095 [0.00334]**
Male education	0.03659 [0.00863]**	0.03194 [0.00813]**	0.03304 [0.00894]**	0.03381 [0.00869]**
Female education	-0.03357 [0.00880]**	-0.02775 [0.00829]**	-0.02884 [0.00912]**	-0.02833 [0.00886]**
Market distortions	-0.00007 [0.00010]	-0.00007 [0.00010]	-0.00009 [0.00011]	-0.0001 [0.00010]
Constant	0.07115 [0.03036]*	0.10682 [0.02860]**	0.09922 [0.03147]**	0.11535 [0.03058]**
Observations R-squared	36 0.48	36 0.55	36 0.49	36 0.55

Standard errors in brackets
* significant at 5%; ** significant at 1%

Paradoxically, it seems that using any alternative database improves the fit of the model. In particular, income appears significant, a result to be expected from a growth regression, while the results for inequality and other variables do not noticeably change. A similar result is observed if Forbes’ alternative measure for inequality is used (Table A3. 24) and with the preferred combination of growth and income variables (Table A3.25).

Hanushek and Kimko (2000) – Schooling, Labor Force Quality, and the Growth of Nations

Hanushek and Kimko (2000), henceforth HK, estimate the effect of labor force quality on economic growth using the direct measures of labor force quality from international mathematics and science test scores, and an endogenous growth model. In the cross-country estimation, the average growth rate of real per capita GDP (1960-1990) is

[40] The regression outcome obtained from Forbes is identical to our results; probably just the number of observations is wrongly reported in the paper.
[41] The average growth rate was calculated if at least 22 out of 26 possible observations (yearly growth rates) were available.

regressed on initial per capita income, quantity of schooling, population growth and labor force quality. They employ two alternative measures of labor quality (which differ in the method of aggregating mathematics and science test scores). Further, the labor force quality is projected for countries for which the scores are not available.

The source of the dependent variable is PWT (1991). Table 13 presents the replication of the results from column 2 in Table 5 (page 1195). This is the regression that uses the expanded dataset with the projected labor force quality values.

The alternative dependent variables are real per capita GDP growth based on data from IFS, WDI, and PWT.[42]

Table 13: HK – Labor force quality and growth

	HK original data	IFS	HK (IFS sample)	PWT	HK (PWT sample)	WDI	HK (WDI sample)
Initial income	-0.39 [0.079]**	-0.334 [0.096]**	-0.397 [0.097]**	-0.334 [0.106]**	-0.361 [0.087]**	-0.343 [0.093]**	-0.351 [0.081]**
Quantity of schooling	0.117 [0.093]	0.094 [0.123]	0.152 [0.122]	0.024 [0.114]	0.098 [0.094]	0.024 [0.105]	0.061 [0.089]
Annual population growth	-0.097 [0.212]	-0.123 [0.307]	0.043 [0.291]	-0.022 [0.255]	-0.063 [0.226]	-0.255 [0.231]	-0.166 [0.214]
Labor force quality (measure 1)	0.104 [0.023]**	0.075 [0.042]	0.102 [0.035]**	0.125 [0.029]**	0.106 [0.023]**	0.101 [0.031]**	0.101 [0.026]**
Constant	-1.184 [1.241]	0.26 [2.267]	-1.472 [1.960]	-1.692 [1.490]	-1.307 [1.261]	-0.391 [1.535]	-0.779 [1.299]
Observations	78	51	51	73	73	68	68
R-squared	0.42	0.2	0.31	0.37	0.38	0.31	0.37

Robust standard errors in brackets
* significant at 5%; ** significant at 1%

Table 13 shows that the results for the first labor force quality measure are sensitive to the choice of database. While the results about the effect of labor force quality on economic growth continue to hold with the PWT and WDI measures, using IFS reduces the coefficient of labor force quality by one quarter and renders its effect on economic growth insignificant. This effect is fully caused by the dependent variable, because the original HK result continues to hold also in the reduced sample. Using the alternative measure of labor force quality (Table A3. 26),[43] we also observe a loss of significance of labor force quality. The result in this case, however, is partly due to the sample reduction, since using the original HK data in the sample reduced to the observations that are also available from IFS yields a similar result, though the reduction of the coefficient is less pronounced. A further two results are presented in Table A3. 27 and Table A3. 28. These regressions in HK provide a kind of robustness check for the main results; the countries with direct observations are distinguished from those with projections (variable "assessment available") and with point estimates on marginal test score effects ("observed labor force quality"). Here again, a reduction of coefficient and a loss of significance are observed, but mainly as an artefact of the size of the sample. Results of the sensitivity analysis for the four specifications are very similar if the preferred combination of GDP growth from IFS and GDP level from PWT is used.

We thus conclude that the results are not robust to the choice of database for the dependent variable and if IFS data are used, the main result of the paper does not hold.

[42] The average growth rate was calculated if at least 25 out of 30 possible observations were available.

[43] This table replicates column 6. We could not perfectly replicate the results from the paper as two observations reported in the paper are missing from the HK dataset. The results are, however, similar.

Mankiw, Romer and Weil (1992) – A Contribution to the Empirics of Economic Growth

The paper of Mankiw, Romer and Weil (1992), henceforth MRW, tests the predictions of the Solow model (also augmented for the accumulation of human capital) for cross-country differences in income and economic growth. The theoretical model tested here is the model for conditional convergence, i.e. the prediction that poorer countries grow faster than richer ones if the steady state determinants are controlled for:[44]

$$\ln\left(\frac{Y(t)}{L(t)}\right)-\ln\left(\frac{Y(0)}{L(0)}\right)=\left(1-e^{-\lambda t}\right)\frac{\alpha}{1-\alpha-\beta}\ln(s_k)+\left(1-e^{-\lambda t}\right)\frac{\beta}{1-\alpha-\beta}\ln(s_h)$$
$$-\left(1-e^{-\lambda t}\right)\frac{\alpha+\beta}{1-\alpha-\beta}\ln(n+g+\delta)-\left(1-e^{-\lambda t}\right)\ln\left(\frac{Y(0)}{L(0)}\right)+\varepsilon,$$

where $\frac{Y}{L}$ is output per worker, s_k is physical capital investment share of output, s_h is human capital investment share of output, n is population growth, g is technological growth, δ is rate of depreciation, λ is a rate of convergence and ε is a country specific shock. g and δ are assumed to be constant across countries and s and n are assumed to be independent of ε. The change in log income per working age person during 1960-1985 is regressed on log income per working age person in 1960, investment rate, the compound rate of population and technological growth and depreciation, and the percentage of working age population that is in secondary school. The source of data in MRW's paper is PWT (1988), except for secondary school enrolment data, which comes from UNESCO. All the data used for the analysis are also available in the paper. The effects are analysed on three samples of countries: "Non-oil", i.e. all countries for which data are available except those for which oil production is the dominant industry, "Intermediate", i.e., countries identified by Summers and Heston as "D" (those with little primary data) and countries with a population of less than one million in 1960, and "OECD", i.e., 22 OECD countries with a population greater than one million.

The dependent variable is the log difference of GDP per working age person. The number (or share) of working age persons is, however, available from PWT only (implicitly, by dividing GDP per capita by GDP per adult). As we would have to impose the growth rate of the working age population to the IFS and WDI data from a different database anyway, we choose to erase the effect of this variable completely. Therefore, we utilize the growth rate of the working age population from MRW's database on our three alternative measures.[45] Since the dependent variable is the difference in the logarithms of levels, we cannot tolerate breaks in the series and, therefore, only observations for countries that have a full time-series of data 1960-1985 enter the estimation.

The coefficients and standard errors obtained from running the regressions according to MRW are generally the same as reported in the paper, except for the constant. Table 14 below presents the results of the replications of MRW's paper for the "non-oil", i.e. the largest, group of countries, with alternative dependent variables. Results for the other two groups of countries are presented in Table A3. 30 and Table A3. 31.

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[44] Equation 16 and Table V in the original paper. MRW first test the Solow model in levels with and without human capital investment.

[45] The PWT variable first had to be multiplied by PWT (adult) population.

Table 14: MRW – test for conditional convergence (non-oil countries)

	MRW original data	IFS	MRW (IFS data)	PWT	MRW (PWT data)	WDI	MRW (WDI data)
Initial income	-0.29 [0.06]**	-0.26 [0.08]**	-0.36 [0.08]**	-0.29 [0.06]**	-0.29 [0.06]**	-0.21 [0.07]**	-0.29 [0.07]**
Physical-capital investment	0.52 [0.09]**	0.65 [0.14]**	0.69 [0.13]**	0.57 [0.09]**	0.57 [0.09]**	0.52 [0.10]**	0.55 [0.10]**
n+g+δ	-0.51 [0.29]	-0.18 [0.40]	-0.54 [0.38]	-0.31 [0.30]	-0.4 [0.30]	-0.5 [0.31]	-0.53 [0.31]
Human-capital investment	0.23 [0.06]**	0.07 [0.11]	0.09 [0.10]	0.22 [0.06]**	0.2 [0.06]**	0.16 [0.07]*	0.24 [0.07]**
Constant	-0.45 [0.70]	0.17 [0.94]	-0.15 [0.89]	-0.01 [0.71]	-0.23 [0.71]	-0.91 [0.77]	-0.58 [0.76]
Observations R-squared	98 0.49	41 0.49	41 0.59	90 0.52	90 0.51	86 0.38	86 0.45

Absolute value of t statistics in brackets
* significant at 5%; ** significant at 1%

The main observations based on the set of results are as follows. In general, the significance of initial income for growth is robust to the choice of database for the dependent variable, if the initial income from PWT (the one employed by MRW) is used. Otherwise, employing the growth rates based on IFS or WDI results in the loss of significance of some coefficients (in particular, human capital investment measured by school enrolment). Limiting the sample to that defined by the availability of the alternative dependent variables may have a similar effect on the coefficients in the regressions with MRW data. Results are the same with the preferred combination of dependent and initial income variables.

Rousseau and Wachtel (2000) – Equity Markets and Growth

The Rousseau and Wachtel (2000) paper, henceforth RW, evaluates the importance of financial and capital markets for economic growth. Cross-section and panel (VAR) estimation is carried out. Replicated is cross-sectional IV regression (Table 2, p. 1949). The average annual growth rate of real per capita GDP (1980-1987 and 1988-1995, two observations per country) is regressed on initial per capita income (1980 and 1988), initial secondary enrolment rate, number of revolutions and coups, black market exchange rate premium, and one of three alternative financial market development indicators (ratio of M3 to GDP, ratio of market capitalization to GDP, ratio of total value trade to GDP).

The source for the dependent variable in the paper is WDI. The alternative dependent variables are average real per capita GDP growth based on data from IFS, WDI, PWT if at least 5 out of 7/8 possible observations are available. The message would be the same if a higher restriction on complete availability of data was imposed.

Results of the sensitivity analysis replicating this study with alternative sources of the dependent variables show that while the main results of these regressions are robust to the change of dependent variable, the effects of some variables (namely the black market premium) become stronger if the alternative dependent variables are used.

Table 15: RW – Equity markets and growth (liquid liabilities)

	RW original data	IFS	RW (IFS sample)	PWT	RW (PWT sample)	WDI	RW (WDI sample)
Initial income	-0.0077 [0.0030]*	-0.0072 [0.0028]*	-0.0064 [0.0030]*	-0.008 [0.0026]**	-0.0077 [0.0030]*	-0.009 [0.0028]**	-0.0077 [0.0030]*
Initial secondary enrolment rate	0.0109 [0.0071]	0.0059 [0.0069]	0.0032 [0.0073]	0.011 [0.0061]	0.0109 [0.0071]	0.013 [0.0065]*	0.0109 [0.0071]
Liquid liabilities	0.0153 [0.0096]	0.0167 [0.0088]	0.0121 [0.0093]	0.0148 [0.0083]	0.0153 [0.0096]	0.017 [0.0088]	0.0153 [0.0096]
Number of revolutions and coups	-0.0102 [0.0106]	-0.0102 [0.0096]	-0.0118 [0.0102]	-0.0133 [0.0092]	-0.0102 [0.0106]	-0.0133 [0.0097]	-0.0102 [0.0106]
Black market exchange rate premium	-0.0319 [0.0203]	-0.0455 [0.0189]*	-0.0414 [0.0201]*	-0.0399 [0.0176]*	-0.0319 [0.0203]	-0.0416 [0.0186]*	-0.0319 [0.0203]
Constant	0.0281 [0.0215]	0.0471 [0.0217]*	0.0535 [0.0230]*	0.0337 [0.0187]	0.0281 [0.0215]	0.0323 [0.0197]	0.0281 [0.0215]
Observations R-squared	92 0.17	89 0.23	89 0.21	92 0.24	92 0.17	92 0.25	92 0.17

Standard errors in brackets
* significant at 5%; ** significant at 1%

Results based on the other two alternative definitions of equity market development are provided in Table A3. 33 and Table A3. 34. Results with the combination of GDP growth rate based on IFS and initial income level based on PWT are shown in Table A3.35. They support the conclusion above.

5. Conclusions

We have demonstrated that one has to be careful when selecting the appropriate measure of economic growth for a particular analysis. International datasets on which measures of economic growth are based are available primarily from IFS, PWT and WDI. Each of these databases, however, makes certain adjustments to the data, which can possibly interfere with whatever empirical investigation a researcher undertakes. In particular, data in PWT are constructed to better reflect cross-country variability in levels. This is done at cost of altering the time variation of the variables comparable in cross-section, whose growth is not identical to that based on national accounts. Consequently, the variables may be unsuitable and may produce biased results if used inappropriately.

The analysis in this paper has shown that important differences exist between the annual real GDP per capita growth rates based on data from IFS, PWT and also WDI and that the level of a country's development and a particular time period can account for the difference between IFS and PWT. We do not find evidence of the Gerschenkron effect (i.e., that a country's GDP growth rate would be understated when the price structure of later years or of a more developed country were imposed, if growth in output is connected with falling prices). Nor is evidence found for the spurious correlation effect (i.e., that imposing an international price structure creates a systematic relationship between the level of a country's income and the difference between the growth rate based on international prices and that based on national prices). Rather we find some support for the opposite effect, which is also possibly related to convergence and would occur if development in those sectors driving economic growth were not connected with falling prices.

In line with theory, we propose that the most appropriate variable to measure economic growth in times series as well as cross-section is the growth of real GDP per capita from IFS, since this variable draws directly from the national accounts and preserves the price structure that actually influenced the decisions of the agents in the economy. At the same time, the initial level of income in convergence analysis should be adjusted for differences in price levels. Still, it is unclear how to satisfactorily combine desirable cross-sectional characteristics with preservation of the time-series characteristics in panel data. Appropriate econometric techniques can, however, alleviate this problem.

The paper further illustrates that choosing the appropriate database for the dependent variable for a cross-country growth regression may have important implications for the quality of the results of this regression. In the growth studies examined, we find that the results of the selected regressions are, in general, sensitive to replacing the study's original dependent variable (growth in GDP per capita or per worker from PWT or WDI) by our preferred growth measure based on IFS. The evidence is, however, mixed as to whether this can be the effect of the imposed price structure. An important factor appears to be changes in the sample coverage, which occur most often when the IFS growth measure is employed. Since this measure is cleaned of analytical breaks in the data, we can speculate as to whether the problem of analytical comparability is present in the other two databases, as well. It can be summarized that, basically, policy conclusions based on these analyses should be made with caution.

6. References:

Aghion, P., P. Howitt, and D. Mayer-Foulkes (2004): "The Effect of Financial Development on Convergence; Theory and Evidence," *Quarterly Journal of Economics*, 120(1), pp. 173-222.

Atkinson, A. B., and A. Brandolini (2001): "Promise and Pitfalls in the Use of "Secondary" Data-Sets: Income Inequality in OECD Countries As a Case Study", *Journal of Economic Literature*, 39(3), pp. 771-99.

Barro, R. J. (1991): "Economic Growth in a Cross Section of Countries", *Quarterly Journal of Economics*, 106(2), pp. 407-444.

Baumol, W. J. (1986): "Productivity Growth, Convergence and Welfare: What the Long Run Data Show", *American Economic Review*, 76, pp. 1072-1085.

Bosworth, B. P., and S. M. Collins (2003): "The Empirics of Growth: An Update", *Brookings Papers on Economic Activity*, 0(2), pp. 113-79.

Deiningen, K., and L. Squire (1996): "A New Data Set Measuring Income Inequality", *World Bank Economic Review*, 10(3), pp. 565-591.

Filer, R. K., D. Hájková and J. Hanousek (2004): "The Mirage of Convergence: Why Poor Countries May Only Seem to Be Closing the Income Gap", CEPR Discussion Paper Nr. 4349.

Forbes, K. J. (2000): "A Reassessment of the Relationship Between Inequality and Growth", *American Economic Review*, 90(4), pp. 869-87.

Gerschenkron, A. (1951): *A Dollar Index of Soviet Machinery Output, 1927-28 to 1937*, Santa Monica, CA: Rand Corporation.

Hanousek J., D. Hájková and R. K. Filer, (2007): "A Rise By Any Other Name? Sensitivity of Growth Regressions to Data Source", *Journal of Macroeconomics*, forthcoming.

Hanushek, E. A., and D. D. Kimko (2000): "Schooling, Labor-Force Quality, and the Growth of Nations", *American Economic Review*, 90(5), pp.1184-1208.

Heston, A., and R. Summers (1996): "International Price and Quantity Comparisons: Potentials and Pitfalls", *American Economic Review*, 86(2).

IMF (2005): Review of the Method of Valuation of the SDR, http://www.imf.org/external/np/pp/eng/2005/102805.pdf

Islam, N. (2003): "What Have We Learnt From the Convergence Debate", *Journal of Economic Surveys*, 17(3), pp. 309-62.

Kalaitzidakis, P., T. P. Mamuneas and T. Stengos (2000): "A Non-Linear Sensitivity Analysis of Cross-Country Growth Regressions", *Canadian Journal of Economics*, 33(3), pp. 604-17.

Kravis, I. B., A. Heston and R. Summers (1981): "New Insights into the structure of the World Economy", *Review of Income and Wealth*, 27(4), pp. 339-355.

Kravis, I. B., A. Heston and R. Summers (1982): *World Product and Income*, John Hopkins University Press.

Levine, R., N. Loayza and T. Beck (2000): "Financial intermediation and growth: Causality and causes", *Journal of Monetary Economics*, 46(1), pp. 31-78.

Levine, R., and D. Renelt (1992): "A Sensitivity Analysis of Cross-Country Growth Regressions", *American Economic Review*, 82(4), pp. 942-63.

Lucas, R. E. (1988): "On the Mechanics of Economic Development", *Journal of Monetary Economics* 22, pp. 3-42.

Mankiw, N. G., D. Romer and D. N. Weil (1992): "A Contribution to the Empirics of Economic Growth", *Quarterly Journal of Economics*, 107, pp. 407-437.

Miller, S. M., and M. P. Upadhyay (2002): "Total Factor Productivity and the Convergence Hypothesis", *Journal of Macroeconomics*, 24(2), pp. 267-286.

Nordhaus, W. (2007): "Alternative Measures of Output in Global Economic-Environmental Models: Purchasing Power Parity or Market Exchange Rates?", *Energy Economics*, 29, pp. 349-372.

Nuxoll, D. A. (1994): "Differences in Relative Prices and international Differences in Growth Rates", *American Economic Review*, 84(5), pp. 1423-1436.

Romer, P. (1986): "Increasing Returns and Long-Run Growth", *Journal of Political Economy*, 94 (5), pp. 1002-37.

Rousseau, P., and P. Wachtel (2000): "Equity Markets and Growth: Cross Country Evidence on Timing and Outcomes, 1980-1995", *Journal of Banking and Finance*, 24, pp. 1933-1957.

Sala-i-Martin, X. (1997): "I Just Ran Two Million Regressions", *American Economic Review,* 87(2), pp. 178-83.

Sala-i-Martin, X. (2002): "The Disturbing "Rise" of Global Income Inequality", NBER Working Paper Nr. 8904.

Samuelson, P. A. (1974): "Analytical Notes on International Real-Income Measures", *The Economic Journal*, 84, pp. 595-608.

Summers, R., and A. Heston (1988): "A New Set of International Comparisons of Real Product and Price Levels Estimates for 130 Countries, 1950-1985", *Review of Income and Wealth*, 34(1), pp. 1-25.

Summers, R. and A. Heston (1991): "The Penn World Table (Mark 5): An Expanded Set of International Comparisons, 1950-1988", *Quarterly Journal of Economics*, 106(2), pp. 327-68.

Temple, J. (1999): "The New Growth Evidence", *Journal of Economic Literature*, 37(1), pp. 112-156.

Wölfl, A. (2004): "Productivity Growth in Services Industries: Is There a Role for Measurement?", *International Productivity Monitor*, 8, pp. 66-80.

World Bank (1997): *Expanding the Measure of Wealth*.

World Bank (2005): *Where is the Wealth of Nations?: Measuring Capital for the 21st Century*.

World Development Indicators (2000): the World Bank.

Appendix 1: Data

Comparisons are based on the variable real GDP per capita. This variable is directly obtainable from the Penn World Table (PWT) and World Development Indicators (WDI), while it must be computed from other time series in the International Financial Statistics (IFS).

The **PWT** data were downloaded on 29.11.05 from http://pwt.econ.upenn.edu/.[46] The period coverage is 1950-2000. From three available variables on real GDP per capita (in international US dollars and current prices, and in international US dollars in 1986 constant prices computed by the Laspeyres index and by chain index), that expressed in international US dollars in 1986 constant prices computed by chain index was chosen. Data are reported for 168 countries; for some only one value (year 1986) is available.

The **WDI** data were obtained on the CD-ROM *WDI 2004*. The period coverage is 1960-2002. The selected variable is GDP per capita in constant units of local currency. Some data are available for 191 countries.

The **IFS** data were downloaded from an electronic version of IFS on 21.1.06 (IFS December 2005), covering the period 1945-2004. The variable real GDP per capita must be calculated based on data on real GDP and population. For many countries, several time series are available for real GDP; they are expressed in constant prices of different years, but they typically do not cover the whole period of interest. Therefore, the GDP volume index with the real GDP in 1995 or 2000 equal to 100 was used from this database. The real GDP per capita rate of growth was then computed as the ratio of the growth in real GDP and growth of population.

The analysis includes 135 countries and covers the years 1960-2000 (Table A1. 1). Presented results are based on observations for which the GDP per capita growth rate was available in all three databases.[47] As a standard, observations were excluded from the database if indicated by the IFS as a "break in comparability" for GDP volume index and/or population. In addition, in some selected cases, the growth rate implied by the IFS was considered unlikely and hence relevant observations were also left out of the analysis. These suspect observations were identified according to the following method:

1. Real GDP growth rate per capita based on data from IFS was (in its absolute value) at least twice as high as at least one of those based on data from WDI or PWT (except that growth rates are less than 2 percentage points apart);

2. (if growth rates from WDI or PWT were not available) The yearly growth (or drop) rate in IFS was greater than 15 %.

Table A1. 2 lists the excluded observations and indicates the reason for the exclusion; *IFS-GDP* means that the observation for the GDP volume was indicated in the IFS database as a break in comparability, *IFS-POP* means that the observation for the population was indicated in the IFS database as a break in comparability, *authors* means that that observation was excluded by the authors even if no relevant break in comparability was indicated. Table A1. 3 explains the reasons why particular observations were excluded at the discretion of the authors.

[46] Alan Heston, Robert Summers and Bettina Aten, Penn World Table Version 6.1, Center for International Comparisons, University of Pennsylvania (CICUP), October 2002.

[47] Pairwise comparisons on all available data were done simultaneously, but the results are reported only when deemed useful.

Two special cases required adjustment in the database. First, the newest version of IFS introduced new values of the real GDP variables for Austria (GDP in 1995 prices and GDP volume index) for the period 1989-1994 that implied non-intuitive growth rates. These values were disregarded and replaced by values based on other real GDP time series available in the IFS database (GDP at 1964 and 1983 prices). Second, there seemed to be a misplaced decimal point in the 1954 value of the GDP volume index for Peru. This supposition was supported by the values of the neighboring observations and the number of digits available in general for this time series. Therefore, this observation was corrected.

Table A1. 1: List of countries in the sample

country	income group	country	income group	country	income group
Albania	2	France	4	Nicaragua	1
Angola	2	Gambia, The	1	Niger	1
Antigua and Barbuda	3	Germany	4	Nigeria	1
Argentina	3	Ghana	1	Norway	4
Armenia	2	Greece	4	Pakistan	1
Australia	4	Grenada	3	Panama	3
Austria	4	Guatemala	2	Papua New Guinea	1
Bangladesh	1	Guinea-Bissau	1	Paraguay	2
Barbados	3	Guyana	2	Peru	2
Belarus	2	Haiti	1	Philippines	2
Belgium	4	Honduras	2	Poland	3
Belize	3	Hong Kong, China	4	Portugal	4
Benin	1	Hungary	3	Romania	2
Bolivia	2	Iceland	4	Rwanda	1
Botswana	3	India	1	Senegal	1
Brazil	2	Indonesia	2	Seychelles	3
Bulgaria	2	Iran, Islamic Rep.	2	Sierra Leone	1
Burkina Faso	1	Ireland	4	Singapore	4
Burundi	1	Israel	4	Slovak Republic	3
Cambodia	1	Italy	4	Slovenia	4
Cameroon	1	Jamaica	2	South Africa	3
Canada	4	Japan	4	Spain	4
Cape Verde	2	Jordan	2	Sri Lanka	2
Chad	1	Kazakhstan	2	St. Kitts and Nevis	3
Chile	3	Kenya	1	St. Lucia	3
China	2	Korea, Rep.	4	St. Vincent and	
Colombia	2	Kyrgyz Republic	1	the Grenadines	3
Congo, Dem. Rep.	1	Latvia	3	Swaziland	2
Congo, Rep.	1	Lesotho	1	Sweden	4
Costa Rica	3	Lithuania	3	Switzerland	4
Cote d'Ivoire	1	Luxembourg	4	Syrian Arab Republic	2
Croatia	3	Macao, China	4	Tanzania	1
Cyprus	4	Madagascar	1	Thailand	2
Czech Republic	3	Malawi	1	Togo	1
Denmark	4	Malaysia	3	Trinidad and Tobago	3
Dominica	3	Mali	1	Tunisia	2
Dominican Republic	2	Malta	4	Turkey	3
Ecuador	2	Mauritius	3	Uganda	1
Egypt, Arab Rep.	2	Mexico	3	United Kingdom	4
El Salvador	2	Morocco	2	United States	4
Equatorial Guinea	3	Mozambique	1	Uruguay	3
Estonia	3	Namibia	2	Venezuela, RB	3
Ethiopia	1	Nepal	1	Vietnam	1
Fiji	2	Netherlands	4	Yemen, Rep.	1
Finland	4	New Zealand	4	Zambia	1
				Zimbabwe	1

Table A1. 2: Excluded observations (reason indicated by star)

country	year	IFS-GDP	IFS-POP	AUTHORS
Angola	1960, 1975		*	
Argentina	1975		*	
Austria	1975		*	
Austria	1999	*		
Belgium	1999	*		
Benin	1979		*	
Bolivia	1975, 1984		*	
Brazil	1960, 1985		*	
Bulgaria	2000		*	
Burkina Faso	1973, 1998		*	
Burundi	1965, 1975		*	
Cambodia	1975, 1998		*	
Cameroon	1960,1965		*	
Cameroon	1978, 1990		*	
Chile	1978		*	
Colombia	1977		*	
Congo, Dem. Rep.	1975, 1979		*	
Congo, Dem. Rep.	1992		*	
Cote d'Ivoire	1968		*	
Dominica	1999		*	
Ecuador	1962		*	
El Salvador	1961, 1972		*	
Ethiopia	1960, 1967		*	
Ethiopia	1977		*	
Fiji	1989		*	
France	1999	*		
Gambia, The	1968, 1992		*	
Gambia, The	1971-1981			*
Germany	1991			*
Germany	1999	*		
Ghana	1960, 1963		*	
Ghana	1965	*		
Ghana	1979		*	
Grenada	1983			*
Guatemala	1964, 1974		*	
Guatemala	1976		*	
Guinea-Bissau	1970		*	
Guyana	1977	*		
Guyana	1984-1985			*
Hong Kong, China	1961, 1977		*	
Hungary	1988	*		
India	1961, 1978		*	
Indonesia	1976, 1990		*	
Indonesia	1998		*	
Israel	1970-1979			*
Italy	1999	*		
Jordan	1961, 1977		*	
Jordan	1984		*	
Kazakhstan	1994	*		
Kenya	1972-1985			*
Kenya	1990, 1993		*	
Kenya	1997		*	
Korea, Rep.	1960		*	
Kyrgyz Republic	1993	*		
Luxembourg	1985			*
Luxembourg	1999	*		
Madagascar	1975, 1984		*	
Madagascar	1990, 1992		*	
Malaysia	1960		*	
Mali	1961, 1975		*	
Mali	1977, 1986		*	
Malta	1968, 1975		*	
Malta	1979, 2000	*		
Morocco	1982		*	
Namibia	1990	*		
Nepal	1970		*	
Netherlands	1967, 1970			*
Netherlands	1999	*		
Nigeria	1960, 1984		*	
Pakistan	1972, 1976		*	
Pakistan	1998		*	
Panama	1979			*
Papua New Guinea	1997		*	
Philippines	1991		*	
Poland	1960		*	
Poland	1980	*		
Portugal	1960, 1979		*	
Portugal	1999	*		
Spain	1999	*		
Swaziland	1997		*	
Syrian Arab Republic	1960		*	
Syrian Arab Republic	1978	*	*	
Tanzania	1976, 1998		*	
Tanzania	1987	*		
Trinidad and Tobago	1975		*	
Tunisia	1973		*	
United Kingdom	1961		*	
United States	1960		*	
Uruguay	1975		*	
Venezuela, RB	1975		*	
Vietnam	1975		*	
Vietnam	1977		*	
Yemen, Rep.	1994		*	
Zimbabwe	1975		*	

Table A1. 3: Reasons for exclusion of IFS data beyond those indicated in the database

Country	Years	Reason
The Gambia	1971–81	Illogical value of deflator in 1971, 1974 and 1980 leading to reported change in real GDP substantially different from other sources.
Germany	1991	Effect of reunification. The IFS database indicates a break in the series for nominal GDP and the deflator, but not for the GDP volume. Statistical Office of Germany reports a “.“ growth for this year.
Grenada	1983	A drop in the deflator by 16%.
Guyana	1984–85	The deflator moved up and then back down by an equal amount.
Israel	1970–79	IFS GDP volume data report zero growth in 1969, 1971, 1972 and 1974. 1975 and 1980 are marked as points where multiple series have been linked by splicing (this is not considered by IFS as a break in comparability). Problem may lie in the deflators for 1970, 1973 and 1977, no obvious explanation was found. As a result, level GDP volume moves down and up in 1977 and 1978. Data on Israeli GDP are also available from the Israeli Statistical Office and do not share this characteristic.
Kenya	1972–85	Probably a problem with the deflator. No break is indicated in the IFS database, but could be in years 1972, 1977, 1978 and 1979. 1972 GDP volume is marked as linking multiple series by splicing. GDP volume decreases in 1978 and returns to about its previous levels in 1979. No obvious explanation was found for the 23% rise in 1985.
Luxembourg	1985	Nominal GDP growth 22%, GDP deflator growth 15%, GDP vol. (2000=100) -40% (while series GDP at constant 1985 prices indicates a growth of 3%) – might be a base shift in this year.
Netherlands	1967, 1970	Probably a problem of deflators for 1966 and 1969. Eurostat provides data on real GDP from 1969 onwards. Implied growth rate for 1970 is about 5 % (IFS has about 29 %). Netherlands' Statistical Office has data since 1921, respective real growth rates for 1967 and 1970 are 5.3% and 5.7%.
Panama	1979	Probably a problem of the deflator in this particular year leading to a reported change in real GDP substantially different from other sources.

The analysis pays special attention to heterogeneity in the differences in growth measurement across income levels. The sample can be broken down into four groups by level of income according to the World Bank's classification. Countries are divided according to 2004 GNI per capita, calculated using the World Bank's Atlas method.[48] Table A1. 4 shows the structure of the country coverage.

Table A1. 4: Number of countries by income group

Income group	Name	Income	number of countries
1	Low income	$825 or less	39
2	Lower middle income	$826 - $3,255	34
3	Upper middle income	$3,256 - $10,065	31
4	High income	$10,066 or more	31

Table A1. 5: WDI: Use of the Atlas conversion factor

country	use of the Atlas conversion factor	country	use of the Atlas conversion factor
Angola	1991–96	Latvia	1991–95
Argentina	1971–84	Libya	1986
Armenia	1990–95	Lithuania	1990–95
Azerbaijan	1992–95	Moldova	1987–95
Bangladesh	1960–03	Mozambique	1992–95
Belarus	1990–95	Nepal	1966–03
Benin	1992	Nicaragua	1965–93
Bolivia	1960–85	Niger	1993
Bulgaria	1978-89, 1991–92	Nigeria	1971–98
Burkina Faso	1992–93	Pakistan	1972–03
Cameroon	1965–01	Papua New Guinea	1989
Canada		Paraguay	1982–88
Colombia	1992–94	Peru	1985–91
Congo, Dem.	1999–2001	Romania	1987–89, 1992
Egypt, Arab	1965–91	Russian Federation	1987–95
El Salvador	1982–90	Sierra Leone	1971–79, 1987
Estonia	1991–95	Somalia	1977–90
Ethiopia	1965–03	Sudan	1970–95
Gabon	1993	Syrian Arab Rep.	1970–03
Georgia	1990–95	Tajikistan	1990–95
Ghana	1973–87	Turkmenistan	1987–95
Guinea-Bissau	1970–86	Uganda	1980–99
Haiti	1991	Ukraine	1990–95
Honduras	1988–89	Uzbekistan	1990–95
China	1978–93	Vietnam	1991
India	1960–03	Yemen, Rep.	1991–96
Iran, Islamic Rep.	1980–90	Zambia	1990–92
Kazakhstan	1987–95	Zimbabwe	1991, 1998
Kyrgyz Republic	1990–95		

48 http://web.worldbank.org/WBSITE/EXTERNAL/DATASTATISTICS/0,,contentMDK:20420458~menuPK:64133156~pagePK:64133150~piPK:64133175~theSitePK:239419,00.html

Appendix 2: Additional comparison of economic growth rates

Table A2. 1: Correlations of GDP per capita growth rate by income and time period

Income 1

Time Period	Number of Obs.	IFS and PWT	IFS and WDI	WDI and PWT
1961-1965	40	0.23	0.74	0.46
1966-1970	53	0.42	0.60	0.53
1971-1975	91	0.39	0.68	0.76
1976-1980	106	0.41	0.72	0.69
1981-1985	123	0.62	0.87	0.77
1986-1990	152	0.61	0.93	0.67
1991-1995	173	0.63	0.91	0.60
1996-2000	144	0.34	0.79	0.43

Income 2

Time Period	Number of Obs.	IFS and PWT	IFS and WDI	WDI and PWT
1961-1965	63	0.76	0.84	0.85
1966-1970	89	0.74	0.84	0.88
1971-1975	97	0.74	0.88	0.80
1976-1980	105	0.75	0.91	0.80
1981-1985	121	0.55	0.91	0.64
1986-1990	132	0.80	0.96	0.85
1991-1995	150	0.78	0.95	0.81
1996-2000	152	0.83	0.96	0.79

Income 3

Time Period	Number of Obs.	IFS and PWT	IFS and WDI	WDI and PWT
1961-1965	49	0.73	0.71	0.84
1966-1970	56	0.38	0.83	0.47
1971-1975	66	0.73	0.77	0.84
1976-1980	87	0.60	0.77	0.60
1981-1985	114	0.60	0.81	0.72
1986-1990	118	0.63	0.78	0.79
1991-1995	134	0.67	0.95	0.77
1996-2000	141	0.90	0.97	0.90

Income 4

Time Period	Number of Obs.	IFS and PWT	IFS and WDI	WDI and PWT
1961-1965	94	0.39	0.83	0.22
1966-1970	112	0.85	0.87	0.99
1971-1975	123	0.97	0.98	0.99
1976-1980	132	0.94	0.96	0.98
1981-1985	139	0.90	0.91	0.98
1986-1990	144	0.90	0.92	0.97
1991-1995	147	0.88	0.96	0.88
1996-2000	136	0.88	0.97	0.90

Table A2. 2: Comparison of the direction of implied economic growth, PWT and WDI vs. IFS

			PWT growth		WDI growth	
			-	+	-	+
Total	IFS growth	-	20	6	22	3
		+	8	67	3	71
Low income	IFS growth	-	32	11	36	7
		+	14	44	6	51
Lower-middle income	IFS growth	-	20	6	24	2
		+	7	67	3	71
Upper-middle income	IFS growth	-	17	5	20	2
		+	8	70	4	74
Upper income	IFS growth	-	11	2	11	2
		+	3	83	2	85

Table A2. 3: Comparison of the direction of implied economic growth, PWT vs. WDI

			PWT growth	
			-	+
Total	WDI growth	-	22	5
		+	7	66
Low income	WDI growth	-	33	8
		+	12	47
Lower-middle income	WDI growth	-	20	6
		+	7	66
Upper-middle income	WDI growth	-	19	5
		+	6	70
Upper income	WDI growth	-	12	1
		+	2	85

Appendix 3: Additional Evidence from Growth Regressions

Table A3. 1: AHM - "empty", financial development approximated by private credit

	AHM original data	IFS	AHM (IFS sample)	PWT	AHM (PWT sample)	WDI	AHM (WDI sample)
Private credit	-0.015	-0.007	-0.005	-0.018	-0.017	-0.015	-0.014
	[0.016]	[0.014]	[0.018]	[0.014]	[0.015]	[0.016]	[0.015]
Initial income	1.507	0.84	0.84	1.538	1.58	1.513	1.418
	[0.480]**	[0.542]	[0.669]	[0.444]**	[0.472]**	[0.482]**	[0.459]**
Interactive term	-0.061	-0.039	-0.046	-0.059	-0.062	-0.048	-0.054
	[0.011]**	[0.012]**	[0.015]**	[0.011]**	[0.011]**	[0.012]**	[0.012]**
Observations	71	50	50	67	67	67	67
R-squared	0.50	0.35	0.35	0.46	0.46	0.5	0.48

Note: Standard errors in brackets; * significant at 5%; ** significant at 1%;
In fact, R-squared values do not have a good meaning in 2SLS (IV) estimation since the model sum of squares is computed based on the values of the RHS endogenous variables and not their instruments, and, since the constant-only model may not be nested within the 2SLS model, TSS may be smaller than RSS.

Table A3. 2: AHM - "empty", financial development approximated by liquid liabilities

	AHM original data	IFS	AHM (IFS sample)	PWT	AHM (PWT sample)	WDI	AHM (WDI sample)
Liquid liabilities	-0.029	-0.014	-0.016	-0.035	-0.034	-0.025	-0.029
	[0.028]	[0.022]	[0.026]	[0.020]	[0.022]	[0.021]	[0.025]
Initial income	2.648	1.305	1.52	2.869	2.859	2.304	2.541
	[0.849]**	[0.860]	[1.009]	[0.647]**	[0.727]**	[0.710]**	[0.830]**
Interactive term	-0.076	-0.039	-0.048	-0.086	-0.084	-0.057	-0.072
	[0.021]**	[0.019]	[0.023]*	[0.017]**	[0.019]**	[0.019]**	[0.022]**
Observations	71	50	50	67	67	67	67
R-squared	0.15	0.2	0.27	0.35	0.27	0.43	0.1

Note: See note for Table A3. 1.

Table A3. 3: AHM - "empty", financial development approximated by bank assets

	AHM original data	IFS	AHM (IFS sample)	PWT	AHM (PWT sample)	WDI	AHM (WDI sample)
Bank assets	-0.019	-0.019	-0.021	-0.022	-0.021	-0.02	-0.021
	[0.018]	[0.018]	[0.022]	[0.017]	[0.019]	[0.018]	[0.021]
Initial income	1.891	1.635	1.873	1.92	1.964	1.982	2.014
	[0.529]**	[0.733]*	[0.908]*	[0.490]**	[0.557]**	[0.558]**	[0.623]**
Interactive term	-0.081	-0.07	-0.085	-0.08	-0.082	-0.076	-0.089
	[0.016]**	[0.022]**	[0.028]**	[0.015]**	[0.017]**	[0.020]**	[0.022]**
Observations	71	50	50	67	67	67	67
R-squared	0.35	0.05	0.04	0.35	0.26	0.4	0.13

Note: See note for Table A3. 1.

Table A3. 4: AHM - "empty", financial development approximated by deposit-money banks' share in total bank assets

	AHM original data	IFS	AHM (IFS sample)	PWT	AHM (PWT sample)	WDI	AHM (WDI sample)
Commercial-central bank	0	0.082	0.116	-0.041	-0.031	-0.035	-0.011
	[0.157]	[0.093]	[0.113]	[0.176]	[0.180]	[0.151]	[0.193]
Initial income	7.166	2.238	2.065	9.714	9.616	8.121	8.158
	[6.870]	[4.724]	[5.751]	[8.026]	[8.236]	[7.051]	[8.983]
Interactive term	-0.11	-0.049	-0.054	-0.138	-0.138	-0.117	-0.124
	[0.085]	[0.060]	[0.073]	[0.099]	[0.102]	[0.091]	[0.116]
Observations	71	50	50	67	67	67	67
R-squared	.	.	.	.	.	.	.

Note: See note for Table A3. 1.

Table A3. 5: AHM - "empty", final - results with preferred combination of growth and level data

	Private credit			**Liquid liabilities**		
	AHM original data	final	AHM (final sample)	AHM original data	final	AHM (final sample)
Initial income	1.507	0.331	1.032	2.648	1.896	2.318
	[0.480]**	[0.391]	[0.619]	[0.849]**	[0.829]*	[1.051]*
Financial development	-0.015	0.007	-0.01	-0.029	-0.01	-0.03
	[0.016]	[0.010]	[0.016]	[0.028]	[0.016]	[0.025]
Interactive term	-0.061	-0.028	-0.048	-0.076	-0.062	-0.075
	[0.011]**	[0.009]**	[0.014]**	[0.021]**	[0.022]**	[0.027]**
Constant	0.353	-0.923	0.013	1.141	0.015	0.947
	[1.001]	[0.692]	[1.079]	[1.552]	[0.931]	[1.377]
Observations	71	48	48	71	48	48
R-squared	0.5	0.43	0.31	0.15	0.16	0.1

Standard errors in brackets
* significant at 5%; ** significant at 1%
Note: See note for Table A3. 1.

	Bank assets			**Commercial-central bank**		
	AHM original data	final	AHM (final sample)	AHM original data	final	AHM (final sample)
Initial income	1.891	1.319	1.976	7.166	-1.509	1.568
	[0.529]**	[0.615]*	[0.903]*	[6.870]	[2.115]	[5.522]
Financial development	-0.019	0	-0.023	0	0.087	0.122
	[0.018]	[0.014]	[0.023]	[0.157]	[0.053]	[0.120]
Interactive term	-0.081	-0.064	-0.086	-0.11	0.007	-0.047
	[0.016]**	[0.021]**	[0.028]**	[0.085]	[0.026]	[0.069]
Constant	0.137	-0.766	0.234	-1.114	-8.112	-12.022
	[1.032]	[0.818]	[1.261]	[13.764]	[4.779]	[10.734]
Observations	71	48	48	71	48	48
R-squared	0.35	0.11	.	.	0.04	.

Standard errors in brackets
* significant at 5%; ** significant at 1%
Note: See note for Table A3. 1.

Table A3. 6: AHM - "policy", financial development approximated by private credit

	AHM original data	IFS	AHM (IFS sample)	PWT	AHM (PWT sample)	WDI	AHM (WDI sample)
Private credit	-0.013	-0.003	0	-0.019	-0.016	-0.014	-0.013
	[0.020]	[0.019]	[0.022]	[0.017]	[0.018]	[0.015]	[0.018]
Initial income	1.193	0.484	0.107	1.687	1.362	1.12	0.973
	[0.642]	[0.811]	[0.955]	[0.602]**	[0.650]*	[0.517]*	[0.614]
Interactive term	-0.063	-0.039	-0.044	-0.064	-0.064	-0.051	-0.057
	[0.012]**	[0.014]**	[0.016]**	[0.012]**	[0.012]**	[0.010]**	[0.012]**
Observations	63	46	46	60	60	59	59
R-squared	0.54	0.41	0.47	0.48	0.49	0.59	0.52

Note: See note for Table A3. 1.

Table A3. 7: AHM - "policy", financial development approximated by liquid liabilities

	AHM original data	IFS	AHM (IFS sample)	PWT	AHM (PWT sample)	WDI	AHM (WDI sample)
Liquid liabilities	-0.03	-0.012	-0.01	-0.031	-0.028	-0.025	-0.025
	[0.030]	[0.028]	[0.032]	[0.021]	[0.023]	[0.022]	[0.025]
Initial income	2.388	1.103	0.841	2.498	2.108	2.176	2.073
	[1.000]*	[1.243]	[1.397]	[0.753]**	[0.825]*	[0.834]*	[0.948]*
Interactive term	-0.077	-0.043	-0.049	-0.083	-0.08	-0.067	-0.072
	[0.020]**	[0.021]	[0.024]*	[0.016]**	[0.018]**	[0.018]**	[0.020]**
Observations	63	46	46	60	60	59	59
R-squared	0.31	0.29	0.41	0.39	0.39	0.31	0.26

Note: See note for Table A3. 1.

Table A3. 8: AHM - "policy", financial development approximated by bank assets

	AHM original data	IFS	AHM (IFS sample)	PWT	AHM (PWT sample)	WDI	AHM (WDI sample)
Bank assets	-0.02	-0.016	-0.015	-0.025	-0.022	-0.021	-0.021
	[0.019]	[0.020]	[0.024]	[0.018]	[0.020]	[0.017]	[0.021]
Initial income	1.335	1.138	0.885	1.849	1.517	1.473	1.355
	[0.692]	[1.037]	[1.235]	[0.643]**	[0.723]*	[0.633]*	[0.790]
Interactive term	-0.081	-0.064	-0.074	-0.083	-0.082	-0.079	-0.087
	[0.017]**	[0.023]**	[0.027]**	[0.016]**	[0.017]**	[0.017]**	[0.021]**
Observations	63	46	46	60	60	59	59
R-squared	0.4	0.19	0.25	0.37	0.33	0.39	0.22

Note: See note for Table A3. 1.

Table A3. 9: AHM - "policy", financial development approximated by deposit-money banks' share in total bank assets

	AHM original data	IFS	AHM (IFS sample)	PWT	AHM (PWT sample)	WDI	AHM (WDI sample)
Commercial-central bank	0.031	0.09	0.129	0.006	0.028	0.031	0.042
	[0.184]	[0.129]	[0.153]	[0.181]	[0.189]	[0.167]	[0.197]
Initial income	5.279	1.972	0.961	7.471	6.297	4.573	4.441
	[7.220]	[7.395]	[8.812]	[7.176]	[7.506]	[6.457]	[7.628]
Interactive term	-0.1	-0.051	-0.049	-0.124	-0.113	-0.086	-0.09
	[0.085]	[0.088]	[0.105]	[0.084]	[0.088]	[0.076]	[0.090]
Observations	63	46	46	60	60	59	59
R-squared	.	.	.	.	.	.	.

Note: See note for Table A3. 1

Table A3. 10: AHM - "policy", final - results with preferred combination of growth and level data

	Private credit			Liquid liabilities		
	AHM original data	final	AHM (final sample)	AHM original data	final	AHM (final sample)
Initial income	1.193	-0.399	0.399	2.388	0.357	0.892
	[0.642]	[0.630]	[0.984]	[1.000]*	[0.947]	[1.230]
Financial development	-0.013	0.012	-0.005	-0.03	0.005	-0.013
	[0.020]	[0.013]	[0.021]	[0.030]	[0.017]	[0.026]
Interactive term	-0.063	-0.027	-0.046	-0.077	-0.041	-0.061
	[0.012]**	[0.011]*	[0.016]**	[0.020]**	[0.018]*	[0.024]*
Observations	63	44	44	63	44	44
R-squared	0.54	0.54	0.39	0.31	0.46	0.36

Standard errors in brackets
* significant at 5%; ** significant at 1%
Note: See note for Table A3. 1.

	Bank assets			Commercial-central bank		
	AHM original data	final	AHM (final sample)	AHM original data	final	AHM (final sample)
Initial income	1.335	0.326	1.081	5.279	-2.192	0.613
	[0.692]	[0.871]	[1.275]	[7.220]	[3.797]	[9.923]
Financial development	-0.02	0.004	-0.017	0.031	0.118	0.136
	[0.019]	[0.015]	[0.025]	[0.184]	[0.074]	[0.178]
Interactive term	-0.081	-0.047	-0.073	-0.1	-0.002	-0.045
	[0.017]**	[0.019]*	[0.027]*	[0.085]	[0.046]	[0.116]
Observations	63	44	44	63	44	44
R-squared	0.4	0.38	0.17		0.09	

Standard errors in brackets
* significant at 5%; ** significant at 1%
Note: See note for Table A3. 1.

Table A3. 11: AHM - "full", financial development approximated by private credit

	AHM original data	IFS	AHM (IFS sample)	PWT	AHM (PWT sample)	WDI	AHM (WDI sample)
Private credit	-0.016	-0.004	-0.002	-0.022	-0.019	-0.014	-0.015
	[0.020]	[0.018]	[0.022]	[0.018]	[0.020]	[0.015]	[0.018]
Initial income	1.131	0.313	0.064	1.764	1.376	0.739	0.706
	[0.758]	[0.842]	[1.013]	[0.768]*	[0.814]	[0.629]	[0.751]
Interactive term	-0.063	-0.035	-0.042	-0.066	-0.064	-0.048	-0.054
	[0.014]**	[0.014]*	[0.017]*	[0.014]**	[0.014]**	[0.011]**	[0.013]**
Observations	63	46	46	60	60	59	59
R-squared	0.56	0.49	0.51	0.47	0.5	0.62	0.56

Note: See note for Table A3. 1.

Table A3. 12: AHM - “full”, financial development approximated by liquid liabilities

	AHM original data	IFS	AHM (IFS sample)	PWT	AHM (PWT sample)	WDI	AHM (WDI sample)
Liquid liabilities	-0.027	-0.012	-0.008	-0.03	-0.026	-0.021	-0.022
	[0.030]	[0.027]	[0.030]	[0.022]	[0.023]	[0.023]	[0.025]
Initial income	2.384	1.031	0.747	2.494	2.035	1.961	1.934
	[1.133]*	[1.229]	[1.366]	[0.893]**	[0.957]*	[0.997]	[1.112]
Interactive term	-0.073	-0.04	-0.044	-0.081	-0.077	-0.063	-0.067
	[0.020]**	[0.020]	[0.022]	[0.017]**	[0.018]**	[0.018]**	[0.020]**
Observations	63	46	46	60	60	59	59
R-squared	0.38	0.41	0.52	0.43	0.45	0.37	0.35

Note: See note for Table A3. 1.

Table A3. 13: AHM - “full”, financial development approximated by bank assets

	AHM original data	IFS	AHM (IFS sample)	PWT	AHM (PWT sample)	WDI	AHM (WDI sample)
Bank assets	-0.022	-0.016	-0.016	-0.028	-0.024	-0.021	-0.022
	[0.020]	[0.019]	[0.023]	[0.019]	[0.021]	[0.018]	[0.022]
Initial income	1.365	1	0.841	2.054	1.651	1.302	1.306
	[0.820]	[1.039]	[1.265]	[0.827]*	[0.906]	[0.799]	[0.994]
Interactive term	-0.081	-0.058	-0.069	-0.086	-0.083	-0.077	-0.086
	[0.018]**	[0.022]*	[0.026]*	[0.018]**	[0.020]**	[0.019]**	[0.024]**
Observations	63	46	46	60	60	59	59
R-squared	0.43	0.36	0.38	0.36	0.35	0.42	0.27

Note: See note for Table A3. 1.

Table A3. 14: AHM - “full”, financial development approximated by deposit money banks’ share in total bank assets

	AHM original data	IFS	AHM (IFS sample)	PWT	AHM (PWT sample)	WDI	AHM (WDI sample)
Commercial-central bank	0.013	0.091	0.119	0	0.028	-0.005	0.005
	[0.184]	[0.110]	[0.136]	[0.188]	[0.191]	[0.156]	[0.188]
Initial income	5.645	-0.394	-0.801	7.378	5.705	4.839	4.823
	[7.792]	[6.589]	[8.121]	[8.305]	[8.438]	[6.696]	[8.051]
Interactive term	-0.102	-0.022	-0.027	-0.118	-0.102	-0.089	-0.094
	[0.089]	[0.077]	[0.095]	[0.095]	[0.096]	[0.076]	[0.092]
Observations	63	46	46	60	60	59	59
R-squared	.	0.15	0.15	.	.	.	.

Note: See note for Table A3. 1.

Table A3. 15: AHM - “full” , final - results with preferred combination of growth and level data

	Private credit			Liquid liabilities		
	AHM original data	final	AHM (final sample)	AHM original data	final	AHM (final sample)
Initial income	1.131	-0.713	0.426	2.384	0.235	0.963
	[0.758]	[0.695]	[1.067]	[1.133]*	[1.024]	[1.268]
Financial development	-0.016	0.012	-0.008	-0.027	0.005	-0.013
	[0.020]	[0.013]	[0.021]	[0.030]	[0.017]	[0.025]
Interactive term	-0.063	-0.022	-0.045	-0.073	-0.037	-0.058
	[0.014]**	[0.011]	[0.017]*	[0.020]**	[0.018]	[0.023]*
Observations	63	44	44	63	44	44
R-squared	0.56	0.61	0.44	0.38	0.56	0.47

Standard errors in brackets
* significant at 5%; ** significant at 1%
Note: See note for Table A3. 1.

	Bank assets			Commercial-central bank		
	AHM original data	final	AHM (final sample)	AHM original data	final	AHM (final sample)
Initial income	1.365	0.097	1.093	5.645	-4.552	-0.829
	[0.820]	[0.936]	[1.323]	[7.792]	[3.902]	[9.897]
Financial development	-0.022	0.004	-0.019	0.013	0.136	0.122
	[0.020]	[0.014]	[0.024]	[0.184]	[0.067]*	[0.167]
Interactive term	-0.081	-0.041	-0.068	-0.102	0.024	-0.026
	[0.018]**	[0.019]*	[0.026]*	[0.089]	[0.046]	[0.113]
Observations	63	44	44	63	44	44
R-squared	0.43	0.52	0.31		0.39	

Standard errors in brackets
* significant at 5%; ** significant at 1%
Note: See note for Table A3. 1.

Table A3. 16: BC –"initial conditions", 1960-2000

	BC original sample	IFS	BC (IFS sample)	WDI	BC (WDI sample)	PWT	BC (PWT sample)
Initial income	-6.29 [0.60]**	-4.74 [0.76]**	-5.39 [0.78]**	-5.74 [0.68]**	-5.64 [0.67]**	-5.66 [0.72]**	-5.83 [0.65]**
Life expectancy	0.07 [0.01]**	0.07 [0.02]**	0.07 [0.02]**	0.07 [0.01]**	0.06 [0.01]**	0.06 [0.01]**	0.06 [0.01]**
Log of population	0.29 [0.06]**	0.25 [0.08]**	0.25 [0.08]**	0.33 [0.07]**	0.32 [0.07]**	0.27 [0.07]**	0.3 [0.06]**
Trade instrument	4.77 [1.15]**	4.41 [1.33]**	4.91 [1.37]**	4.57 [1.23]**	4.46 [1.20]**	5.46 [1.27]**	4.8 [1.15]**
Geography	0.53 [0.13]**	0.25 [0.20]	0.47 [0.20]*	0.54 [0.16]**	0.49 [0.16]**	0.52 [0.15]**	0.5 [0.14]**
Institutions	2.84 [0.63]**	2.12 [0.95]*	2.26 [0.98]*	2.43 [0.71]**	2.67 [0.69]**	2.31 [0.72]**	2.68 [0.65]**
Constant	-7.05 [1.22]**	-6.87 [1.71]**	-6.43 [1.76]**	-7.38 [1.41]**	-7.25 [1.38]**	-6.47 [1.38]**	-6.98 [1.24]**
Observations Adjusted R-squared	84 0.76	49 0.69	49 0.71	71 0.74	71 0.74	79 0.69	79 0.73

Standard errors in brackets; * significant at 5%; ** significant at 1%

Table A3. 17: BC –"policy", 1960-2000

	BC original sample	IFS	BC (IFS sample)	WDI	BC (WDI sample)	PWT	BC (PWT sample)
Initial income	-6.24 [0.58]**	-4.84 [0.73]**	-5.49 [0.74]**	-5.71 [0.67]**	-5.62 [0.65]**	-5.63 [0.71]**	-5.81 [0.63]**
Life expectancy	0.06 [0.01]**	0.06 [0.02]**	0.06 [0.02]**	0.06 [0.01]**	0.06 [0.01]**	0.06 [0.01]**	0.06 [0.01]**
Log of population	0.28 [0.06]**	0.24 [0.08]**	0.24 [0.08]**	0.31 [0.07]**	0.3 [0.07]**	0.27 [0.07]**	0.28 [0.06]**
Trade instrument	3.55 [1.20]**	3.64 [1.39]*	4.02 [1.41]**	3.59 [1.27]**	3.38 [1.23]**	4.38 [1.36]**	3.64 [1.19]**
Geography	0.48 [0.13]**	0.34 [0.19]	0.56 [0.19]**	0.53 [0.16]**	0.48 [0.15]**	0.49 [0.15]**	0.47 [0.13]**
Institutions	2.34 [0.65]**	1.44 [0.95]	1.5 [0.97]	1.92 [0.73]*	2.13 [0.71]**	1.86 [0.76]*	2.18 [0.67]**
Inflation	-0.01 [0.01]	0 [0.01]	0 [0.01]	-0.01 [0.01]	-0.01 [0.01]	-0.01 [0.01]	-0.01 [0.01]
Budget balance	0.07 [0.03]*	0.1 [0.05]*	0.1 [0.05]*	0.06 [0.03]*	0.06 [0.03]*	0.03 [0.03]	0.06 [0.03]*
Sachs-Warner openness	0.48 [0.29]	0.61 [0.43]	0.69 [0.44]	0.34 [0.33]	0.42 [0.32]	0.55 [0.33]	0.46 [0.29]
Constant	-6 [1.22]**	-5.47 [1.73]**	-4.92 [1.76]**	-6.3 [1.47]**	-6.04 [1.42]**	-5.73 [1.42]**	-5.97 [1.25]**
Observations Adjusted R-squared	84 0.79	49 0.74	49 0.76	71 0.76	71 0.77	79 0.71	79 0.77

Standard errors in brackets; * significant at 5%; ** significant at 1%

Table A3. 18: BC –“ initial conditions”, 1960-1980

	BC original sample	IFS	BC (IFS sample)	WDI	BC (WDI sample)	PWT	BC (PWT sample)
Initial income	-6.23 [0.88]**	-5.04 [1.10]**	-6.17 [1.06]**	-5.75 [0.98]**	-5.8 [0.95]**	-5.71 [1.11]**	-6.04 [0.97]**
Life expectancy	0.08 [0.02]**	0.11 [0.03]**	0.1 [0.03]**	0.07 [0.02]**	0.07 [0.02]**	0.09 [0.02]**	0.08 [0.02]**
Log of population	0.21 [0.09]*	0.3 [0.11]**	0.31 [0.11]**	0.2 [0.10]*	0.19 [0.09]*	0.19 [0.10]	0.21 [0.09]*
Trade instrument	3.39 [1.67]*	4.17 [1.90]*	5.04 [1.84]**	2.75 [1.77]	3.05 [1.71]	4.19 [1.97]*	3.35 [1.72]
Geography	0.32 [0.19]	0.43 [0.30]	0.7 [0.29]*	0.27 [0.24]	0.2 [0.23]	0.39 [0.23]	0.33 [0.20]
Institutions	2.62 [0.92]**	0.1 [1.37]	0.3 [1.33]	2.76 [1.01]**	2.9 [0.98]**	1.64 [1.12]	2.53 [0.98]*
Constant	-5.38 [1.77]**	-7.71 [2.50]**	-7.17 [2.43]**	-5.02 [2.02]*	-4.94 [1.96]*	-4.97 [2.13]*	-5.28 [1.86]**
Observations	84	45	45	70	70	79	79
Adjusted R-squared	0.55	0.57	0.65	0.5	0.52	0.44	0.51

Standard errors in brackets; * significant at 5%; ** significant at 1%

Table A3. 19: BC –“policy”, 1960-1980

	BC original sample	IFS	BC (IFS sample)	WDI	BC (WDI sample)	PWT	BC (PWT sample)
Initial income	-6.51 [0.82]**	-4.99 [0.97]**	-6.04 [1.00]**	-6.08 [0.95]**	-6.17 [0.91]**	-5.82 [0.99]**	-6.44 [0.92]**
Life expectancy	0.07 [0.02]**	0.11 [0.03]**	0.09 [0.03]**	0.06 [0.02]**	0.06 [0.02]**	0.06 [0.02]**	0.07 [0.02]**
Log of population	0.24 [0.09]**	0.26 [0.11]*	0.24 [0.11]*	0.25 [0.10]*	0.23 [0.10]*	0.22 [0.10]*	0.25 [0.09]**
Trade instrument	3.46 [1.72]*	3.53 [1.83]	4.06 [1.90]*	3.16 [1.84]	3.19 [1.77]	4.06 [1.92]*	3.51 [1.79]
Geography	0.37 [0.19]	0.27 [0.28]	0.63 [0.29]*	0.38 [0.26]	0.33 [0.25]	0.51 [0.22]*	0.4 [0.21]
Institutions	2.09 [0.95]*	-0.14 [1.35]	-0.31 [1.40]	1.94 [1.08]	2.1 [1.04]*	0.83 [1.10]	2.02 [1.02]
Inflation	-0.01 [0.01]	-0.01 [0.01]	0 [0.01]	0 [0.01]	0 [0.01]	0 [0.01]	-0.01 [0.01]
Budget balance	0.14 [0.04]**	0.2 [0.06]**	0.16 [0.06]*	0.13 [0.05]**	0.12 [0.04]**	0.06 [0.05]	0.13 [0.05]**
Sachs-Warner openness	0.32 [0.35]	0.23 [0.51]	0.58 [0.52]	0.32 [0.41]	0.47 [0.39]	0.85 [0.39]*	0.31 [0.37]
Constant	-4.41 [1.78]*	-6.18 [2.66]*	-4.66 [2.75]	-4.06 [2.09]	-3.82 [2.01]	-3.59 [2.03]	-4.38 [1.89]*
Observations	77	44	44	65	65	72	72
Adjusted R-squared	0.65	0.7	0.72	0.6	0.62	0.55	0.61

Standard errors in brackets; * significant at 5%; ** significant at 1%

Table A3. 20: BC –" initial conditions", 1980-2000

	BC original sample	IFS	BC (IFS sample)	WDI	BC (WDI sample)	PWT	BC (PWT sample)
Initial income	-7.7 [1.12]**	-7.29 [1.29]**	-7.84 [1.19]**	-7.34 [1.26]**	-7.21 [1.21]**	-5.06 [1.51]**	-6.81 [1.21]**
Life expectancy	0.09 [0.02]**	0.09 [0.02]**	0.08 [0.02]**	0.1 [0.02]**	0.09 [0.02]**	0.04 [0.03]	0.07 [0.02]**
Log of population	0.38 [0.10]**	0.38 [0.11]**	0.33 [0.10]**	0.38 [0.10]**	0.37 [0.10]**	0.32 [0.12]*	0.37 [0.10]**
Trade instrument	8.27 [1.87]**	7.05 [1.99]**	7.13 [1.85]**	7.79 [1.97]**	8.09 [1.89]**	6.21 [2.83]*	5.98 [2.26]*
Geography	0.76 [0.22]**	0.47 [0.25]	0.61 [0.23]**	0.69 [0.25]**	0.74 [0.24]**	0.72 [0.30]*	0.76 [0.24]**
Institutions	4.67 [1.14]**	5.27 [1.38]**	5.6 [1.27]**	4.51 [1.23]**	4.34 [1.19]**	3.33 [1.50]*	4.36 [1.20]**
Constant	-11.98 [2.03]**	-12.21 [2.30]**	-10.77 [2.13]**	-12.27 [2.17]**	-11.59 [2.08]**	-7.45 [2.70]**	-10.68 [2.16]**
Observations Adjusted R-squared	84 0.63	70 0.57	70 0.6	81 0.58	81 0.59	78 0.36	78 0.56

Standard errors in brackets; * significant at 5%; ** significant at 1%

Table A3. 21: BC –"policy", 1980-2000

	BC original sample	IFS	BC (IFS sample)	WDI	BC (WDI sample)	PWT	BC (PWT sample)
Initial income	-7.48 [1.07]**	-7.05 [1.28]**	-7.62 [1.19]**	-7.23 [1.24]**	-7.16 [1.17]**	-4.74 [1.50]**	-6.77 [1.18]**
Life expectancy	0.07 [0.02]**	0.08 [0.03]**	0.07 [0.02]**	0.08 [0.02]**	0.07 [0.02]**	0.03 [0.03]	0.06 [0.02]*
Log of population	0.37 [0.09]**	0.41 [0.10]**	0.35 [0.10]**	0.38 [0.10]**	0.37 [0.09]**	0.33 [0.12]**	0.38 [0.09]**
Trade instrument	6.51 [1.82]**	5.82 [2.02]**	5.94 [1.87]**	6.3 [1.96]**	6.44 [1.84]**	4.56 [2.82]	4.63 [2.21]*
Geography	0.68 [0.21]**	0.43 [0.24]	0.58 [0.23]*	0.64 [0.24]**	0.69 [0.23]**	0.65 [0.29]*	0.7 [0.23]**
Institutions	3.7 [1.12]**	4.49 [1.40]**	4.81 [1.30]**	3.65 [1.24]**	3.44 [1.17]**	2.1 [1.52]	3.45 [1.19]**
Inflation	-0.01 [0.01]	-0.01 [0.01]	-0.01 [0.01]	-0.01 [0.01]	-0.01 [0.01]	-0.01 [0.01]*	-0.01 [0.01]
Budget balance	0.05 [0.03]	0.08 [0.05]	0.06 [0.05]	0.05 [0.04]	0.05 [0.03]	0.04 [0.05]	0.04 [0.04]
Sachs-Warner openness	1.19 [0.46]*	0.62 [0.54]	0.69 [0.50]	0.93 [0.51]	1.13 [0.48]*	0.86 [0.60]	1.1 [0.47]*
Constant	-10.02 [2.01]**	-11.05 [2.31]**	-9.67 [2.14]**	-10.66 [2.19]**	-9.75 [2.06]**	-6.17 [2.70]*	-9.23 [2.12]**
Observations Adjusted R-squared	84 0.68	70 0.61	70 0.64	81 0.63	81 0.65	78 0.43	78 0.62

Standard errors in brackets; * significant at 5%; ** significant at 1%

Table A3. 22: BC –"initial conditions", final - results with preferred combination of growth and level data

	1960-2000			1960-1980			1980-2000		
	BC original sample	final	BC final sample	BC original sample	final	BC final sample	BC original sample	final	BC final sample
Initial income	-6.29	-4.3	-5.34	0.08	0.12	0.11	0.09	0.1	0.08
	[0.60]**	[0.69]**	[0.78]**	[0.02]**	[0.03]**	[0.03]**	[0.02]**	[0.02]**	[0.02]**
Life expectancy	0.07	0.08	0.07	-6.23	-4.5	-6.12	-7.7	-7.38	-7.84
	[0.01]**	[0.02]**	[0.02]**	[0.88]**	[0.99]**	[1.07]**	[1.12]**	[1.35]**	[1.19]**
Log of population	0.29	0.25	0.28	0.21	0.32	0.34	0.38	0.4	0.33
	[0.06]**	[0.08]**	[0.08]**	[0.09]*	[0.11]**	[0.11]**	[0.10]**	[0.11]**	[0.10]**
Trade instrument	4.77	3.68	4.84	3.39	3.18	4.78	8.27	6.7	7.13
	[1.15]**	[1.35]**	[1.38]**	[1.67]*	[1.91]	[1.87]*	[1.87]**	[2.02]**	[1.85]**
Geography	0.53	0.11	0.39	0.32	0.19	0.58	0.76	0.39	0.61
	[0.13]**	[0.20]	[0.21]	[0.19]	[0.31]	[0.30]	[0.22]**	[0.25]	[0.23]**
Institutions	2.84	2.54	2.42	2.62	0.73	0.55	4.67	5.57	5.6
	[0.63]**	[0.95]*	[0.98]*	[0.92]**	[1.38]	[1.35]	[1.14]**	[1.44]**	[1.27]**
Constant	-7.05	-7.57	-7.19	-5.38	-9.05	-8.16	-11.98	-12.94	-10.77
	[1.22]**	[1.75]**	[1.83]**	[1.77]**	[2.57]**	[2.56]**	[2.03]**	[2.35]**	[2.13]**
Observations	84	47	47	84	43	43	84	70	70
Adjusted R-squared	0.76	0.71	0.72	0.55	0.59	0.65	0.63	0.56	0.6

Standard errors in brackets
* significant at 5%; ** significant at 1%

Table A3. 23: BC –"policy", final - results with preferred combination of growth and level data

	1960-2000			1960-1980			1980-2000		
	BC original sample	final	BC final sample	BC original sample	final	BC final sample	BC original sample	final	BC final sample
Initial income	-6.24	-4.38	-5.44	-6.51	-4.63	-6.05	-7.48	-7.13	-7.62
	[0.58]**	[0.66]**	[0.73]**	[0.82]**	[0.92]**	[1.01]**	[1.07]**	[1.35]**	[1.19]**
Life expectancy	0.06	0.07	0.06	0.07	0.11	0.09	0.07	0.08	0.07
	[0.01]**	[0.02]**	[0.02]**	[0.02]**	[0.03]**	[0.03]**	[0.02]**	[0.03]**	[0.02]**
Log of population	0.28	0.25	0.27	0.24	0.26	0.25	0.37	0.42	0.35
	[0.06]**	[0.08]**	[0.08]**	[0.09]**	[0.11]*	[0.11]*	[0.09]**	[0.10]**	[0.10]**
Trade instrument	3.55	3.02	3.96	3.46	3.3	4.12	6.51	5.48	5.94
	[1.20]**	[1.38]*	[1.41]**	[1.72]*	[1.88]	[1.92]*	[1.82]**	[2.04]**	[1.87]**
Geography	0.48	0.2	0.49	0.37	0.22	0.64	0.68	0.36	0.58
	[0.13]**	[0.20]	[0.20]*	[0.19]	[0.29]	[0.30]*	[0.21]**	[0.24]	[0.23]*
Institutions	2.34	1.88	1.66	2.09	0.3	-0.3	3.7	4.77	4.81
	[0.65]**	[0.96]	[0.97]	[0.95]*	[1.41]	[1.42]	[1.12]**	[1.46]**	[1.30]**
Inflation	-0.01	0	0	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
Budget balance	0.07	0.1	0.11	0.14	0.2	0.16	0.05	0.08	0.06
	[0.03]*	[0.05]*	[0.05]*	[0.04]**	[0.06]**	[0.07]*	[0.03]	[0.05]	[0.05]
Sachs-Warner openness	0.48	0.55	0.71	0.32	0.05	0.57	1.19	0.63	0.69
	[0.29]	[0.43]	[0.44]	[0.35]	[0.52]	[0.53]	[0.46]*	[0.55]	[0.50]
Constant	-6	-6.27	-5.67	-4.41	-6.57	-4.84	-10.02	-11.75	-9.67
	[1.22]**	[1.76]**	[1.80]**	[1.78]*	[2.74]*	[2.80]	[2.01]**	[2.36]**	[2.14]**
Observations	84	47	47	77	43	43	84	70	70
Adjusted R-squared	0.79	0.76	0.78	0.65	0.69	0.72	0.68	0.6	0.64

Standard errors in brackets
* significant at 5%; ** significant at 1%

Table A3. 24: Forbes – Inequality (low quality measure) and growth

	Forbes original data	IFS	WDI	PWT
Inequality (low quality measure)	-0.00047 [0.00027]	-0.00018 [0.00026]	-0.00026 [0.00028]	-0.00028 [0.00028]
Income	-0.00196 [0.00304]	-0.00743 [0.00300]*	-0.00694 [0.00322]*	-0.00836 [0.00318]*
Male education	0.03871 [0.00794]**	0.03266 [0.00784]**	0.03347 [0.00841]**	0.03435 [0.00831]**
Female education	-0.03456 [0.00827]**	-0.02728 [0.00817]**	-0.02851 [0.00876]**	-0.02785 [0.00866]**
Market distortions	-0.00013 [0.00009]	-0.00011 [0.00009]	-0.00011 [0.00010]	-0.00014 [0.00009]
Constant	0.06142 [0.02641]*	0.08828 [0.02608]**	0.08833 [0.02799]**	0.10067 [0.02765]**
Observations R-squared	39 0.48	39 0.5	39 0.47	39 0.51

Standard errors in brackets
* significant at 5%; ** significant at 1%

Table A3. 25: Forbes – final - results with preferred combination of growth and level data

	Forbes original sample	final	Forbes final sample	Forbes original sample	final	Forbes final sample
Inequality (low quality measure)	-0.00047 [0.00027]	-0.00022 [0.00027]	-0.00047 [0.00027]			
Inequality (high quality measure)				-0.00049 [0.00028]	-0.00043 [0.00027]	-0.00049 [0.00028]
Income	-0.00196 [0.00304]	-0.00527 [0.00277]	-0.00196 [0.00304]	-0.00362 [0.00331]	-0.00605 [0.00293]*	-0.00362 [0.00331]
Male education	0.03871 [0.00794]**	0.03644 [0.00790]**	0.03871 [0.00794]**	0.03659 [0.00863]**	0.03658 [0.00820]**	0.03659 [0.00863]**
Female education	-0.03456 [0.00827]**	-0.03234 [0.00781]**	-0.03456 [0.00827]**	-0.03357 [0.00880]**	-0.03356 [0.00802]**	-0.03357 [0.00880]**
Market distortions	-0.00013 [0.00009]	-0.00011 [0.00009]	-0.00013 [0.00009]	-0.00007 [0.00010]	-0.00008 [0.00010]	-0.00007 [0.00010]
Constant	0.06142 [0.02641]*	0.07686 [0.02695]**	0.06142 [0.02641]*	0.07115 [0.03036]*	0.09018 [0.02926]**	0.07115 [0.03036]*
Observations R-squared	39 0.48	39 0.47	39 0.48	36 0.48	36 0.5	36 0.48

Standard errors in brackets
* significant at 5%; ** significant at 1%

Table A3. 26: HK – Labor force quality and growth (measure 2)

	HK original data	IFS	HK (IFS sample)	PWT	HK (PWT sample)	WDI	HK (WDI sample)
Initial income	-0.377 [0.081]**	-0.308 [0.097]**	-0.367 [0.101]**	-0.328 [0.107]**	-0.358 [0.093]**	-0.321 [0.094]**	-0.333 [0.083]**
Quantity of schooling	0.089 [0.102]	0.038 [0.137]	0.094 [0.138]	-0.015 [0.128]	0.072 [0.105]	-0.037 [0.113]	0.01 [0.098]
Annual population growth	-0.224 [0.213]	-0.23 [0.285]	-0.134 [0.278]	-0.133 [0.254]	-0.164 [0.233]	-0.34 [0.239]	-0.261 [0.217]
Labor force quality (measure 2)	0.081 [0.017]**	0.064 [0.026]*	0.079 [0.023]**	0.101 [0.024]**	0.083 [0.018]**	0.087 [0.022]**	0.084 [0.019]**
Constant	-0.233 [1.082]	0.888 [1.532]	-0.288 [1.454]	-0.742 [1.365]	-0.431 [1.133]	0.218 [1.254]	-0.06 [1.088]
Observations	78	51	51	73	73	68	68
R-squared	0.39	0.21	0.31	0.34	0.35	0.32	0.37

Robust standard errors in brackets
* significant at 5%; ** significant at 1%

Table A3. 27: HK – Labor force quality and growth (robustness, measure 1)

	HK original data	IFS	HK (IFS sample)	PWT	HK (PWT sample)	WDI	HK (WDI sample)
Initial income	-0.453 [0.078]**	-0.393 [0.105]**	-0.462 [0.096]**	-0.384 [0.101]**	-0.405 [0.081]**	-0.378 [0.101]**	-0.4 [0.083]**
Quantity of schooling	0.112 [0.093]	0.031 [0.134]	0.067 [0.118]	-0.01 [0.126]	0.067 [0.098]	-0.032 [0.105]	0.015 [0.089]
Labor force quality (measure 1)	0.076 [0.027]**	0.052 [0.066]	0.065 [0.051]	0.1 [0.032]**	0.07 [0.028]*	0.096 [0.039]*	0.086 [0.030]**
Assessment available	-1.392 [1.455]	-0.424 [3.033]	-0.832 [2.337]	-0.614 [1.869]	-1.787 [1.544]	0.938 [1.794]	0.058 [1.396]
Observed labour-force quality	0.054 [0.032]	0.039 [0.069]	0.049 [0.054]	0.039 [0.041]	0.065 [0.034]	0.011 [0.041]	0.029 [0.033]
Constant	-0.475 [1.069]	0.947 [2.796]	0.199 [2.163]	-0.88 [1.227]	-0.172 [1.119]	-0.853 [1.523]	-0.632 [1.132]
Observations	78	51	51	73	73	68	68
R-squared	0.49	0.3	0.42	0.44	0.48	0.4	0.48

Robust standard errors in brackets
* significant at 5%; ** significant at 1%

Table A3. 28: HK – Labor force quality and growth (robustness, measure 2)

	HK original data	IFS	HK (IFS sample)	PWT	HK (PWT sample)	WDI	HK (WDI sample)
Initial income	-0.436 [0.080]**	-0.367 [0.107]**	-0.432 [0.099]**	-0.37 [0.101]**	-0.401 [0.084]**	-0.342 [0.097]**	-0.369 [0.082]**
Quantity of schooling	0.107 [0.103]	0.005 [0.145]	0.047 [0.128]	-0.039 [0.139]	0.059 [0.110]	-0.097 [0.105]	-0.036 [0.091]
Labor force quality (measure 2)	0.063 [0.023]**	0.044 [0.048]	0.052 [0.039]	0.088 [0.028]**	0.058 [0.024]*	0.09 [0.029]**	0.078 [0.024]**
Assessment available	-0.784 [1.341]	-0.242 [2.410]	-0.501 [1.959]	0.151 [1.711]	-1.015 [1.412]	1.652 [1.476]	0.853 [1.205]
Observed labour-force quality	0.038 [0.027]	0.032 [0.050]	0.038 [0.042]	0.021 [0.033]	0.045 [0.028]	-0.003 [0.031]	0.011 [0.026]
Constant	-0.189 [0.925]	1.182 [2.240]	0.57 [1.809]	-0.658 [1.120]	0.099 [0.977]	-0.793 [1.253]	-0.496 [0.968]
Observations	78	51	51	73	73	68	68
R-squared	0.46	0.31	0.42	0.41	0.44	0.4	0.47

Robust standard errors in brackets
* significant at 5%; ** significant at 1%

Table A3. 29: HK – final - results with preferred combination of growth and level data

	HK original sample	final	HK final sample	HK original sample	final	HK final sample
Initial income	-0.453	-0.292	-0.43	-0.436	-0.273	-0.408
	[0.078]**	[0.077]**	[0.098]**	[0.080]**	[0.078]**	[0.101]**
Quantity of schooling	0.112	0.074	0.058	0.107	0.036	0.031
	[0.093]	[0.141]	[0.129]	[0.103]	[0.153]	[0.138]
Labor force quality (measure 1)	0.076	0.033	0.048			
	[0.027]**	[0.069]	[0.053]			
Assessment available	-1.392	-1.49	-1.601	-0.784	-0.951	-1.014
	[1.455]	[3.112]	[2.380]	[1.341]	[2.437]	[1.993]
Observed labour force quality	0.054	0.064	0.069	0.038	0.048	0.051
	[0.032]	[0.072]	[0.056]	[0.027]	[0.051]	[0.043]
Labor force quality (measure 2)				0.063	0.03	0.039
				[0.023]**	[0.048]	[0.040]
Constant	-0.475	1.581	0.775	-0.189	1.674	1.01
	[1.069]	[2.889]	[2.227]	[0.925]	[2.297]	[1.867]
Observations	78	48	48	78	48	48
R-squared	0.49	0.33	0.43	0.46	0.34	0.43

Absolute value of t statistics in parentheses
* significant at 5%; ** significant at 1%

	HK original sample	final	HK final sample	HK original sample	final	HK final sample
Initial income	-0.39	-0.273	-0.373	-0.377	-0.26	-0.353
	[0.079]**	[0.080]**	[0.104]**	[0.081]**	[0.083]**	[0.110]**
Quantity of schooling	0.117	0.161	0.168	0.089	0.11	0.116
	[0.093]	[0.132]	[0.135]	[0.102]	[0.150]	[0.151]
Annual population growth	-0.097	-0.111	0.122	-0.224	-0.17	0.003
	[0.212]	[0.307]	[0.307]	[0.213]	[0.304]	[0.303]
Labor force quality (measure 1)	0.104	0.072	0.101			
	[0.023]**	[0.041]	[0.036]**			
Labor force quality (measure 2)				0.081	0.063	0.082
				[0.017]**	[0.026]*	[0.024]**
Constant	-1.184	0.207	-1.789	-0.233	0.61	-0.888
	[1.241]	[2.230]	[2.031]	[1.082]	[1.569]	[1.574]
Observations	78	48	48	78	48	48
R-squared	0.42	0.21	0.29	0.39	0.23	0.29

Absolute value of t statistics in parentheses
* significant at 5%; ** significant at 1%

Table A3. 30: MRW – test for conditional convergence (intermediate countries)

	MRW original data	IFS	MRW (IFS data)	PWT	MRW (PWT data)	WDI	MRW (WDI data)
Initial income	-0.37 [0.07]**	-0.29 [0.09]**	-0.38 [0.08]**	-0.33 [0.07]**	-0.37 [0.07]**	-0.28 [0.08]**	-0.37 [0.07]**
Physical-capital investment	0.54 [0.10]**	0.74 [0.16]**	0.72 [0.16]**	0.58 [0.11]**	0.54 [0.11]**	0.61 [0.12]**	0.54 [0.12]**
n+g+δ	-0.54 [0.29]	-0.15 [0.43]	-0.49 [0.42]	-0.3 [0.31]	-0.58 [0.31]	-0.37 [0.32]	-0.55 [0.31]
Human-capital investment	0.27 [0.08]**	0.01 [0.14]	0.1 [0.13]	0.26 [0.08]**	0.27 [0.08]**	0.18 [0.10]	0.28 [0.10]**
Constant	-0.01 [0.69]	0.35 [0.96]	0.03 [0.94]	0.26 [0.72]	-0.04 [0.73]	-0.26 [0.78]	-0.01 [0.75]
Observations	75	37	37	71	71	67	67
R-squared	0.47	0.51	0.59	0.48	0.46	0.41	0.45

Absolute value of t statistics in brackets
* significant at 5%; ** significant at 1%

Table A3. 31: MRW – test for conditional convergence (OECD countries)

	MRW original data	IFS	MRW (IFS data)	PWT	MRW (PWT data)	WDI	MRW (WDI data)
Initial income	-0.4 [0.07]**	-0.37 [0.07]**	-0.48 [0.10]**	-0.36 [0.07]**	-0.4 [0.07]**	-0.4 [0.07]**	-0.42 [0.08]**
Physical-capital investment	0.33 [0.17]	0.21 [0.15]	0.22 [0.21]	0.32 [0.18]	0.34 [0.18]	0.36 [0.17]*	0.35 [0.19]
n+g+δ	-0.86 [0.34]*	-0.4 [0.42]	-0.34 [0.57]	-0.85 [0.36]*	-0.88 [0.35]*	-0.81 [0.46]	-0.96 [0.53]
Human-capital investment	0.23 [0.15]	0.1 [0.16]	0.07 [0.21]	0.22 [0.15]	0.22 [0.15]	0.16 [0.15]	0.2 [0.17]
Constant	0.18 [1.17]	1.9 [1.84]	3.14 [2.50]	-0.06 [1.26]	0.11 [1.24]	0.36 [1.79]	0.11 [2.04]
Observations	22	15	15	21	21	19	19
R-squared	0.72	0.79	0.76	0.68	0.72	0.77	0.74

Absolute value of t statistics in brackets
* significant at 5%; ** significant at 1%

Table A3. 32: MRW – final - results with preferred combination of growth and level data

	Non-oil countries			Intermediate countries			OECD countries		
	MRW orig	final	MRW final sample	MRW orig	final	MRW final sample	MRW orig	final	MRW final sample
Initial income	-0.29 [0.06]**	-0.22 [0.08]**	-0.36 [0.08]**	-0.37 [0.07]**	-0.28 [0.09]**	-0.38 [0.08]**	-0.4 [0.07]**	-0.47 [0.07]**	-0.49 [0.11]**
Physical-capital investment	0.52 [0.09]**	0.62 [0.15]**	0.69 [0.14]**	0.54 [0.10]**	0.72 [0.17]**	0.72 [0.16]**	0.33 [0.17]	0.27 [0.13]	0.21 [0.22]
n+g+δ	-0.51 [0.29]	-0.25 [0.44]	-0.54 [0.39]	-0.54 [0.29]	-0.28 [0.47]	-0.49 [0.43]	-0.86 [0.34]*	-0.31 [0.37]	-0.31 [0.63]
Human-capital investment	0.23 [0.06]**	0.03 [0.11]	0.09 [0.10]	0.27 [0.08]**	-0.02 [0.14]	0.1 [0.14]	0.23 [0.15]	-0.05 [0.13]	0.07 [0.22]
Constant	-0.45 [0.70]	-0.12 [0.99]	-0.14 [0.93]	-0.01 [0.69]	0.05 [1.01]	0.05 [0.98]	0.18 [1.17]	3.35 [1.72]	3.26 [2.78]
Observations	98	40	40	75	36	36	22	14	14
R-squared	0.49	0.47	0.59	0.47	0.5	0.59	0.72	0.87	0.76

Absolute value of t statistics in brackets
* significant at 5%; ** significant at 1%

Table A3. 33: RW – Equity markets and growth (market capitalization)

	RW original data	IFS	RW (IFS sample)	PWT	RW (PWT sample)	WDI	RW (WDI sample)
Initial income	-0.0064	-0.0057	-0.0054	-0.0068	-0.0064	-0.0076	-0.0064
	[0.0029]*	[0.0026]*	[0.0028]	[0.0025]**	[0.0029]*	[0.0027]**	[0.0029]*
Initial secondary enrolment rate	0.0096	0.0042	0.0018	0.01	0.0096	0.0118	0.0096
	[0.0071]	[0.0069]	[0.0072]	[0.0062]	[0.0071]	[0.0065]	[0.0071]
Market capitalisation	0.0076	0.0051	0.0057	0.0055	0.0076	0.0065	0.0076
	[0.0072]	[0.0065]	[0.0069]	[0.0063]	[0.0072]	[0.0066]	[0.0072]
Number of revolutions and coups	-0.0107	-0.0111	-0.0122	-0.014	-0.0107	-0.0141	-0.0107
	[0.0105]	[0.0095]	[0.0100]	[0.0092]	[0.0105]	[0.0097]	[0.0105]
Black market exchange rate premium	-0.0363	-0.0523	-0.0456	-0.0448	-0.0363	-0.0471	-0.0363
	[0.0198]	[0.0183]**	[0.0194]*	[0.0173]*	[0.0198]	[0.0182]*	[0.0198]
Constant	0.0304	0.0508	0.0565	0.0354	0.0304	0.0342	0.0304
	[0.0214]	[0.0215]*	[0.0227]*	[0.0187]	[0.0214]	[0.0197]	[0.0214]
Observations	92	89	89	92	92	92	92
R-squared	0.19	0.25	0.23	0.24	0.19	0.26	0.19

Standard errors in brackets
* significant at 5%; ** significant at 1%

Table A3. 34: RW – Equity markets and growth (value traded)

	RW original data	IFS	RW (IFS sample)	PWT	RW (PWT sample)	WDI	RW (WDI sample)
Initial income	-0.0081	-0.0075	-0.007	-0.0084	-0.0081	-0.0093	-0.0081
	[0.0028]**	[0.0025]**	[0.0027]*	[0.0024]**	[0.0028]**	[0.0025]**	[0.0028]**
Initial secondary enrolment rate	0.0107	0.0056	0.0032	0.0108	0.0107	0.0127	0.0107
	[0.0066]	[0.0062]	[0.0068]	[0.0057]	[0.0066]	[0.0060]*	[0.0066]
Total value traded	0.0518	0.0516	0.0477	0.0476	0.0518	0.0526	0.0518
	[0.0182]**	[0.0158]**	[0.0173]**	[0.0156]**	[0.0182]**	[0.0164]**	[0.0182]**
Number of revolutions and coups	-0.0125	-0.0127	-0.0138	-0.0155	-0.0125	-0.0158	-0.0125
	[0.0099]	[0.0086]	[0.0094]	[0.0085]	[0.0099]	[0.0090]	[0.0099]
Black market exchange rate premium	-0.0292	-0.0432	-0.0376	-0.0377	-0.0292	-0.0394	-0.0292
	[0.0188]	[0.0168]*	[0.0184]*	[0.0162]*	[0.0188]	[0.0170]*	[0.0188]
Constant	0.0362	0.0549	0.0601	0.0412	0.0362	0.0405	0.0362
	[0.0203]	[0.0195]**	[0.0214]**	[0.0175]*	[0.0203]	[0.0183]*	[0.0203]
Observations	92	89	89	92	92	92	92
R-squared	0.28	0.38	0.32	0.35	0.28	0.36	0.28

Standard errors in brackets
* significant at 5%; ** significant at 1%

Table A3. 35: RW – final - results with preferred combination of growth and level data

	Liquid liabilities			Market capitalisation			Total value traded		
	RW orig	fin	RW fin sample	RW orig	fin	RW fin sample	RW orig	fin	RW fin sample
Initial income	-0.0077	-0.0115	-0.0064	-0.0064	-0.0107	-0.0054	-0.0081	-0.0134	-0.007
	[0.0030]*	[0.0043]**	[0.0030]*	[0.0029]*	[0.0041]*	[0.0028]	[0.0028]**	[0.0038]**	[0.0027]*
Initial secondary enrolment rate	0.0109	0.0058	0.0032	0.0096	0.0055	0.0018	0.0107	0.0067	0.0032
	[0.0071]	[0.0067]	[0.0073]	[0.0071]	[0.0066]	[0.0072]	[0.0066]	[0.0059]	[0.0068]
Financial market development	0.0153	0.0141	0.0121	0.0076	0.0058	0.0057	0.0518	0.0517	0.0477
	[0.0096]	[0.0085]	[0.0093]	[0.0072]	[0.0065]	[0.0069]	[0.0182]**	[0.0155]**	[0.0173]**
Number of revolutions and coups	-0.0102	-0.0099	-0.0118	-0.0107	-0.0114	-0.0122	-0.0125	-0.0127	-0.0138
	[0.0106]	[0.0094]	[0.0102]	[0.0105]	[0.0092]	[0.0100]	[0.0099]	[0.0083]	[0.0094]
Black market exchange rate premium	-0.0319	-0.0507	-0.0414	-0.0363	-0.0564	-0.0456	-0.0292	-0.0484	-0.0376
	[0.0203]	[0.0194]*	[0.0201]*	[0.0198]	[0.0187]**	[0.0194]*	[0.0188]	[0.0170]**	[0.0184]*
Constant	0.0281	0.0938	0.0535	0.0304	0.0948	0.0565	0.0362	0.1095	0.0601
	[0.0215]	[0.0295]**	[0.0230]*	[0.0214]	[0.0291]**	[0.0227]*	[0.0203]	[0.0267]**	[0.0214]**
Observations	92	89	89	92	89	89	92	89	89
R-squared	0.17	0.24	0.21	0.19	0.27	0.23	0.28	0.4	0.32

Absolute value of t statistics in parentheses
* significant at 5%; ** significant at 1%

Appendix 4: Construction of international prices and relative price levels for benchmark countries in PWT[49]

The international prices and aggregate price levels are obtained using the iterative Geary-Khamish formula, which utilizes local currency expenditures $(pq)_{ij}$ and price parities p_{ij} , where *i* stands for basic headings and *j* stands for countries.[50] The price parities are relative to the United States. Local currency expenditures and price parities are divided by the exchange rate, so that all input values are in nominal US dollars. Further, notional quantities q_{ij} are obtained by dividing expenditures by price parities.

The price parity of heading *i* in country *j* is equal to the nominal expenditure $(pq)_{ij}$ divided by the real expenditure $\pi_i q_{ij}$ (the product of the international price of heading π_i and the notional quantity q_{ij}). The ratio of the sum of these expenditures over all headings is the price level for country *j*:

$$pl_j = \frac{\sum_i (pq)_{ij}}{\sum_i \pi_i q_{ij}}$$

The international price of heading π_i is the weighted average of the prices relative to the price levels, with weights equal to the quantities. PWT uses expenditures and notional quantities:

$$\pi_i = \sum_j \frac{(pq)_{ij}}{pl_j} \times \frac{1}{\sum_j q_{ij}}$$

The international prices are expressed relative to the U.S. dollar.

[49] This appendix is based on technical descriptions available on the PWT website as well as Summers and Heston (1996).

[50] These originate from the World Bank and are constructed out of the OECD 1996 benchmarks, special comparisons for several countries in South America and Mexico, as well as updates of 1993 comparisons for Africa, the Caribbean, the ESCAP region and the Middle East. Expenditures are multiplied by 'super-country weights' in order to minimize the sensitivity of results to adding or subtracting some countries from aggregation. Super-country weights allocate the weight in world total of countries not included in the sample to similar countries that are included in the sample.

CHAPTER II: MEASURING MULTI-FACTOR PRODUCTIVITY GROWTH

(with Anita Wölfl)

Abstract

This paper analyses the sensitivity of calculated multi-factor productivity (MFP) growth to assumptions of growth accounting, concentrating on the measurement of quantity, composition and the respective shares of labor and capital inputs, and the time period. The analysis is carried out for seven OECD countries. The importance of the measurement issues varies substantially. The MFP growth rates are greatly influenced by the decision how the labor input is accounted for and by the assumptions about the efficiency of production and competition in product markets, which determine the weights with which capital and labor enter the growth accounting equation.

1. Introduction

Multi-factor productivity (MFP) measures the efficiency with which the factors of production (capital and labor are the two most commonly considered) are combined to create output. This measure captures the ability to produce the maximum output with given inputs, or, conversely, to minimize inputs for a given output. Growth in MFP may result from implementing the results of research and development, such as new and more effective tools stemming from business innovations, organizational efficiency improvements, and the like. Since a complex measure of technological development is very hard to come up with, technological development is often linked to the development of multi-factor productivity as well.[51]

A standard approach in measuring MFP is growth accounting, which breaks GDP growth down into the weighted sum of growth rates of the main factor inputs, labor and capital, and the growth of MFP. From this exercise, MFP comes out as a residual, i.e. the part of economic growth that cannot be explained by the contribution of other factors of production. Based on the pioneering work of Solow (1957) it is often also called a Solow residual. Being a residual, its precision suffers (i.e. if there is an ambition, for instance, to associate it with the true technological progress) from any misspecification of the underlying model and any errors in the measurement of the other variables entering the model. This problem has long been recognized.

Jorgenson and Griliches (1967) found that the contribution of multi-factor productivity to output growth declined from initially about 47% of total output growth to about 2.7% after correcting for potential errors in measuring output, capital and labor input, as well as the method of aggregation. They concluded that *"if quantities of output and input are measured accurately, growth in total output is largely explained by growth in total input"*. In this case, *"…the observed growth in total factor productivity is negligible."* (page 249)

The authors point out that the quantity indexes of total input and total output have to be constructed from the quantities of each output and each input, respectively. This means that any heterogeneity in inputs and outputs must be accounted for, using the (constantly

[51] Technological advances clearly belong among the drivers of economic growth. Economic theory is divided about the correct modelling of this phenomenon. The neo-classical model, which assumes technological development to be an exogenous process (e.g. Solow, 1956; Mankiw, 1995) stands against the endogenous growth literature (Romer, 1986; Lucas, 1988).

updated) relative shares of the value of each output in total output and shares of each input in total input as weights.

Ever since Jorgenson and Griliches outlined the most important prerequisites for a growth accounting exercise to provide correct results, there has been great progress in the awareness of the measurement issues in play and improvement of the statistical data available. Issues concerning the measurement of labor input have been studied by Jorgenson et al. (1987), while recent empirical applications can be found in e.g. Ahmad et al. (2003), the U.S. Bureau of Labor Statistics (2004) or Schwerdt and Turunen (2006). The measurement of capital input is discussed by Griliches and Jorgenson (1966), Harper (1997) and OECD (2001a). Nadiri and Schankerman (1981) allow for economies of scale when computing MFP, while Jorgenson and Yip (1999) construct constant quality indexes for capital and labor for G7 countries. Schreyer (forthcoming) discusses the implications of some standard production function assumptions for the measurement of total factor productivity. In some countries, the measure of multi-factor productivity is officially published, e.g. in the U.S. and in Australia.

The present paper examines the impact of several different methodologies and assumptions related to the measurement of the contribution of labor and capital on the resulting MFP estimate. This analysis is similar to that undertaken in Jorgenson and Griliches (1967). It builds on data from the OECD Productivity Database, which itself goes far to provide comparable measures of growth contributions of capital and labor, including the contribution of different capital assets. The analysis is, however, not exhaustive of all measurement challenges facing a researcher analysing multi-factor productivity. The important issues not tackled here include unmeasured inputs, capacity utilization, and adjustment cost. The effects on measured MFP of explicit account for factor utilization and adjustment costs are discussed, for instance, in Basu et al. (2001). Schreyer (forthcoming) analyses, among other issues, the effects of unmeasured inputs and non-zero mark-ups.

The strategy pursued in this paper is to depart from the measurement of multi-factor productivity as recommended in OECD 2001 (and available from the OECD Productivity Database) and to show how deviations in some measurements from this “benchmark” affect the resulting values of the measure. This includes, on the one hand, knowingly selecting worse measures of some variables in order to imitate a case when the appropriate statistics are not available for some countries or when researchers ignore a good measurement. This concerns mainly the measurement of the quantity of labor and capital input into production. On the other hand, we analyse possibilities that may improve the measurement, like accounting for structural changes in labor, or have some practical aspects for the measurement, like choosing between actual and trend values, and the time span of analysis.

2. MFP in a growth accounting framework – main measurement issues

We analyse four measurement issues for multi-factor productivity that we consider to be most relevant for its standard use and interpretation. The first two are associated with the computation of constant-quality indexes of capital and labor input. Measurement issues related to capital concern, in particular, how ‘productive capital’ is defined, how differences in the productivity of capital assets over time or across assets are taken into account and how underlying price indexes are constructed (whether rapid quality changes in some capital assets, notably information and communication technology, are taken into account). The main labor-related issue is how to correctly measure the quality and utilization of labor. The third measurement issue relates to what should be the relative weights for capital and labor in the growth accounting exercise, which means, in fact, questioning the underlying assumptions of the growth-accounting model. The last measurement issue considered is whether the choice of time span for assessing changes to multi-factor productivity makes a difference, and whether the use of some trend values would not be superior.

2.1. The general framework for MFP measurement

In general, multi-factor productivity is defined as output per unit of factor input. In order to measure multi-factor productivity, a neo-classical production function is used in Solow (1957), Barro (1998) and Hulten (2000):

$$Y = \hat{F}(A, K, L) \tag{1}$$

where *Y* is total output, *A* is the level of technology, *K* is the capital input and *L* is the labor input. If technology appears as Hicks-neutral, i.e., $\hat{F}(A, K, L) = A \cdot F(K.L)$, the shift parameter A_t measures the shift in the production function at given levels of labor and capital. Growth in multi-factor productivity is then defined as Hicks-neutral and an exogenous shift of the production function over time:

$$\frac{A_t}{A_0} = \frac{Y_t / Y_0}{F(K_t, L_t) / F(K_0, L_0)} \tag{2}$$

Solow addressed the key question of measuring A_t by using the total differential of the production function and thus a non-parametric index number that does not impose a specific form on the production function:

$$g = \dot{Y}/Y - \left(\frac{F_K K}{Y}\right) \cdot \left(\dot{K}/K\right) - \left(\frac{F_L L}{Y}\right) \cdot \left(\dot{L}/L\right) \tag{3}$$

where $g = \dot{A}/A$ is multi-factor productivity growth, $\dot{Y}/Y$ is the growth rate of output, $\dot{K}/K$ the growth rate of capital input and $\dot{L}/L$ the growth rate of labor input. In this formulation, F_K and F_L stand for the factor marginal products $\partial F/\partial K$ or $\partial F/\partial L$. Using logarithmic terms, equation (3) becomes:

$$g = \frac{d \ln Y}{dt} - \frac{F_K K}{F} \cdot \frac{d \ln K}{dt} - \frac{F_L L}{F} \cdot \frac{d \ln L}{dt}. \tag{4}$$

When product and factor markets are competitive and under constant returns to scale, a profit-maximizing firm will hire labor and invest in capital such that inputs are paid their social marginal products. This means that the social marginal product of capital input is equal to the price per unit of capital input (*uk*) in real terms, $F_K = uk / P$ and the social marginal product of labor is equal to the average wage rate per employed person or per hour (*w*), $F_L = w / P$. If *wL* represents total compensation of labor and *ukK* the total remuneration of capital (in time t), then the standard primal estimate of the rate of growth of MFP follows from:

$$g = \frac{d \ln Y}{dt} - s_K \frac{d \ln K}{dt} - s_L \frac{d \ln L}{dt} \tag{5}$$

with s_K and s_L being the share of labor and capital in total cost or income. The choice between total costs or total income as the reference for the input shares depends on the assumptions underlying the production function and factor and product markets. This issue is discussed in more detail below.

Since available statistical data are not continuous over time, but come in discrete time units, the continuous Divisia index can be approximated by the Törnqvist index. This means that the continuous-time factor shares s_K and s_L are replaced by the average between-period shares of period t and t-1.

If the contributions of capital and labor are to be correctly accounted for, the measures $d\ln K/dt$ and $d\ln L/dt$ must contain the effects that originate in the heterogeneity of the inputs. In particular, the structural and quality changes should be correctly accounted for. In particular, if $K=\sum_i K_i$ and $L=\sum_j L_j$, then (5) becomes

$$g=\frac{d\ln Y}{dt}-\sum_i \frac{F_{Ki}K_i}{F}\cdot\frac{d\ln K_i}{dt}-\sum_j \frac{F_{Lj}L_j}{F}\cdot\frac{d\ln L_j}{dt}\ , \qquad (6)$$

where F_{Ki} and F_{Lj} are the marginal products of the inputs at the lowest level of dis-aggregation. These issues are further analysed later in this section.

It is useful for the interpretation of the empirical results later on to clearly distinguish two different definitions of MFP growth, or *g*. The classical approach used by Solow sets growth in MFP equal to technological progress, in the form of a shift over time in the technology that is underlying the production function. The other approach is to think of MFP growth in a broader sense; in addition to pure technological change, it may involve the effect of unobserved factors, like changes in the efficiency of production, for instance, due to non-constant returns to scale or imperfect competition. Gauging the contribution of pure technological change would require quantifying the effect of unobserved factors to subtract it from the measure and would involve making additional assumptions.

Schreyer (forthcoming) calls the measure "apparent" MFP if it follows the latter definition. In this case, no assumptions are made about constant returns to scale and perfectly competitive markets. Total costs in the form of labor and capital remuneration, therefore, do not have to be equal to total factor income. As a consequence, the weights in equation (5), i.e., the shares of capital and labor, s_K and s_L , are the shares of capital and labor in total cost and not in total income, as they would be in the neoclassical growth accounting framework. This version of "apparent" MFP is also available from the OECD Productivity Database and used further in this paper.

Because it is a residual, *g* to a certain extent remains a '*measure of our ignorance*', as Abramovitz (1956) called it. Hulten (2000) specifies: *"This ignorance covers many components, some wanted (like the effects of technical and organizational innovation), others unwanted (measurement error, omitted variables, aggregation bias, model misspecification)"*, (page 11). The economists still continue to strive to eliminate the effects of unrelated developments.

2.2. The benchmark MFP measure by the OECD

The measure employed by the OECD is described in OECD (2004b) and has the following form:

$$g = \frac{d\ln Y}{dt} - \frac{ukK}{C}\sum_i \frac{uk_i K_i}{ukK}\cdot\frac{d\ln K_i}{dt} - \frac{wL}{C}\cdot\frac{d\ln L}{dt}, \tag{7}$$

where K_i is the capital input derived from asset *i* measured by the quantity of capital services as described in Schreyer et al. (2003), $ukK = \sum_i uk_i K_i$ represents the total remuneration of capital, measured as the sum of the values of capital services for all individual asset types *i* (where the user costs of asset *i* are based on an exogenous expected net rate of return), *w* is average wage per hour in the economy, *L* is a composite measure of labor input measured by hours of worked (Ahmad et al., 2003) and $C = ukK + wL$ is total factor remuneration.

The aggregation in (7) employs the Törnqvist index number formula, constructing the respective weights for capital and labor as the average of the values in the period over which the growth rate of the input is computed.

2.3. Measuring capital input

The appropriate measure for capital input within the growth accounting framework is the flow of productive services that can be drawn from the cumulative stock of past investments in capital assets (Griliches and Jorgenson, 1966; Harper, 1997; OECD, 2001a). Flows of productive services include the services of machinery, storage services of a warehouse, transport services of a truck, etc.

The main message of the theory is that the aggregate flow of capital services is not well measured by the aggregate measure of capital stock, even if wear and tear and obsolescence is accounted for (in which case the measure is called net capital stock). Jorgenson (1995), Hulten (1990), Diewert (2001), OECD (2001a), Schreyer et al. (2003) construct measures of capital services that derive from the productive capital stock but cannot be identified with it.

In principle, the correct measure of capital input into production takes into account the contribution of capital services derived from each capital asset and weights them by the marginal product of the capital service as in (6).

In the aggregate measure of net capital stock, the capital assets are weighted by their (market) value. If markets are functioning, the market value of an asset equals the sum of discounted future income from this asset, which can be the value of the rentals that the asset is expected to generate in the future. The rental price of an asset for a given period will be identical to the value of capital services from this capital asset during that period (the marginal product of this asset; the value of the unit of capital service is equal to F_{Ki}). It is clear that the value of an asset with long service life will, ceteris paribus, be higher than that of an asset with a shorter service life. Thus weighting the contribution of individual assets by their value will overestimate the absolute value of the contribution of the assets with longer service lives. The correct set of weights for individual capital assets, if the productive contribution is to be accounted for, reflects their marginal productivity, and, therefore, the rental prices should be used.[52]

We analyze three measurement issues related to productive capital input. These include measurement of the flow of capital services per capital asset, choosing a correct deflator, and aggregating across these capital assets to obtain an aggregate measure.

One important issue that is not analyzed here is capacity utilization. The measure of capital services, because it is derived from existing capital, captures rather the potential contribution of capital to growth than the actual contribution. It measures the potential quantity of capital services linked to existing capital stock and does not fluctuate with the rate of use of capital during the business cycle. It thus does not improve on the measure of capital contribution vis-à-vis capital stock in this respect.[53]

Measurement of the flow of capital services per capital asset

In order to measure the change in the flow of capital services per asset, Schreyer et al. (2003) assume that the flow of services derived from an asset is proportional to the productive stock of this capital asset, which is the sum of past investment corrected for the probability of retirement and loss of productive efficiency.[54] Ideally, and it is the case for the OECD measure, this measure also corrects for the so-called vintage effect: New capital assets are more productive than old ones not only because they have not depreciated but also because they are better than the old ones when these were new.[55] The volume index of the productive capital stock of one type of asset can thus be identified with the volume index of capital services of this type of asset.

In the OECD Productivity Database, the productive stock of asset i at the end of period $t-1, S^i_{t-1}$, is computed as the accumulation of past investments, I^i_{t-s-1}, taking into account changes of productivity per asset over time, as represented by the retirement function, F^i_s, and the age-efficiency-function, h^i_s:

$$S^i_{t-1} = \sum_{s=0}^{t-1} (h^i_s \cdot F^i_s \cdot I^i_{t-s-1}) . \qquad (8)$$

Function F^i_s in equation (8) reflects the retirement pattern, which is needed to describe how assets are withdrawn from service. It is a distribution around the expected or mean service life. Schreyer et al. (2003) use a normal distribution with a standard deviation of

52 One must distinguish between the price of the capital service and the rental price of the capital asset. It is assumed that the quantity of capital services is proportional to the quantity of capital assets (the productive stock of them, i.e. corrected for probability of retirement and loss of productive efficiency), and hence the price of the capital service is proportional to the rental price of the capital asset. In aggregation, therefore, it makes no difference which set of prices is used. None are fully observed, and the rental prices relating to concrete capital assets are easier to approximate.

53 One possible way forward is suggested by Basu et al. (2001) who use the variation in the average weekly hours of production workers to proxy for capital capacity utilization. This line of thinking is planned to be addressed in further research.

54 More precisely, in order to account for the vintage effect, they assume that the flow of capital services from an s-year old asset is in proportion to the volume of investment of that asset s years ago. This assumption is made since typically neither the flow of capital services nor the length of lags between purchases of investment goods and their actual use in the production process are known. Another assumption is made of no variability in capacity utilization.

55 In order to capture changes in the productivity of assets over time, notably across different generations, Hulten (1992) proposes computing investments and the capital stock, or the services that can be derived from the existing capital stock, in terms of efficiency units.

25% of the average service life, truncated at an assumed maximum service life of 1.5 times the average service life.[56]

Function h_s^i in equation (8) is the age-efficiency function which reflects the loss in productive capacity of a capital good (of a particular generation) over time or the rate at which the physical contribution of this capital good to production declines over time. The rationale behind this function is that a cost-minimizing producer will choose a composition of capital assets of different vintages such that the relative productivity of two different vintages is just equal to their relative user costs. A hyperbolic function is used of the following form:

$$h_s^i = (T_i - s)/(T_i - \beta s) \qquad (9)$$

The expected service life is T_i and parameter β is set to 0.8.

The sensitivity analysis here concentrates on the problem when the loss of productive efficiency of an asset over its service life is not correctly taken into account. We choose to present the extreme scenario which assumes that the existing capital assets can be used with full efficiency over the entire lifetime of the asset and that their productivity drops to zero after they are retired. In this case $h_s^i = 1$. This amounts to the use of the gross stock of capital in the computation.

Choosing a correct deflator

When constructing price indexes, it is often difficult to separate the quantity and quality of different consumption and investment goods. This is particularly important in the case of goods or capital assets where quality changes rapidly. For the construction of the measure of capital services, a critical issue is to account correctly for the price development of the information and communication technology investment. Accurate price indexes should adjust for changes in quality (Triplett, 2004), i.e. hedonic methods to construct deflators (in particular, for the ICT assets) should be used.[57] If this is not fulfilled, the productive stock of capital assets, whose quality increases and whose price index does not reflect it, will be undervalued.

The OECD measure of capital services is based on a harmonized hedonic price index for ICT-related components, which uses U.S. price indexes for ICT and non-ICT related goods. A polynomially smoothed ratio of the ICT and non-ICT related price index is used. The ratio of the price of an ICT capital asset *i* and the price of non-ICT assets is assumed to be similar across countries and is assumed to be well measured in the United States. Then the harmonized hedonic price index for ICT-related assets for another country X is computed as the product of the price index for the non-ICT-related assets from X and the smoothed ratio of price indexes in the U.S.:

$$P_{ICT}^{i,X} = P_{nonICT}^{i,X} \cdot \frac{P_{ICT}^{i,U.S.}}{P_{nonICT}^{i,U.S.}}$$

[56] The assumed average service lives are as follows: 7 years for IT equipment, 15 years for communications equipment, transport and other equipment, 60 years for non-residential structures, 3 years for software and 7 years for remaining other products.

[57] A hedonic price index accounts for changes in the quality of a product by making use of the relation of the prices of different varieties of a product and the number of characteristics in each variety that has an influence on the price. A comprehensive treatment of hedonic indexes is given in Triplett (2004).

The next comparison, therefore, includes the measure of MFP calculated using capital services based on harmonized price indexes for the ICT assets and with domestic price indexes.

Aggregation of the quantity of capital services across assets

As has been outlined above, the correct set of weights when aggregating the volume index of capital services across assets captures the rental prices of the capital assets the services derive from. The problem with rental prices is that they are not observed for all capital assets. They are observed for capital assets for which there are complete markets, as is the case for an office building, for instance. For many assets, however, the capital is owned by the user and therefore, the assets are not rented via market and, therefore, are not observed. The rentals, however, can be imputed. The implicit rent that capital good owners 'pay' themselves gives rise to the term *user costs of capital*. Hulten (1990) shows that the user cost of capital for an asset can be expressed as the product of the purchase price of this asset and the gross rate of return on this asset.

Schreyer et al. (2003) construct user cost for each type of asset and each vintage as a function of the purchase price of this asset, its depreciation rate and expected price change, and the required net rate of return, the last being identical for all capital assets.

In the analysis here we investigate what happens if the differences in productivity across capital assets are not appropriately taken into account in the contribution of capital to GDP growth, which is done when the measure of net capital stock is used in the growth accounting exercise. To do this we replace the user cost per asset, which is the appropriate weight for the aggregation across assets to calculate the volume of capital services, by market prices. This can also be considered as some composition effect.

This can be seen by comparing g with the growth rate of MFP, $\hat{g}$, where differences in marginal productivities across capital assets are not taken into account.

$$\hat{g} = \frac{d\ln Y}{dt} - \frac{uK}{C}\cdot\sum_{i=1}^{N}\frac{m_i K_i}{WK}\frac{d\ln K_i}{dt} - \frac{wL}{C}\cdot\frac{d\ln L}{dt} = g + \frac{uK}{C}\sum_{i=1}^{N}\left(\frac{u_i K_i}{uK} - \frac{m_i K_i}{WK}\right)\cdot\frac{d\ln K_i}{dt}, \quad (10)$$

where m_i stands for the market price of each asset and $WK = \sum_{i=1}^{N} m_i K_i$ is the measure of net (wealth) capital. The composition effect (net of other measurement issues discussed) thus reflects the difference in the sets of weights used for aggregation; in contrast with $\hat{g}$, the measure g puts more weight on (and hence excludes from the measured MFP) the growth in the stock of productive assets with shorter lives and high user cost, whose effect will thus be entirely associated with the contribution of capital.[58,59]

[58] In fact, it is not possible to totally disentangle the effect. Computation of the composition effect of capital input may capture to some degree an effect related to the general age-efficiency of capital assets as well as an effect due to differences in productivity between ICT- and non-ICT capital.

[59] In Chapter III of this dissertation, the resulting MFP growth rates based on capital services and capital stock for the Czech Republic are presented and the contributions of particular groups of assets in both approaches discussed.

2.4. Measuring labor input

The appropriate measure of labor input in growth accounting reflects, according to (6), the variation in each type of labor input. The labor force is clearly very heterogeneous and it cannot by any means be assumed that the marginal productivity of all workers is the same, a fact reflected in the distribution of wages. In theory, this heterogeneity should be taken into account and the labor contributions should be measured for each "type" of labor (differing by skills, experience, etc.). In other words, the labor contribution should be well measured as regards its quantity as well as its productive ability (which can be referred to as quality). If the labor force becomes on average more skilled, which would be reflected in a movement towards better paid jobs, this should indicate that labor is making a higher productive contribution, even if the number of workers stays the same and they work the same hours. We investigate here two issues. The first one is the measurement of the quantity of labor at the level of the national economy, the second one relates to its quality.

The quantity of labor input

It has long been recognized that labor input to production should be measured as total hours worked.[60] Measuring labor input by total employment, a case observable in the literature, neglects in the short to middle term any changes in the hours worked per worker that can be for various reasons more pronounced over the cycle than changes in total employment. In the long term, it can result in the neglect of some structural changes in the economy. Using the correct measure is even more important for cross-country comparison of productivity measures as average hours worked per worker vary substantially across countries.[61]

The OECD multi-factor productivity measures are based on total hours worked, a measure developed by the OECD for this purpose. We analyse what the impact is of measuring total labor input by total employment instead of total hours worked.

Labor quality

On top of correctly measuring of the quantity of labor worked in the economy, one should correctly account for the heterogeneity of labor, if MFP growth is to be computed according to (6). One possible way is to adjust labor input by a change in the skill composition of total employment. Scarpetta et al. (2000), for instance, distinguish six different employment groups (corresponding to j in (6)): three education levels (below upper secondary, upper secondary, and tertiary education) for each gender. Total change in labor input results from the weighted sum of growth in labor input per gender-education group, the weights being based on relative marginal productivity (approximated by relative wages) and employment shares of each gender-education group.

The composition of labor input is not adjusted for in the current version of the OECD Productivity Database. This means that any changes in the marginal productivity of labor originating from changes in the skills of the labor force are not accounted for by the measure of labor input and are a part of MFP growth. We therefore apply the method used in Scarpetta et al. (2000) and assess the effect of accounting for changes in labor quality.

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[60] Steindel and Stiroh (2001) note that the measure of labor productivity measured as output per worker-hour has been officially calculated in the United States since the 1800s.

[61] Basu and Kimball (1997) argue that the variation in hours worked can be used to account also for the variation in the utilization of capital.

The alternative measure of the growth of labor input is:

$$\frac{dL}{dt} = \sum_j v_j \frac{dL_j}{dt}, \qquad (11)$$

where $v_j = \frac{w_j \cdot L_j}{\sum_i w_i L_i}$ and L_j is the quantity of labor input per gender-education type, *j*, and w_j their respective relative wage rate. Since the number of hours worked per gender-education type is not available, L_j is the number of workers – it is assumed that the rate of change in average hours worked is identical across education and gender groups. We thus use $L_j = e_j L$, where L is a measure of total labor input (i.e. hours worked) and e_j is the employment share of gender-education group j in total employment. The weight v_j reflects the cost share of each type of labor input in the total cost of labor.

In order to separate the effect of labor quality and the effect of hours worked, an index of labor quality (*LQ*), independent of hours worked, is constructed as:

$$\frac{dLQ}{dt} = \sum_j v_j \cdot \frac{de_j}{dt}. \qquad (12)$$

2.5. Measuring labor and capital shares

As derived above, the growth accounting framework can be written as the weighted average of the contribution of growth in labor and capital:

$$g = \frac{d\ln Y}{dt} - \sum_i \frac{F_{Ki}K_i}{F} \cdot \frac{d\ln K_i}{dt} - \sum_j \frac{F_{Lj}L_j}{F} \cdot \frac{d\ln L_j}{dt}$$

which can be transformed to

$$g = \frac{d\ln Y}{dt} - \frac{\sum F_{Ki}K_i}{F} \sum_i \frac{F_{Ki}K_i}{\sum F_{Ki}K_i} \cdot \frac{d\ln K_i}{dt} - \frac{\sum F_{Lj}L_j}{F} \sum_j \frac{F_{Lj}L_j}{\sum F_{Lj}L_j} \cdot \frac{d\ln L_j}{dt}$$

and

$$g = \frac{d\ln Y}{dt} - s_K \frac{d\ln K}{dt} - s_L \frac{d\ln L}{dt} \qquad (13)$$

The measurement of labor share is discussed, for instance, in Krueger (1999) and Gomme and Rupert (2004). In the growth accounting framework in the classical sense, where perfectly competitive markets and constant returns to scale are assumed, s_k and s_l are the respective shares of each factor remuneration in total income (assumed to be equal to total nominal output).[62] Since neither of them is explicitly measured, for this purpose, the total income (or, more precisely, the mixed income) is apportioned according to some method to capital and labor. Usually, this involves assuming some rate of return for one or both of these factors that is endogenous to the method chosen and does not have to correspond to ex-ante beliefs about their true values.

[62] Within the neoclassical growth accounting framework, total income is equal to total costs due to the assumptions of constant returns to scale and perfect competition in input and product markets.

The rates of return on factor inputs in the OECD Productivity Database are, on the contrary, exogenous in the sense that they are specified ex-ante and are not determined by the method chosen for the division of total income. They are computed as the respective shares of each factor remuneration in total factor remuneration:

$$s_K = \frac{ukK}{ukK + wL} \text{ and } s_L = \frac{wL}{ukK + wL}$$

where *wL* represents the total compensation of labor, where the non-observed wage for self-employed persons is approximated by the average wage in dependent employment, and where *ukK* is the total remuneration of capital computed as the value of capital services in a given year. Beyond the homogeneity condition that $s_K + s_L = 1$, no assumption on returns to scale or type of competition is made. This hence reflects, a more general interpretation of MFP, the so-called apparent MFP. Total cost expressed in this way in the form of labor and capital remuneration does not have to be equal to total factor income.[63,64]

To see how MFP estimates are influenced by the way the weights of capital and labor are computed, a variant of the neo-classical MFP estimate is computed. This uses the assumptions of constant returns to scale and perfect competition in the input and output markets and computes endogenous rates of returns to capital. It departs from the simple measure of labor share s_L as computed by $s_L = \frac{wL}{PY}$, where *wL* is defined as above and *PY* is the value of the gross domestic product in market prices. Assuming constant returns to scale and competitive markets, capital share s_K is equivalent to $1 - s_L$. This adjustment goes in the direction suggested by Oulton (2005) who analyses whether ex-ante or ex-post measures of the user cost of capital should be used and suggests a hybrid method. This hybrid method uses ex-ante weights in constructing the index of capital services and an ex-post profit share as the weight to apply to the capital services index when estimating MFP.

The expected effect depends on the relation between the total factor remuneration and nominal GDP; if the latter is bigger than the former, which is, next to their equality, the only economically justifiable case, the capital share computed as a share of GDP will be higher. In case of a positive contribution of capital to growth this would reduce the observed contribution of MFP, and vice versa for a negative capital contribution.[65]

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[63] Schreyer (forthcoming) provides an extensive discussion on the consequences of different assumptions about the production function and markets for MFP measures.

[64] The shares s_K and s_L are Törnqvist indexes in the OECD computation, i.e. the average of the shares in the period over which the growth rate of the input is computed.

[65] We do not investigate here the case in which the shares of capital and labor would be computed based on the share of their remuneration (with exogenously determined rates of returns) in nominal GDP. In general, this would assign a stronger role to MFP growth and a smaller role to factor inputs.

2.6. Measuring MFP growth in time

Evaluating the development of a certain variable in time, especially a cyclical one, can be influenced by the choice of starting point and endpoint of the period of interest. For example, Steindel and Stiroh (2001) remark on the controversial "traditional" breakpoint of the year 1973 for U.S. productivity measurement. Also, one can be more interested in trends than in cyclical variation.[66] It may therefore be more practical to use a measure that clearly says something about the trend.

The final sensitivity analysis thus uses the Hodrick-Prescott filter (Hodrick and Prescott, 1997) to obtain the trend of the time series of GDP, employment, hours worked per person, capital services, and employment shares. Under this method, trend values of the variable y, y^{trend}, are defined such that they minimize:

$$HP(\lambda) = \sum_t (y_t - y_t^{trend})^2 + \lambda \sum_t [(y_{t+1}^{trend} - y_t^{trend}) - (y_t^{trend} - y_{t-1}^{trend})]^2 \qquad (14)$$

where λ is the parameter of the importance given to the smoothness of the trend series as opposed to its proximity to actual values. For yearly data, which are used here, λ was set to 500.[67]

The estimate of trend MFP growth is then obtained as the difference between trend GDP growth and the sum of the contributions of trend growth in labor and capital input, weighted by their shares as defined above. Trend labor input is defined as the product of trend series of employment and hours worked per person. Labor input is not adjusted for composition in this case.

[66] The stylized fact is that MFP growth shows strong fluctuations which are similar to GDP growth. There are typically four explanations for the pro-cyclical nature of MFP growth (Basu and Fernald, 2000; Basu et al., 2001). First, MFP measures should pick up changes in technology. Thus, if technological change fluctuates over time, this will show up in cycles of output and productivity growth. Second, cycles in productivity growth may be related to imperfect competition and increasing returns to scale. Figure 5 shows strong cyclical behaviour in inputs, notably labor inputs. With imperfect competition and increasing returns to scale, increases in inputs may result in productivity increases. Third, not only investment in inputs but also their utilization may vary over the business cycle. A cyclically-related reallocation of resources across uses with different marginal products (e.g., industries with different market power) is a fourth possible reason for the cyclicality of aggregate MFP.

[67] The end-of-sample-bias was reduced by applying the growth rates of the related series (business sector capital stock for total economy capital stock and services) in the OECD Medium Term Reference Scenario forecasts to the existing data up to 2008.

3. Data

The data for the reference measure of MFP, as defined by (7), capital services and productive capital stock, as defined by (8), total employment, average hours worked per person, labor and capital remuneration, and GDP are publicly available from the OECD Productivity Database. This database was developed with the explicit aim of creating a consistent set of data for productivity measurement. Original description is available from OECD (2004a), OECD (2004b), Schreyer et al. (2003) and Schreyer (forthcoming).

Output is measured as GDP at constant prices for the entire economy and comes from OECD Annual National Accounts.[68] Labor input is measured as total hours worked in the economy; the data series have been constructed for this purpose. The data are derived as the product of average hours worked (several sources are combined: OECD Employment Outlook, OECD Annual National Accounts, OECD Labor Force Statistics, and national sources) and a consistent measure of employment for each country. Capital input is measured as the volume of capital services and computed by OECD; it is based on the capital service flows for seven types of assets. The shares of labor and capital in growth accounting are based on cost shares, where total cost of inputs is the sum of remuneration for labor and remuneration for capital. The remuneration of labor accounts for both dependent employment and self employment; it is computed based on data from OECD Annual National Accounts as the average remuneration per employee multiplied by total employment in the economy. The remuneration of capital is computed by OECD as the value of capital services. The logarithmic change of total input is then computed as the average of the logarithmic changes of labor and capital services weighted by the corresponding Törnqvist index of cost shares. Multi-factor productivity contribution to growth is then measured as the difference between the logarithmic changes of output and total input.

The analysis in this study is based on data from December 2003 and covers the period 1990 – 2001 (1990 – 2000, for Japan and United Kingdom, and 1992 – 2001 for Germany). Data on the structure of capital assets and investment, and price indexes for capital stock and investment, necessary for the analysis in section 2.3, were available to the authors from the OECD internal database while they were working at the OECD.

The measure of labor composition that is used in the sensitivity analysis was constructed according the procedure presented in section 2.4 above. It is based on data on the level of educational attainment from Scarpetta et al. (2000), complemented with information from the Barro and Lee (1996) database. Data on relative wages are from Jean and Nicoletti (2002) for Canada, Denmark, Spain, France, the United Kingdom, Ireland, Italy, Sweden, and the United States, and complemented with data from Scarpetta et al. (2000) for Australia, Germany, Finland, the Netherlands, and Portugal. For Japan, data from four educational categories are available from the Japanese Statistical Office but which are not directly comparable with the other countries. However, for this country, full information on wages and employment for the years 1985, 1990, 1995, 2000 could be used.

[68] Although, conceptually, at the level of the total economy, GDP equals the sum of gross value added (which is the corresponding supply-side concept to output), there may be statistical discrepancies or some differences due to the treatment of taxes if GDP is constructed from the expenditure side. The main reasons for the use of GDP data instead of gross value added data are greater timeliness, availability and international comparability of GDP data.

4. The impact of measurement on MFP growth – a sensitivity analysis

The following section presents results from the sensitivity analyses outlined above which assess the empirical impact of the selected different measurements of MFP growth. This is done by computing MFP growth on the basis of different scenarios according to the description in sections 2.3-2.6 and comparing it to the benchmark scenario described in 2.2, i.e. MFP growth with growth in labor input measured using total hours worked, capital input measured by capital services (based on a hyperbolic age-efficiency profile per capital asset, harmonized hedonic prices of ICT-capital assets, and taking into account the different productive efficiency of capital assets), shares of capital and labor input as their shares in total costs, and using actual time series.

This sensitivity analysis is primarily intended to show the potential size of the difference in measured MFP growth when based on different assumptions. It provides a selective picture of the measurement problems related to growth of MFP and explains to some degree why MFP growth estimates are different in various empirical studies.[69] In addition, it is not possible to disentangle completely some measurement problems and ascribe the effects to one particular factor. It is therefore not possible to calculate the total impact of measurement as the sum of the individual effects analysed.

The results are summarized in Table 1, which shows the average effect of the analysed measurement problems across countries on MFP growth. The rows correspond to the measurement issues as outlined above. The numbers represent the differences in percentage points from the reference MFP growth as computed by the OECD, averaged over the period 1990-2001.

Table 1: Average impact of selected measurement issues on annual MFP growth (percentage points, 1990-2001)

	Australia	Canada	France	Germany	Japan	United Kingdom	United States
Productive efficiency of capital	-0.08	-0.04	-0.03	-0.05	-0.04	-0.01	-0.01
ICT price index	-0.15	0.04	0.03	0.13	0.11	0.15	0.00
Capital composition	0.33	0.28	0.18	0.21	0.10	0.24	0.39
Labour quantity	-0.10	-0.04	-0.53	-0.40	-0.86	-0.29	-0.05
Labour composition	0.00	-0.10	-0.19	0.09	-0.19	-0.16	-0.06
Labour and capital shares	-0.10	-0.51	-0.41	-0.24	-0.38	-0.27	-0.45
Time series	-0.15	0.05	0.08	0.24	0.14	-0.14	0.16

Table 1 shows that the effect of measurement can be rather substantial. For some measurement issues the average effect is of the same direction, as was expected. This regards, in particular, imperfectly accounting for the loss of productive efficiency of capital, capital composition, and labor and capital shares. However, these average effects mask some variation that should be analysed for proper assessment of the measurement

[69] Among the list of other measurement issues, on top of those already meantioned in sections 1 and 2 are, for instance, questions related to cross-country differences in capital tax regimes, the treatment of own-account software, and private versus public sector investment.

issues. Tables 2-8 show the development of the effects in the analysed period.[70] In general, three main conclusions can be drawn from these results. First, different measures typically change the level of MFP growth of in a rather systematic way, but not the growth pattern over time. In almost all scenarios, the impact of different measurement issues is a relatively stable deviation from the level of MFP growth, which means that the alternative MFP growth rates move relatively parallel to the MFP growth rates of the reference scenario. The obvious exception is the measure based on trend values of MFP growth, in contrast with the rather volatile development of the measure based on actual series. An important fluctuation in the MFP growth difference is observed if the contributions of labor input measured by total employment instead of hours worked are compared. For several countries, notably Canada, France, Japan and the United Kingdom, and in particular for the time period before 1995/1996, the deviations fluctuate and reflect a substantial difference of the employment-based measure of MFP from the one based on hours worked.

Second, the size of the measurement effect varies substantially across scenarios and depends on the measurement issue that is analysed. Substantial differences in MFP growth can be observed in Table 2, where employment-based MFP growth rates are compared with MFP growth rates using total hours worked. While on average, the MFP growth measure is lower for all countries if based on the total number of employed persons than the ones based on total hours worked, this does not hold for all years.[71] The explanation may be that the average hours worked adjust during the business cycle more than does total employment.

Table 2: Difference in MFP if variation in worked hours not taken into account

	Australia	Canada	France	Germany	Japan	United Kingdom	United States
1990	-0.13	-0.57	0.09		-1.37	-0.59	-0.42
1991	-0.46	-0.90	-0.41		-1.17	0.02	-0.51
1992	-0.25	-0.33	0.00	0.77	-1.21	-1.73	0.13
1993	0.77	0.14	-0.54	-0.97	-2.35	-0.28	0.43
1994	0.13	0.73	-0.27	-0.06	-0.29	0.60	0.13
1995	-0.10	-0.23	-1.08	-0.68	-0.60	0.11	0.09
1996	-0.31	0.42	0.18	-0.79	0.35	-0.04	-0.31
1997	-0.05	0.53	-0.27	-0.28	-1.09	-0.04	0.40
1998	-0.18	0.13	-0.54	-0.28	-0.89	-0.26	0.13
1999	0.14	0.29	-0.27	-0.42	-1.23	-0.51	0.09
2000	-0.18	0.04	-2.20	-0.70	0.44	-0.51	-0.40
2001	-0.63	-0.69	-1.09	-0.56			-0.40

The effects of adjusting labor input for compositional changes are depicted in Table 3. A non-zero effect results since changes in the composition of labor are attributed to labor and not to MFP. The lower MFP growth in the alternative scenario suggests that composition changes in labor in the 1990s have had a positive impact on labor input growth in these countries. This implies changes in the composition of labor towards more productive employees, as measured by higher compensation per employee. Rather suprisingly, the average effect is fairly muted and somewhat volatile. However, it can be observed that in Canada, France, Japan and the United Kingdom there was, for some periods, a relatively

[70] Illustration of the impact of these effects of the measurement of MFP for a particular country is given in Figures A.3-A.9 in the Appendix.

[71] Annual growth rates of total employment were higher than those of total hours worked in the analysed period. The average hours worked per person have, in fact, been decreasing since the 1980s in most OECD countries. This is partly due to the growth of part-time employment.

strong effect of the adjustment for labor composition and a significant contribution of change in labor composition to economic growth. In these cases, the MFP measure where labor input is adjusted for its composition is lower than the reference scenario.

Table 3: Difference in MFP if labor quality accounted for

	Australia	Canada	France	Germany	Japan	United Kingdom	United States
1990	-0.01	0.38	-0.17		-0.15	0.13	0.09
1991	0.01	-0.32	-0.38		-0.11	-0.68	-0.19
1992	0.15	-0.22	-0.25	0.20	-0.11	-1.11	-0.33
1993	-0.32	-0.56	-0.71	-0.03	-0.12	-0.43	-0.18
1994	0.05	-0.02	-0.24	0.11	-0.12	-0.76	-0.02
1995	0.08	-0.11	0.03	-0.30	-0.13	-0.18	-0.06
1996	-0.06	-0.45	-0.46	0.28	-0.28	-0.27	0.03
1997	0.09	-0.10	0.03	0.00	-0.27	0.00	0.00
1998	-0.17	0.00	-0.36	0.22	-0.26	0.02	-0.25
1999	0.14	0.13	0.00	-0.01	-0.26	0.81	0.06
2000	0.00	0.11	0.26	0.39	-0.27	0.74	0.08
2001	0.00	0.00	0.00	0.00			0.00

Table 4 compares MFP growth rates where capital input is computed using a different assumption as regards the age-efficiency function. Comparing the MFP measures where the stock of capital assets is not adjusted for the loss of productive efficiency until the end of its service life shows very similar patterns. The direction of the effect is consistent with theory: the MFP time series of the alternative scenario are slightly lower than the ones of the reference scenario for most countries analysed. Assuming full efficiency of capital assets of one particular generation over their whole lifetime would overestimate the contribution of capital input to production growth as compared to the more realistic assumption of decreasing efficiency over time.

Table 4: Difference in MFP if productive capital stock is measured by gross capital stock

	Australia	Canada	France	Germany	Japan	United Kingdom	United States
1990	-0.03	-0.06	0.04		0.01	-0.03	-0.05
1991	-0.06	-0.06	0.01		-0.01	-0.06	-0.07
1992	-0.11	-0.10	-0.02	0.01	-0.05	-0.03	-0.06
1993	-0.13	-0.10	-0.06	-0.02	-0.05	-0.04	-0.04
1994	-0.14	-0.07	-0.07	-0.07	-0.05	-0.04	-0.02
1995	-0.10	-0.05	-0.08	-0.07	0.00	-0.02	0.01
1996	-0.08	-0.05	-0.08	-0.07	0.01	-0.01	0.02
1997	-0.06	0.00	-0.06	-0.08	-0.01	0.00	0.04
1998	-0.06	-0.01	-0.03	-0.07	-0.07	0.07	0.05
1999	-0.08	0.00	-0.01	-0.06	-0.09	0.04	0.03
2000	-0.10	0.10	0.01	-0.05	-0.07	0.02	0.00
2001	-0.07	-0.04	-0.01	-0.06			-0.06

Results concerning capital composition are more straightforward (Table 5). The series show the effect on measured MFP of approximating capital input by the market value of capital (and seeing the capital input as homogenous), as compared to the reference scenario where the capital input is approximated by capital services and differences in productive efficiency among assets are accounted for. The alternative capital input series do not account for changes in quality across different forms of capital assets within the contribution of capital to output growth; these variations are ascribed to MFP. Table 5 shows that for all countries, in most years, this 'unadjusted' alternative scenario of MFP growth is higher compared to the reference scenario, and this reflects strong growth in the quality of capital. Together with the previous findings concerning the age-efficiency of capital, these results support the hypothesis of Hulten (1992), that changes in the quality of capital are mainly driven by changes or variations in quality across different forms or vintages of capital assets and only to a small degree by changes in the efficiency of the capital assets of one particular generation over time.

Table 5: Difference in MFP if capital quality not taken into account

	Australia	Canada	France	Germany	Japan	United Kingdom	United States
1990	0.09	0.11	0.29		0.11	0.09	0.19
1991	-0.07	0.06	0.22		0.08	0.04	0.16
1992	-0.03	0.07	0.14	0.28	0.04	-0.07	0.20
1993	0.21	0.11	0.08	0.14	0.01	-0.06	0.22
1994	0.38	0.16	0.08	0.08	-0.04	0.07	0.25
1995	0.31	0.18	0.06	0.09	0.06	0.13	0.34
1996	0.17	0.25	0.08	0.13	0.21	0.16	0.45
1997	0.25	0.37	0.12	0.19	0.20	0.18	0.58
1998	0.53	0.50	0.20	0.24	0.15	0.34	0.67
1999	0.84	0.59	0.27	0.29	0.14	0.68	0.68
2000	0.84	0.59	0.32	0.33	0.18	1.07	0.58
2001	0.45	0.35	0.29	0.30			0.33

The effects are relatively modest with regard to the choice of price index (Table 6). This relatively weak, but growing, effect over time may be due to the still relatively small, but growing, share of ICT-capital goods in total capital. The direction of the changes is as indicated in the theoretical discussion above: using hedonic prices takes into account that the quality of some capital assets may change rapidly over time. Since these rapid changes in quality are 'adjusted for' in the capital measure itself, this reduces the size of the MFP measure. Comparing the MFP estimates based on these different price assumptions comes close to the approach proposed by Hulten (1992) to estimate average embodied technological efficiency by the ratio of prices of capital goods in efficiency and natural units. The results, notably the growing effect due to quality adjusted price indexes for ICT capital assets in most recent years, therefore reflects that changes in the quality of capital and thus the contribution of capital are mainly driven by changes in the composition towards capital assets of higher efficiency, such as ICT.

Table 6: Difference in MFP if national price indexes for ICT capital assets used

	Australia	Canada	France	Germany	Japan	United Kingdom	United States
1990	-0.21	-0.12	-0.02		0.07	0.05	0.00
1991	-0.13	-0.15	0.01		0.05	0.06	0.00
1992	-0.09	-0.11	0.00	0.01	0.06	0.07	0.00
1993	-0.09	-0.03	0.00	0.03	0.08	0.07	0.00
1994	-0.06	0.00	0.02	0.06	0.10	0.10	0.00
1995	-0.04	0.03	0.01	0.09	0.11	0.11	0.00
1996	-0.05	0.04	0.04	0.13	0.14	0.14	0.00
1997	-0.11	0.12	0.05	0.17	0.15	0.20	0.00
1998	-0.18	0.19	0.06	0.21	0.12	0.28	0.00
1999	-0.18	0.21	0.07	0.23	0.11	0.28	0.00
2000	-0.39	0.18	0.09	0.21	0.21	0.30	0.00
2001	-0.31	0.08	0.08	0.16			0.00

A very important impact on the MFP estimate can be found as regards the share with which labor and capital enter the growth accounting framework (Table 7). Since, overall, the measure of total factor remuneration is smaller than nominal GDP, this measure gives more weight to capital contribution and MFP is thus expected to be reduced in times of more buoyant development in capital input than in labor input. In several countries, such as Canada, France, Japan, the United Kingdom, and the United States, the MFP measure using income shares (i.e. assuming endogenous rates of return to capital and constant returns to scale) is up to 1 percentage point lower than the MFP estimate using cost shares (i.e., assuming exogenous rates of return that allow for non-constant returns to scale and imperfections on the input and product market). This emphasizes that the interpretation of MFP growth matters. Furthermore, the importance of the assumptions about returns to scale stands out. For most countries analysed here, the relative contribution of labor and capital is biased towards a stronger contribution of capital to output growth if the capital share is computed as 1 minus the share of labor remuneration in total output.

Table 7: Difference in MFP if income share of labor used

	Australia	Canada	France	Germany	Japan	United Kingdom	United States
1990	-0.25	-0.85	-0.50		-0.24	-0.14	-0.28
1991	-0.29	-0.99	-0.60		-0.23	-0.30	-0.47
1992	-0.08	-0.35	-0.52	-0.53	-0.33	-0.69	-0.26
1993	-0.01	-0.10	-0.61	-0.66	-0.64	-0.40	-0.04
1994	0.01	-0.12	-0.35	-0.25	-0.48	-0.10	-0.10
1995	0.02	-0.48	-0.37	-0.21	-0.57	-0.17	-0.25
1996	-0.06	-0.40	-0.19	-0.22	-0.39	-0.17	-0.56
1997	-0.06	-0.67	-0.26	-0.12	-0.43	-0.15	-0.47
1998	-0.09	-0.55	-0.25	-0.06	-0.35	-0.58	-0.66
1999	-0.13	-0.46	-0.20	-0.10	-0.33	-0.27	-0.76
2000	-0.22	-0.54	-0.59	-0.09	-0.24	-0.04	-0.77
2001	-0.06	-0.68	-0.44	-0.18			-0.78

Finally, while the general pattern of MFP growth is not strongly influenced by the different means of measuring capital and labor, the size of the impact of measurement changes over time and depends on the time period and country that is analysed. This is notably the case if one compares MFP growth rates of different scenarios in the 1995-2001 period with those of earlier periods. For instance, increasing effects of measurement over time can be observed for most countries analysed whenever capital is adjusted for its quality. This is the case as regards the computation of the composition effect of capital services as well as computing hedonic price indexes of ICT capital assets. Over time, increasing effects can also be observed regarding MFP growth on cost versus income shares of labor and capital. The time period that is chosen to calculate MFP rates is therefore relevant for interpretation of the results; a finding that is also important when comparing MFP growth rates that have been calculated by different empirical studies. Computing trend values of MFP growth may therefore be informative and give an idea of the long-term development. Moreover, it may help overcome the problem of choosing start and end dates when averages over time are computed. The smoothing effect of using trend values is shown in Table 8.

Table 8: Difference in MFP if trend series of underlying variables used

	Australia	Canada	France	Germany	Japan	United Kingdom	United States
1990	1.91	1.08	0.57		-2.12	1.16	0.58
1991	0.26	1.17	1.00		0.03	1.33	0.98
1992	-1.92	-0.28	0.26	0.00	1.33	-1.49	-1.08
1993	0.47	0.39	1.36	1.44	0.12	-1.44	0.98
1994	0.73	-1.02	-0.29	-0.36	1.08	-1.32	-0.38
1995	0.05	-0.36	-0.25	-0.21	-0.11	0.20	0.90
1996	-1.10	1.45	1.19	0.23	-0.33	0.10	-0.58
1997	-1.18	-1.21	-0.04	0.15	0.16	-0.09	-0.09
1998	-1.47	-0.07	-0.91	0.40	1.84	-0.01	-0.11
1999	0.40	-0.74	-0.02	0.30	0.01	0.38	-0.17
2000	2.06	-0.38	-2.00	-0.37	-0.45	-0.39	-0.30
2001	-2.06	0.55	0.12	0.80			1.24

5. Conclusion

Growth in multi-factor productivity is believed to be an important prerequisite for long-term overall economic growth and economic convergence. The development of multi-factor productivity is thus often monitored and studied as a part of the evaluation of country's economic development. However, it is widely recognized that the measure of multi-factor productivity as obtained from a growth accounting exercise captures not only technological advancements, but also the effects of imperfect competition, non-constant returns to scale and other factors not captured by the simple framework. It is therefore often interpreted in a more general way to depict an improvement or deterioration in the efficiency of the productive use of inputs. In addition, since the multi-factor productivity is a residual in this excercise, the quality of its measure is influenced by the specification of the model as well as by the measurement errors at the level of the other variables entering the model.

To a certain extent, it has to be accepted that the measured MFP growth, which comes out of a growth accounting excercise, includes the effects of developments that are not fully related to the theoretical concept of multi-factor productivity. Still, because of the importance of MFP in interpreting the nature of economic growth, the more one can get rid off the effects of unrelated developments the closer will the measure reflect the technological improvements on the supply side. This places the burden on correct measurement. As for the rest of issues that ought to but cannot be eliminated, one should at least be aware of them, in order to interpret well the observed economic growth.

The analysis presented in this paper provides a description of selected measurement problems that may further obscure MFP development beyond what is now considered best practice. It includes measurement of the quantity of labor and capital inputs, effects of the structural changes within their aggregate measures and quantification of capital and labor shares.

A sensitivity analysis for seven OECD countries confirms that differences in measurement (which implicitly mean different assumptions about economic processes) have a relatively important effect on calculated multi-factor productivity. The results suggest that while some changes in these assumptions mainly affect the level of MFP growth, other changes result in changes in the growth pattern, too. This is important for cross-country comparison if it is based on different available data. Substantial differences in multi-factor productivity growth can be observed namely when the labor contribution is measured by total employment in contrast to total hours worked. Important effects are also observed when changes in capital composition are not fully accounted for and when different assumptions concerning the production function are made which influence the share with which capital and labor enter the growth accounting equation.

6. References

Abramovitz, M. (1956): "Resource and Output Trends in the United States Since 1870," *American Economic Review*, 46, pp. 5-23

Ahmad, N., F. Lequiller, P. Marianna, D. Pilat, P. Schreyer and A. Wolfl (2003): "Comparing Labour Productivity Growth in the OECD Area: the Role of Measurement", Statistics Directorate Working Paper 2003/5, OECD.

van Ark, B., J. Melka, N. Mulder, M. Timmer and G. Ypma (2003): "ICT Investment and Growth Accounts for the European Union, 1980-2000", *Research Memorandum GD-56*, Groningen Growth and Development Centre.

Barro, R. J. (1998): "Notes on Growth Accounting", NBER-Working Paper 6654.

Barro, R. J., and J. W. Lee (1996): "International measures of schooling years and schooling quality", *American Economic Review*, Vol. 86(2), pp. 218-223.

Basu, S., and J. G. Fernald (2000): "Why is productivity procyclical? Why do we care?", NBER-Working paper 7940.

Basu, S., J. G. Fernald and M. D. Shapiro (2001): "Productivity growth in the 1990s: Technology, utilization, or adjustment", NBER Working Paper 8359.

Basu, S., and M. S. Kimball (1997): "Cyclical Productivity with Unobserved Input Variation", NBER Working Paper 5915.

Colecchia, A., and P. Schreyer (2001): "ICT Investment and economic growth in the 1990s: Is the United States a unique case? A comparative study of nine OECD countries", OECD STI Working Paper 2001/7.

Diewert, E. D. (2001); "Measuring the Price and Quantity of Capital Services under Alternative Assumptions"; University of British Columbia Department of Economics Working Paper No 01-24.

Gomme, P., and P. Rupert (2004): "Measuring Labor's Share of Income", Federal Reserve Bank of Cleveland Policy Discussion Paper, Number 7.

Greenwood, J., and B. Jovanovic (1998): "Accounting for Growth", NBER Working Paper 6647.

Griliches, Z., and D. W. Jorgenson (1966): "Sources of Measured Productivity Change: Capital Input", *American Economic Review*, Vol. 56, Issue 1/2, pp. 50-61.

Harper, M. J. (1997): "Estimating Capital Inputs for Productivity Measurement: an Overview of Concepts and Methods", paper prepared for the Conference on Measuring Capital Stock, Canberra, March 10-14, 1997.

Hodrick, R. J., and E. C. Prescott, 1997, "Post-war US business cycles: An empirical investigation", Journal of Money, Credit and Banking, Vol. 29, 1-16.

Hulten, C. R. (1990); "The Measurement of Capital"; in Berndt, Ernst R. and Jack Triplett (eds.); *Fifty Years of Economic Measurement*, University of Chicago Press.

Hulten, C. R. (2000): "Total Factor Productivity: A Short Biography", NBER Working Paper 7471.

Hulten, C. R. (1992): "Growth Accounting when Technical Change Is Embodied in Capital", *American Economic Review,* Volume 82, Issue 4, pp. 964-980.

Jean, S., and G. Nicoletti (2002): "Product Market Regulation and Wage Premia in Europe and North America: An Empirical Investigation", OECD ECO Working Paper 318.

Jorgenson, D. W., and Z. Griliches (1967): "The Explanation of Productivity Change", *Review of Economic Studies*, Vol. 34, Issue 3, pp. 249-283.

Jorgenson D. W., F. M. Gollop and B. M. Fraumeni (1987): *Productivity and U.S. Economic Growth*, Harvard University Press.

Jorgenson, D. W. (1995): *Productivity;* Volumes 1 and 2; MIT Press.

Jorgenson, D.W., E. Yip (1999): "Whatever Happened to Productivity Growth?", in: E. R. Dean, M. J. Harper, and C. R. Hulten, eds., *New Developments in Productivity Analysis*, University of Chicago Press, pp. 205-246.

Krueger, A. B. (1999): "Measuring Labor's Share", NBER Working Paper No. 7006.

Lucas, R. E. (1988): "On the Mechanics of Economic Development", *Journal of Monetary Economics* 22, pp. 3-42.

Mankiw, N. G. (1995): "The Growth of Nations", Harvard Institute of Economic Research Working Paper 1732.

Nadiri, M. I., and M. A. Schankerman (1981): "Technical Change, Returns to Scale, and the Productivity Slowdown", *American Economic Review,* Volume 71, Issue 2, pp.314-319.

OECD (2001a): *Measuring Capital – OECD Manual*, Paris.

OECD (2001b): *Measuring Productivity – OECD Manual*, Paris.

OECD (2003*a*): *ICT and Economic Growth, Evidence from OECD Countries, Industries and Firms*, Paris.

OECD (2003b): OECD Economic Outlook No. 73.

OECD (2003*c*): *The Sources of Economic Growth in the OECD Countries*, Paris.

OECD (2004a): "OECD Measures of Total Hours Worked", OECD. . www.oecd.org/dataoecd/30/41/29867131.pdf

OECD (2004b): OECD Productivity Database: Calculation of multi-factor productivity growth, http://www.oecd.org/dataoecd/31/9/29880777.pdf

OECD (2005): *Education at a Glance*, OECD, Paris.

Oulton, N. (2005): "Ex Post Versus Ex Ante Measures of the User Cost of Capital", CEP Discussion Paper No. 698.

Romer, P. (1986): "Increasing Returns and Long-Run Growth", *Journal of Political Economy*, 94 (5), pp. 1002-37.

Scarpetta, S., A. Bassanini, D. Pilat and P. Screyer (2000): "Economic growth in the OECD area: recent trends at the aggregate and sectoral level", OECD ECO Working Paper 248.

Schreyer, P. (2000): "The contribution of information and communication technology to output growth: a study of the G7 countries", OECD STI Working Paper, 2000/2, Paris.

Schreyer, P. (2001): "Computer Price Indexes and International Growth and Productivity Comparisons", STD/DOC(2001)1, Paris

Schreyer, P. (forthcoming): "Measuring Multi-factor Productivity when Rates of Return are Exogenous", in: W. Erwin Diewert, Bert M. Balk, Dennis Fixler, Kevin J. Fox and Alice O. Nakamura (eds.), Price and Productivity Measurement, Volumes 1 and 2, Trafford Press.

Schreyer, P., E. Bignon, and J. Dupont, (2003): "OECD Capital services estimates: methodology and first results", OECD STD Working Paper.

Schwerdt, D., and J. Turunen (2006): "Growth in Euro Area Labour Quality", CEPR Discussion Paper No. 5509.

Solow, R. M. (1956): "A Contribution to the Theory of Economic Growth", *Quarterly Journal of Economics*, 70, pp. 65-94.

Solow R. (1957): "Technical Change and the Aggregate Production Function", *Review of Economics and Statistics*, 39, pp. 312-320.

Steindel, C., and K. J. Stiroh (2001): "Productivity: What Is It, and Why do We Care About It?", Federal Reserve Bank of New York Staff Reports 122.

Stiroh, K. (2001): "Are ICT Spillovers Driving the Economy?", *Review of Income and Wealth*, Vol. 48, Issue 1, pages 33-57

Triplett, J. (2004): "Handbook on Hedonic Indexes and Quality Adjustment in Price Indexes: Special Application to Information Technology Products", OECD STI Working Paper 2004/9.

U.S. Bureau of Labor Statistics (2004): "Changes in the Composition of Labor for BLS Multi-factor Productivity Measures", http://www.bls.gov/web/mprlabor.pdf.

Appendix 1: MFP data and detailed results by country

Table A.1: MFP growth – reference scenario

	Australia	Canada	France	Germany	Japan	United Kingdom	United States
1990	-0.4	-0.8	0.7		3.5	0.0	0.4
1991	1.4	-0.8	0.3		1.3	0.0	0.0
1992	3.7	0.6	1.0	1.6	0.0	3.0	2.1
1993	1.3	0.0	-0.1	0.2	1.3	3.0	0.0
1994	1.1	1.5	1.6	1.8	0.5	2.8	1.3
1995	1.8	1.0	1.5	1.5	1.6	1.1	0.0
1996	2.9	-0.8	0.1	1.0	1.6	1.0	1.5
1997	2.9	1.8	1.2	1.0	1.0	1.1	1.0
1998	3.1	0.7	2.1	0.6	-0.8	1.1	1.0
1999	1.2	1.4	1.2	0.7	1.0	0.8	1.1
2000	-0.6	1.0	3.1	1.3	1.5	1.5	1.4
2001	3.3	0.2	1.0	0.2			-0.1

Source: OECD Productivity Database, 2003
Note: These estimates were revized in the meantime; estimates as of 2006 are presented in Table A.2

Table A.2: MFP growth – OECD 2006 estimates

	Australia	Canada	France	Germany	Japan	United Kingdom	United States
1990	-0.4	-1.0	1.0		3.8	-0.2	0.8
1991	1.2	-1.0	0.6		1.5	0.1	0.2
1992	3.3	0.8	1.6	1.6	0.0	3.4	2.6
1993	0.9	0.5	0.0	0.3	1.1	2.5	0.2
1994	0.5	1.7	1.7	2.2	0.3	2.3	0.9
1995	1.4	0.9	2.2	1.8	1.4	1.1	-0.5
1996	2.5	-0.4	0.0	1.4	1.6	1.1	1.7
1997	2.4	2.4	1.8	1.7	0.9	1.0	1.0
1998	2.7	0.9	2.2	0.7	-0.8	1.4	1.2
1999	0.7	1.7	1.3	0.8	0.7	1.5	1.6
2000	-0.5	2.2	3.0	1.8	1.1	2.6	1.6
2001	2.7	0.4	0.6	0.9	0.3	0.7	0.9
2002	1.0	1.2	2.2	0.7	0.6	1.5	2.1
2003		-0.1	0.6	0.5		1.6	2.5
2004		-0.2		0.8			2.6

Source: OECD Productivity Database, 2006
Note: Estimates for a total of 19 countries are available.

Figure A.1: Deviations of annual MFP growth from reference values under different scenarios of measurement of capital and labor - Australia, percentage points

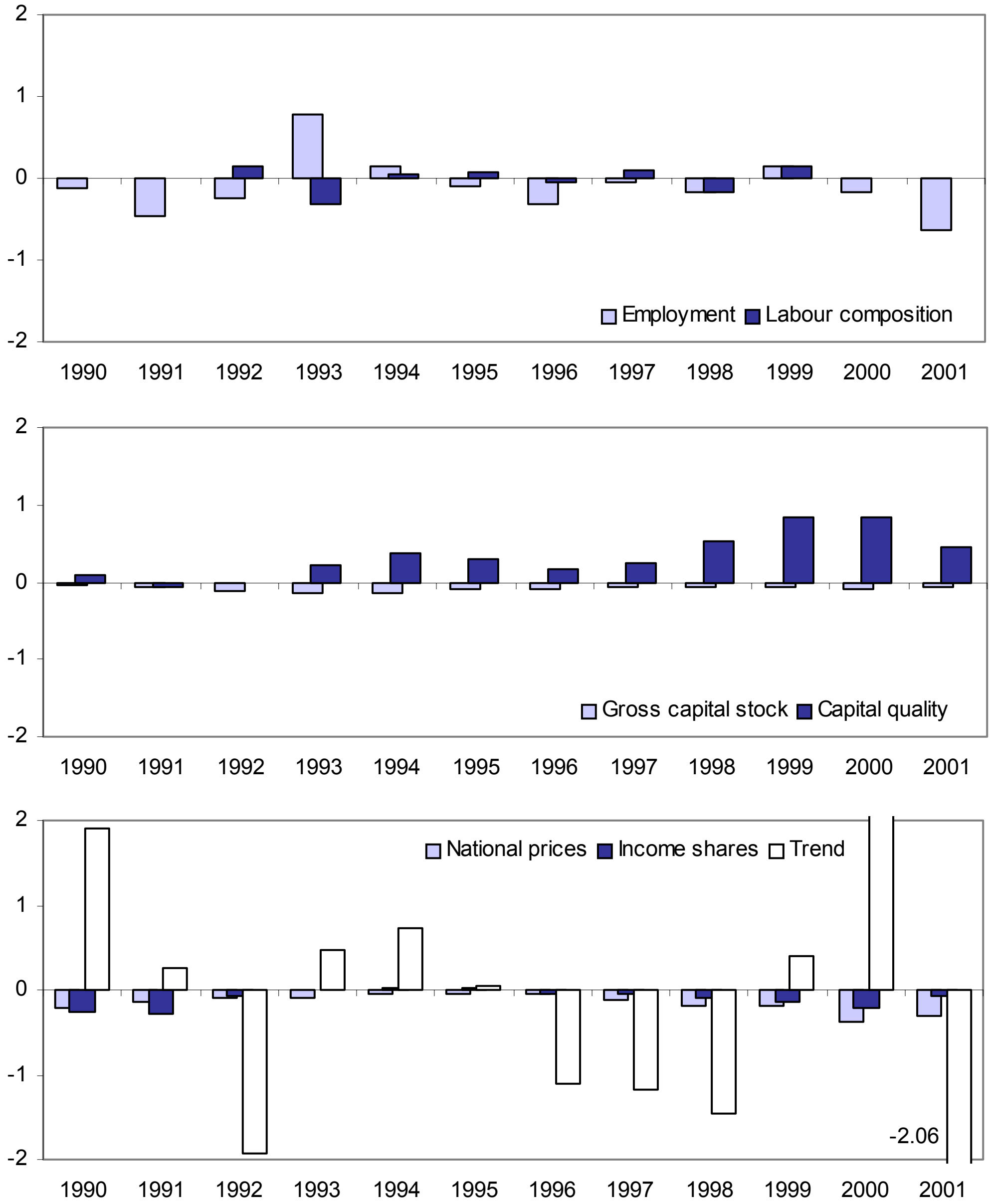


Figure A.2: Deviations of annual MFP growth from reference values under different scenarios of measurement of capital and labor - Canada, percentage points

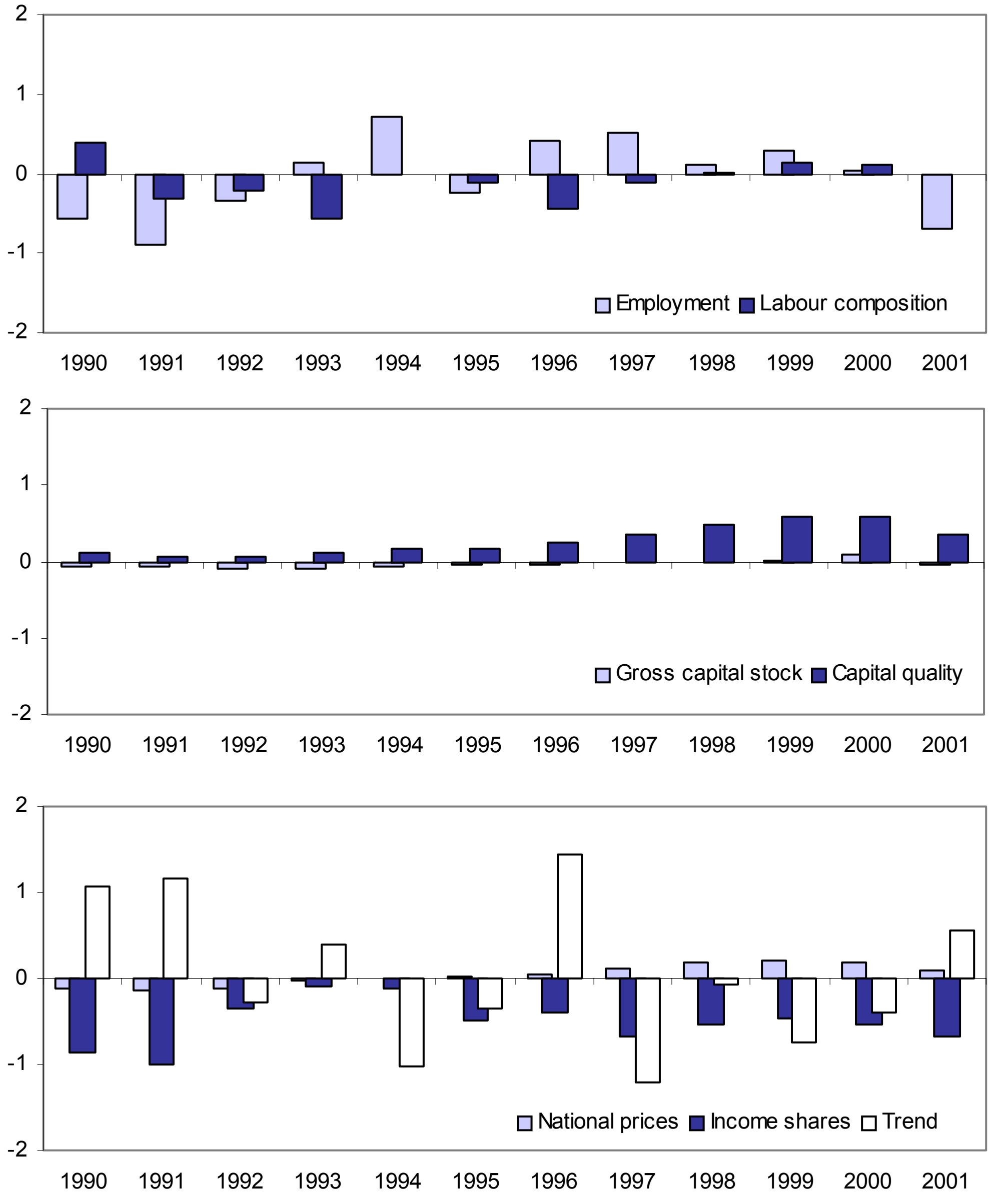


Figure A.3: Deviations of annual MFP growth from reference values under different scenarios of measurement of capital and labor - France, percentage points

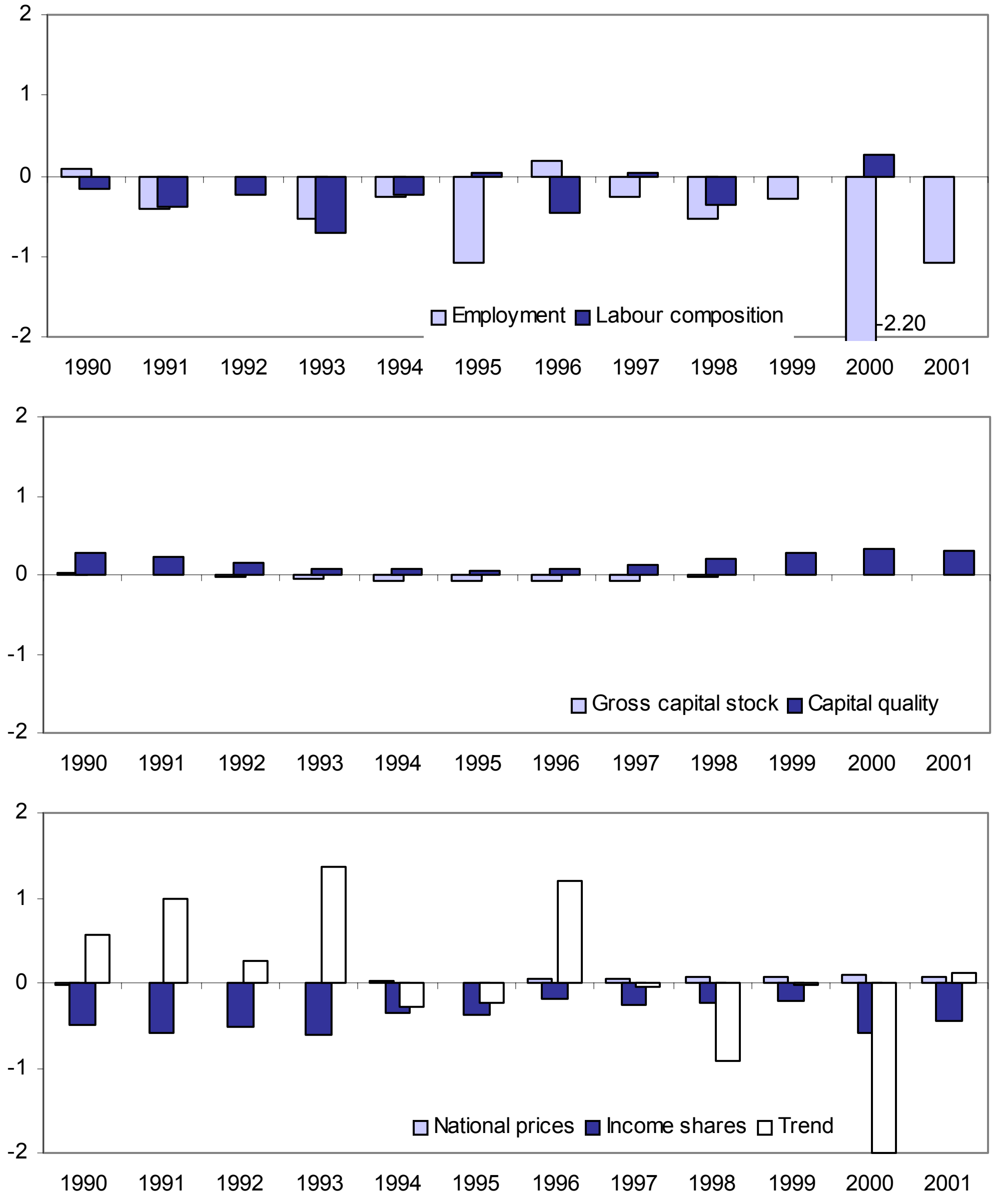


Figure A.4: Deviations of annual MFP growth from reference values under different scenarios of measurement of capital and labor - Germany, percentage points

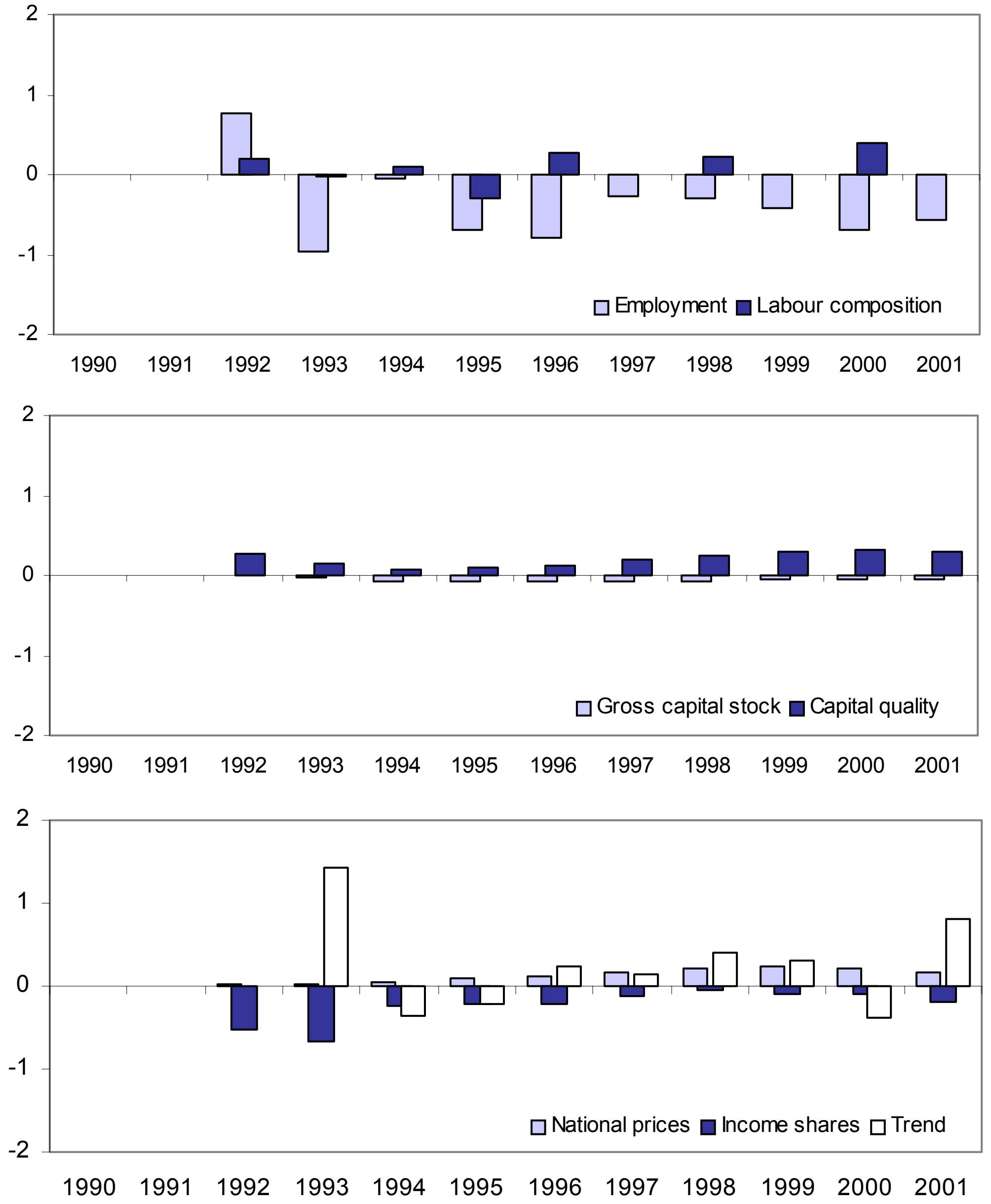


Figure A.5: Deviations of annual MFP growth from reference values under different scenarios of measurement of capital and labor - Japan, percentage points

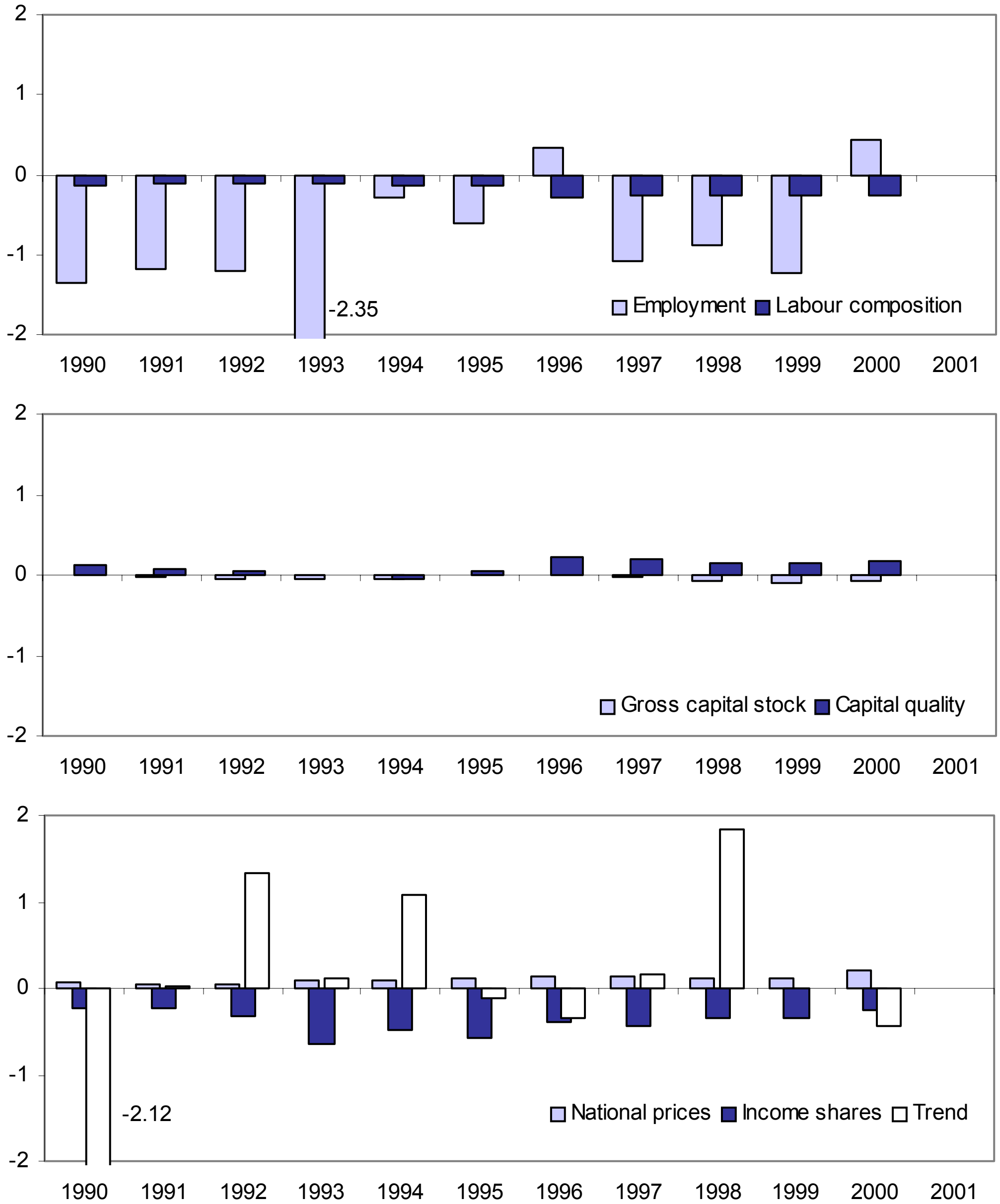


Figure A.6: Deviations of annual MFP growth from reference values under different scenarios of measurement of capital and labor – United Kingdom, percentage points

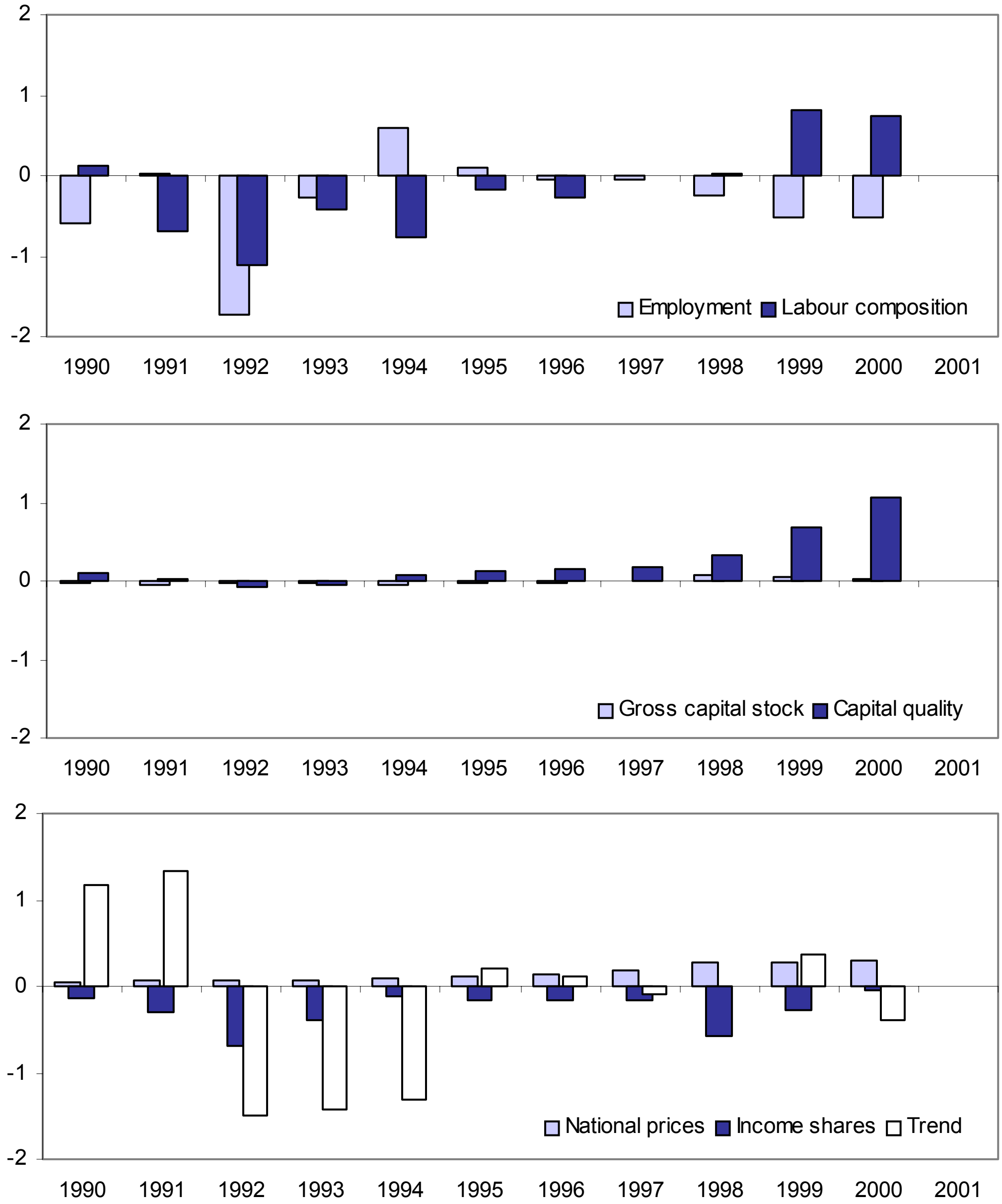
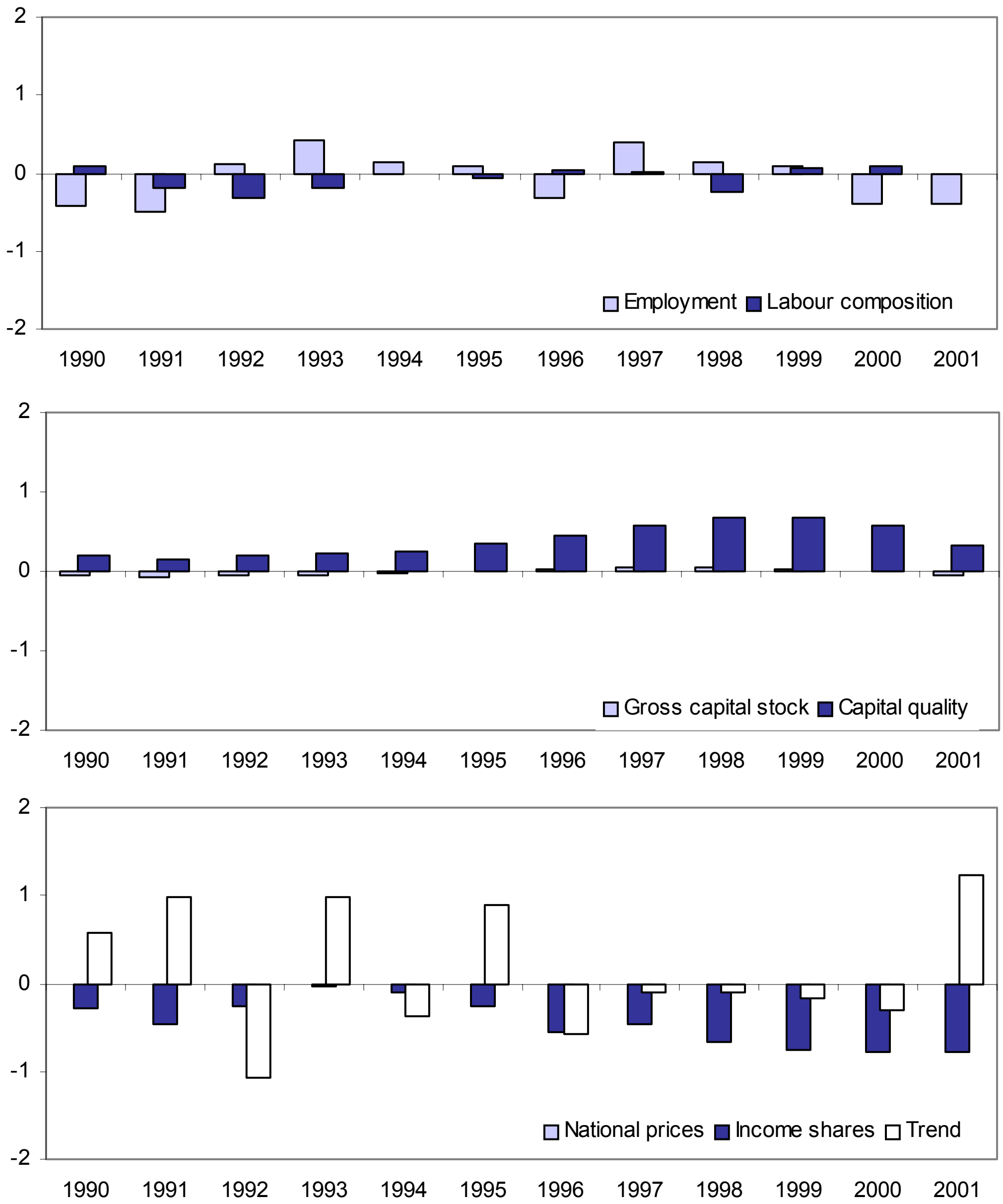


Figure A.7: Deviations of annual MFP growth from reference values under different scenarios of measurement of capital and labor – United States, percentage points



Note: The effect of the choice of ICT-goods price index is nil for the United States, as the hedonic national price of the United States served as the reference for the harmonized hedonic price indexes of the other countries.

CHAPTER III: CAPITAL INPUT INTO CZECH PRODUCTION: AN EXPERIMENTAL MEASURE OF CAPITAL SERVICES

Abstract

In this paper we present an experimental measure of capital services for the Czech economy that is more appropriate than net capital stock when describing capital input to aggregate production. It weights the contributions of different types of assets by their marginal product instead of by their price, which is the case when using net capital stock. The analysis shows that growth in net capital stock, if used as an input into production function, underestimates the growth of capital input by more than one percentage point.

1. Introduction

In the context of evaluating multi-factor productivity (MFP), as described in Chapter II of this dissertation, proper measurement of all input and output variables is essential. This was emphasized in the seminal contribution by Jorgenson and Griliches (1967). They show that the rates of growth of total real output and total real input have to be calculated as the weighted averages of the growth of all individual products and factors. On this condition, and if the production function has constant returns to scale and markets are competitive, the changes of multi-factor productivity are accurately described by the shifts in the production function. This means that, on the real factor input side, attention must be paid to the correct measurement of services that flow from the stock of labor and capital and form inputs into the production function. In particular, the heterogeneity of these inputs must be kept in mind and correctly accounted for. Whenever the composition of these inputs varies, be it from the point of view of quality, age or some other characteristic, this change also adds or subtracts from the contribution of the factor. The measurement of capital input from this point of view is discussed by Griliches and Jorgenson (1966) and OECD (2001a). Jorgenson et al. (1987) and Schwerdt and Turunen (2006), among others analyse the measurement of labor input. A recent discussion of the implications of some standard production function assumptions for the measurement of multi-factor productivity is provided by Schreyer (forthcoming). The current paper focuses on the measurement of the contribution of capital to economic output growth in the Czech Republic.

The stock of capital, while being an appropriate measure of wealth, does not capture correctly the contribution of existing capital to aggregate production. OECD (2001a) identifies three main problems with using measured net capital stock as an input in estimating production functions. The first problem is that unlike other (correctly measured) variables in the production function which enter as flows, this capital measure enters the production function as a stock, and therefore, imposes inconsistency in dimensions. The second drawback to using capital stock is that it does not sufficiently account for the heterogeneity of capital assets. Conventional measures of gross or net capital stock do not fully reflect the productive efficiency of capital assets. Hence, if gross capital stock is used, all capital assets are regarded as new, providing continuously the same quality of service. If a net capital measure is used instead, evaluating the assets at market prices, the measure will most likely underestimate productive efficiency in the early years of the service life when prices typically decline quite rapidly. And thirdly, when aggregating across assets to obtain the total value of (gross or net) capital stock, each asset is weighted by its market value. This basically implies that by using the growth rate of this measure to capture the growth of productive capital input, two assets with the same value will have the same weight in accounting for their contribution to production in a given year. Thus, expensive assets with a long service life are assumed to make a relatively larger contribution to annual production than cheaper assets with short lives.

When assessing the contribution of capital into production, therefore, it is necessary to pay attention to changes in the flow of services that derive from changes in the capital asset structure. Dynamic development of highly productive assets, like information and communication technology assets, for instance, may not result in noteworthy changes to the measured stock of capital. This is because such assets usually have a short service life and therefore a relatively lower price; consequently, they will have a lower weight in total capital stock compared to assets with a long service life. If the asset structure develops towards more productive assets (i.e. assets with higher marginal productivity and, hence, rental cost), using the capital stock as a measure of capital input into production may underestimate the true productive contribution of capital. The measure of capital services will, on the other hand, capture it since it looks precisely at the quantity and value of the flow of productive capital services deriving from capital assets, i.e. the contribution of capital to production.

Notwithstanding its importance to correctly accounting for the productive capital input, measuring capital services is not straightforward. Capital is frequently owned by its user, meaning that the flow of capital services is not intermediated by the market and the full set of quantities and prices of capital inputs is not observed. This is why in many countries, including the Czech Republic, a measure of capital services is not readily available. Exceptions include the United States, Canada and Australia, which publish such measures officially. The United Kingdom and New Zealand have experimental measures. The OECD produces capital measures for nineteen OECD countries.[72]

The measure of capital services has been widely applied in analyses of aggregate and sectoral productivity and of potential output. Vijselaar and Albers (2002), for instance, analyze the effect of new technologies on productivity growth in the Euro Area, while Oulton and Srinivasan (2005) do the same for the United Kingdom. Inklaar et al. (2003) analyze the effects of development and usage of information and communication technology for the difference between the EU and US productivity growth. Beffy et al. (2006) estimate the potential output in selected OECD countries using the measure of capital services.[73]

So far, the measure of capital input into the production function used in studies concentrating on the Czech economy has mostly been the stock of capital as provided by the Czech Statistical Office[74] or as calculated based on data from the Czech Statistical Office[75]. The notion of capital services was, in contrast, used by Piatkowski (2003) in a study of eight Central and Eastern European countries in which the author calculates the contributions of ICT and non-ICT capital services to economic growth in 1992-2000 using

[72] Capital measures for eight OECD countries are presented in Schreyer (2003). Beffy et al. (2006) use capital services measures for nineteen countries.

[73] Application to supply-side analysis need not be the sole use of the measure of capital services. For instance, a correctly estimated measure of total factor productivity would be useful to an analysis of price-level convergence.

[74] E.g. in Hurník and Navrátil (2005).

[75] E.g. Hájek (2005).

data on ICT spending from a private source (International Data Corporation).[76] Dybczak et al. (2006) use the measure of capital services described in this paper to disentangle Czech economic growth at the aggregate level.

The current paper describes the experimental measure of capital services for the Czech Republic used in Dybczak et al. (2006). The methodology described in Schreyer et al. (2003) is followed, though it is simplified to accommodate the data. The contribution of capital based on the presented experimental measure of capital services can be compared with that based on the measure of capital stock and an inference may be drawn about changes in the productive capacity of capital. If the contribution based on the experimental measure of capital services is higher, this would signal positive changes of capital productivity in the Czech Republic. The impact on measured multi-factor productivity can be shown in a simple growth accounting exercise. Constructing the measure of capital services also permits use of an exogenous rate of return to capital in such an exercise.

2. Capital services: method and data

2.1. Capital services

The contribution of capital to production naturally derives from the existing stock of capital. The market value of this stock of capital is not, however, a correct measure of the contribution. Analogous to the contribution of labor, which can be measured as hours worked in the economy, the capital input of machinery, for instance, could be measured as machine hours. The concept of capital services captures the flow of services from a capital asset that forms a contribution to production. In general, the marginal productivity of different assets (machinery, transport equipment, software, etc.) in production will not be the same, and this should be reflected in the weighting scheme that is applied to aggregate the services of different types of assets. Such a weighting scheme should be based on user cost, not on purchase prices, and should be updated regularly by using a chain-weighted index number formulae.

The notion of capital services as a concept different from net capital stock was first described by Griliches and Jorgenson (1966). In contrast to labor input, which is relatively easily measurable,[77] measuring the services of capital is more difficult. The most important problem is that most transactions which entail the use of capital services do not appear on the market, since capital is frequently owned by its user, and the price and quantity of capital services used for production are therefore not observed. An inference must therefore be drawn from the development of the productive stock of particular assets and be combined with information about the user cost of these assets which, in theory, should reflect the value of capital services these assets can provide.

The OECD *Manual on Capital Measurement* (OECD, 2001a) and Schreyer et al. (2003) provide a framework for measuring capital services. Capital services are viewed as a flow of productive services from the cumulative stock of past investments. The quantity of

[76] There are, however, several drawbacks to the measure used in Piatkowski (2003). Due to the lack of data, assumptions are required about the ratio of investment to spending for information technology, communications technology and software, and on ICT investment before 1992.

[77] Some studies choose to account for heterogeneity of labor while some studies choose to ignore it. The heterogeneity of labor input is taken into account e.g. in OECD (2003).

productive services $K_{t,s}^{i}$ in year *t* of a capital asset of type *i* and age *s* years is proportional to the volume of investment in this asset *s* years ago, I_{t-s-1}^{i}, expressed in constant prices,

$$K_{t,s}^{i} = \lambda_t^i F_s^i I_{t-s-1}^{i} \qquad (1)$$

where λ_t^i is a proportionality factor that links the flow of capital services to a vintage investment and F_s^i reflects the retirement pattern of asset *i*. F_s^i represents a distribution around the expected service life of this asset; it is non-negative, falling in *s* and takes the value of 1 for a new asset (i.e., if $s = 0$).

The price of using a capital service $K_{t,s}^{i}$ is $uk_{t,s}^{i}$ and the value of the services in time *t* derived from asset *i* acquired *s* years ago is equal to $uk_{t,s}^{i} K_{t,s}^{i}$. The value of capital services of asset *i* used in time *t* can be expressed as follows:

$$uk_t^i K_t^i = \sum_{s=0}^{t-1} uk_{t,s}^{i} K_{t,s}^{i} \qquad (2)$$

The price of using a capital service must be distinguished from the price of using a unit of capital good (the user cost). The cost of using one unit of vintage investment, $u_{t,s}^{i}$, is proportional to the price of the capital service:

$$u_{t,s}^{i} = \lambda_t^i uk_{t,s}^{i} \qquad (3)$$

The productive stock S_{t-1}^{i} of asset type *i* at the end of period *t-1* can be computed by the perpetual inventory method as the sum of all vintage investment (*s* years ago) in this type of asset, I_{t-s-1}^{i}, expressed in base year prices, corrected for the probability of retirement and for the loss of productive capacity,

$$S_{t-1}^{i} = \sum_{s=0}^{t-1} h_s^i F_s^i I_{t-s-1}^{i} \qquad (4)$$

where h_s, the age-efficiency function, describes the loss of productive capacity of a capital good because of "wear and tear" and technical obsolescence.[78] It is a non-negative function which declines in *s* with h_s=1 for a new capital good and h_s=0 for a capital good that has reached its maximum service life. In a functioning market, the following relationship holds: $h_s^i / h_o^i = u_{t,s}^{i} / u_{t,0}^{i}$. Combining (4) with (1), (2) and (3), one obtains:

$$uk_t^i K_t^i = u_{t,0}^{i} \sum_{s=0}^{t-1} h_s^i F_s^i I_{t-s-1}^{i} = u_{t,0}^{i} S_{t-1}^{i} \qquad (5)$$

i.e., the value of capital services from i-type assets is equal to the product of the productive stock of these assets (expressed in "new equivalent" units) and its user cost. This identity can be used in quantifying the flow of capital services. The change in the volume of capital

[78] A cost-minimizing producer will equalize the relative productivity of assets of different age with their relative user cost. The presented functional form also relies on the assumption that capital goods of the same type are perfectly substitutable.

services flowing from asset i is then measured by the index of the productive stock S_t^i / S_{t-1}^i.[79]

In order to construct the aggregate measure, it is necessary to keep in mind that each type of asset produces a specific flow of capital services in proportion to its productive stock. This proportion, however, differs across assets. The weights for aggregations thus must reflect the marginal productivity of different assets. Market prices of capital assets are not suitable weights because they reflect the flow of capital services of the assets over their expected remaining service life but not for a single year. In contrast, the user cost, in equilibrium, equals the marginal revenue of an asset and hence is the correct weight.

The user cost of an s-year old asset i in time t with information set of $t\text{-}1$ is defined as follows:[80]

$$u_{t,s}^i \middle| \Omega_{t-1} = q_{t-1,s}^i \left(r + d_{t,s}^i - \zeta_t^i + d_{t,s}^i \zeta_t^i \right) \tag{6}$$

where $q_{t-1,s}^i$ is the purchase price of the asset, r is the nominal discount rate, $d_{t,s}^i$ is the depreciation rate and ζ_t^i the rate of asset price change.

The change in the volume of capital services is then given by

$$\ln \frac{S_t}{S_{t-1}} = \sum_i \frac{1}{2} \left(\frac{u_t^i S_{t-1}^i}{u_t S_{t-1}} + \frac{u_{t+1}^i S_t^i}{u_{t+1} S_t} \right) \ln \frac{S_t^i}{S_{t-1}^i} \tag{7}$$

Below we identify i with either the class of assets distinguished by their "type" (i.e. falling into these groups: dwellings, other buildings and structures, transport equipment, other machinery and equipment, cultivated assets, computer software, and other intangible fixed assets) or assets accumulated in a particular industry. The difference between these methods will consist in how well we are able to measure the different characteristics of the particular asset groups. The different elements of user cost (depreciation, price change), for instance, are probably more precisely measured for asset types. On the other hand, the method is more precise with greater degree of disaggregation, and, as will be described below, more detailed data are available for a breakdown by industries. Calculation of the experimental measure of capital services was, therefore, conducted for both these approaches. This provides us with the opportunity to compare the measures and also, to some extent, assess their robustness.[81]

The shortcoming of the measure of capital input into production presented above is that it assumes a proportional flow of capital services from the existing capital stock, i.e. a full (or steady) utilization of the capital stock. It does not pay attention to variation in the rate of capacity utilization that naturally occurs during the production cycle, for instance, because of seasonal or trend changes in demand, breakdown of equipment, etc. The described measure thus in fact represents a measure of potential flow of capital services and hence potential contribution of capital to production. This may be an advantage when a measure of potential output is being constructed. One has to keep this feature in mind, however,

[79] The argument is based on the assumption that the correct deflator for the value of capital services is the user cost of a new asset. An alternative is to deflate the value of capital services by the user cost per unit of capital services. The two options do not have different growth implications if λ^i is time invariant. If there is, however, time variation in this parameter, e.g. cyclical fluctuations in the capacity utilization, the current measure does not fully capture the variation in capital services.

[80] As derived by Schreyer et al. (2003).

[81] Ideally, one could combine the two approaches and use the breakdown by asset <u>and</u> industry, which would profit from the maximum available information. Unfortunately, this could not be pursued because of lack of some necessary data in this breakdown.

when using the measure of capital services for productivity measurement. The measure of capital services will have the tendency to overestimate the capital contribution to production in downturns. A measure of multi-factor productivity based on this measure of capital services will contain this effect.

2.2. Available data

The national accounts[82] data on the net stock of fixed capital, consumption of fixed capital, and changes in the valuation of fixed assets were obtained from the Czech Statistical Office (Czech Statistical Office, 2004). The flow data are expressed in current and constant prices, the net stock data are expressed in current and constant replacement cost.[83] In a breakdown by industry, consistent time series in an annual frequency are available for the measures of gross fixed capital formation and net capital stock in current and constant replacement cost and for capital consumption in current prices. These time series are available in a breakdown for 60 groups of industries (based on NACE classification) for the period 1995-2002 and in a 16-industry breakdown for the period 1995-2004. In the breakdown by type of asset, annual time series are available for gross fixed capital formation in constant and current prices, net capital stock in current replacement cost and capital consumption in current prices. A breakdown by seven groups of assets[84] are available for the period 1995-2003; for the period 2003-2005, quarterly data by six types of assets are available.[85] Unlike the other capital volume time series that are fixed-base Laspeyres indexes, the 2003-2005 data in the asset breakdown are constructed by the chain-linking method. The problem with real variables constructed by the chain-linking method is that the sum of the sub-aggregates expressed in constant prices, in general, does not equal the aggregate expressed in constant prices. As a result, the method described above could not be used for the more recent period, since it relies on summing the contributions of disaggregated data.

In general, the length of publicly available investment time series is insufficient to allow for the application of equation (4) to compute the series of productive stock of capital.[86] If one could assume, however, that at the level of individual classes of assets the net stock of a capital asset in replacement cost (as computed by the Czech Statistical Office) correctly accounts for most of the age and obsolescence effects and thus the loss of productive

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[82] Methodology ESA 1995.

[83] Definitions of current and constant replacement cost by Eurostat (1997, http://forum.europa.eu.int/irc/dsis/coded/info/data/coded/en/gl008781.htm). Current replacement cost: all capital goods are valued at the price prevailing in the current year. The gross capital stock shows the value of the capital goods assuming that all goods were purchased new in the year considered. The net capital stock at current replacement cost is the value of the capital stock assuming that all goods were purchased in their current state in the year considered. Constant replacement cost: capital goods are valued at the prices prevailing in the selected base year. The gross capital stock at constant replacement cost represents the value of the capital goods on the assumption that all capital goods were purchased in the base year. The net capital stock at constant replacement cost shows the value of the capital goods on the assumption that all capital goods were purchased in their present state in the selected base year.

[84] Tangible fixed assets: dwellings, other buildings and structures, transport equipment, other machinery and equipment, cultivated assets; intangible fixed assets: computer software, other intangible fixed assets.

[85] Data on the net capital stock and gross fixed capital formation (both in current prices) are also available broken down by industry and type of assets for the period 1995-2002, but the lack of information about the development of prices in this breakdown prevents us from conducting the measurement from this lower level of disaggregation. Data on gross fixed capital formation in current prices in a breakdown by commodity type are available for 1995-2002 and in a breakdown by industry and commodity for 2000-2002.

[86] A detailed description of the Perpetual Inventory Method including data requirements is given e.g. by Meinen et al. (1998).

capacity of these assets, it would be possible to use the net capital stock data at replacement cost broken down by type of asset and industry. One could thus assume that the productive stock of a particular capital asset, S^i_{t-1}, as defined in (4), can be well described by the measure of the net stock of capital in constant replacement cost, where *i* would stand either for a type of capital asset or for an industry.

Equation (4) requires the accumulated investment into one type of asset to be corrected for the probability of retirement and for the loss of productive capacity by wear and tear and technical obsolescence. This is also what the perpetual inventory method in theory does: net capital stock is compiled as gross capital stock (i.e. the sum of past investment) minus accumulated consumption of fixed capital (i.e. the "amount of fixed assets used up, during the period under consideration, as a result of normal wear and tear and foreseeable obsolescence"[87]).

The Czech Statistical Office uses the perpetual inventory method for calculating the stock and consumption of fixed capital of all types of assets except for dwellings and some selected types of building structures, for which a quantitative method based on information about quantity and unit prices is used. The bell-shaped (lognormal) retirement pattern is used for machinery and equipment and software.[88] Also, the lengths of asset service lives used by the Czech Statistical Office are (along with those used in United States, Canada and the Netherlands) considered by the OECD to "*appear to be based on information that is generally more reliable than is usually available in other countries*" (OECD, 2001a, p. 104).It is therefore reasonable to assume that the net stock of a particular fixed asset (except for dwellings and non-residential building structures) is a fairly accurate approximation of the productive stock of capital for the considered asset classes.

The productive stock of capital S^i_{t-1} is hence not computed. Instead, it is approximated by the corresponding measure of net stock of capital in constant replacement cost from the Czech Statistical Office (2004). The series of net stock of capital in constant replacement cost are available only in the industry breakdown, but they can be constructed from available data for the types of assets analyzed. Because of the methodology change in expressing volume indexes, the current analysis covers the period 1995-2002 (resp. 1995-2003) only.

2.3. Net capital stock in constant replacement cost for groups of assets

As described above, the breakdown by asset type of net stock of capital exists in the Czech Statistical Office (2004) only for data expressed in current replacement cost. In order to construct the time series of net capital stock in constant replacement cost for each asset, we use a version of the perpetual inventory method while ignoring the age structure of the stock of assets:

$$S_{jt} = S_{jt-1} + I_{jt} - D_{jt} \qquad (8)$$

where S_{jt} is the net stock of assets of type *j* in year *t* in constant replacement cost, S_{jt-1} is the net stock of assets of type *j* in the previous year in constant replacement cost, I_{jt} is gross investment in asset *j* in year *t* and D_{jt} is constant-price consumption of fixed capital of type *j* in year *t*.

[87] Eurostat (2005).

[88] Sixta (2004). OECD (2001a) considers the lognormal mortality pattern as a realistic account of the retirement pattern.

We assume that the depreciation is proportional to the previous-year net stock of the capital assets, that the depreciation rate is d_{jt}, and that the capital formation is governed according to the following rule:

$$S_{jt} = (1 - d_{jt})S_{jt-1} + I_{jt} \quad (9)$$

It is important to make an assumption about the behavior of depreciation rate d_{jt}. Jorgenson (1995) uses a geometric pattern of depreciation, i.e. that the constant depreciation rate applies each year on the remaining net stock of capital asset. Schreyer et al. (2003), the U.S. Bureau of Labor Statistics (1983) and the Australian Bureau of Statistics (2000) use a hyperbolic profile, which for certain parameter values can reflect an assumption that assets lose little of their productive capacity in the first years of their service lives, but the loss in productive efficiency grows with their age. Since we cannot carry out the perpetual inventory method completely (we start from a net stock in 1995, where the history starts), we cannot use the latter method, since we do not know at what stage of service life the capital assets in the net stock are. We use, therefore, the first suggested method, applying the geometric pattern of depreciation and constant depreciation rate on the net stock of capital assets of the same type. Assuming that the depreciation rate is constant for each asset type also allows us to ignore temporary fluctuations in the observed depreciation rates, but at the same time it presumes some type of equilibrium behavior, i.e. constant ratio of consumption of capital to its stock.[89]

The constant depreciation rates d_j for each asset type are computed as averages of the realized depreciation rates in the period 1996-2003. The depreciation rate of each asset type in each year is computed as the ratio of the consumption of fixed capital and the average net stock of fixed capital in the respective year, both in current prices.[90]

The time series of net stocks by asset type in constant replacement cost of the year 1995 are then constructed by departing from the values of net stocks for the year 1995 and using the time series of gross investment in assets in constant prices and the asset-specific depreciation rates.

2.4. User cost and aggregation

The weights for the aggregation (the user costs) are constructed as defined in (6). To establish the required nominal rate of return at time t (the opportunity cost of financial capital invested in an asset), we take into account the financing structure of firms and the

[89] Closer inspection of the behaviour of the observed time series of depreciation rates (the development of depreciation rates is depicted in Graph A.1 in Appendix 1) in fact reveals that, while this assumption is probably not excessive for other types of capital assets, a downward trend over time can be observed for computer software. Applying a constant depreciation rate (an average rate) when the true rate is declining can have two consequences in the model: Firstly, growth in the net stock of assets will be overestimated at the beginning of the sample and underestimated at its end. Secondly, the user cost will be underestimated at the beginning of the sample and overestimated at the end of the sample. These two effects will go against each other when computing the growth in capital services. Computing the measure of capital services with variable depreciation rates shows that the first effect slightly dominates the other (mainly because of the overall low weight of computer software capital services in total capital services). Growth in the contribution of software to the growth of capital services based on a variable depreciation rate is slightly lower at the beginning of the analysed period and the same or slightly higher at its end than the measure based on constant depreciation rate. The effect on the average growth rate of capital services is minor. The results are compared in Table A.4 in the Appendix 1.

[90] This measure assumes the same prices of scrapped assets as for functioning ones, which may lead to some underestimation of the depreciation rates and overestimation of the capital stock in constant prices. The computed average depreciation rates are presented in Table 2 below.

effects of taxation. The expected real rate of net return to owners of capital would reflect the real cost of equity and the real cost of debt. As a proxy for the cost of financing equity, the yield of a 10-year interest rate swap was chosen. As a proxy for the cost of debt, the yield on corporate bonds is used, adjusted for the tax shield (interest on corporate credit is available for shorter time series and for the comparable period is not very different from the used measure). [91] Both components are deflated by CPI inflation and their respective weights are 0.6 and 0.4, which approximates the prevailing financial structure of Czech corporations. To obtain a constant real rate of return, these annual values are averaged over the period of availability (1997-2005). The required nominal rate of return is then obtained by adding an expected inflation component (a three-year centred average of observed inflation).

The depreciation rates for capital used in industries are computed identically as described above for asset groups. The purchase prices of the assets are implicitly contained in the measure of the net capital stock in current replacement cost. The expected price change of capital is computed as a three-year centred average of the change in the deflator of gross fixed capital formation.

The capital income in each industry and for each type of asset is then computed as the product of the net stock of fixed assets in current replacement cost and the required gross rate of return (the expression in the parentheses in (6)). The share of each industry (asset) in total capital income then represents the weight that is assigned to the growth in the net stock of fixed assets in constant prices in this industry (asset). The sum of these contributions represents the growth of capital input (capital services) in a given year. This is summarized in (10):

$$\ln\frac{K_t}{K_{t-1}} = \ln\frac{S_{t-1}}{S_{t-2}} = \sum_i \frac{1}{2}\left(\frac{u_t^i S_{t-2}^i}{u_t S_{t-2}} + \frac{u_{t+1}^i S_{t-1}^i}{u_{t+1} S_{t-1}}\right)\ln\frac{S_{t-1}^i}{S_{t-2}^i} \qquad (10)$$

In contrast, the growth of capital input measured by net capital stock *W* where replacement cost weights *p* are used is computed according to (11):

$$\ln\frac{W_t}{W_{t-1}} = \sum_i \frac{p_{t=1}^i S_{t-1}^i}{p_{t-1} S_{t-1}}\ln\frac{S_t^i}{S_{t-1}^i} \qquad (11)$$

3. Capital services: results

The main difference of the capital measure from the measure of net capital stock consists in recognizing that different types of capital assets produce a flow of services with different price and quantity distributions over time. Paying attention to the structure of capital thus better captures the aggregate input into production.

3.1. Information in asset structure

Figure 1 compares development of the measures of net capital stock and capital services constructed based on the asset-type decomposition of capital assets between 1995 and 2004. The time coverage of the two time series is shifted because according to the model employed, capital services derive from previous-year productive stock. The growth rate of

[91] The data for 1997-2005 on the IRS come from CNB's internal database. The yield on corporate bonds is the PRI index downloaded from Bloomberg.

capital services is in all years higher than the growth rate of net capital stock. This means that measuring the capital contribution to production by net capital stock would underestimate the productive capital input.

Figure 1: Growth rate of net capital stock and capital services, asset-type approach (%)

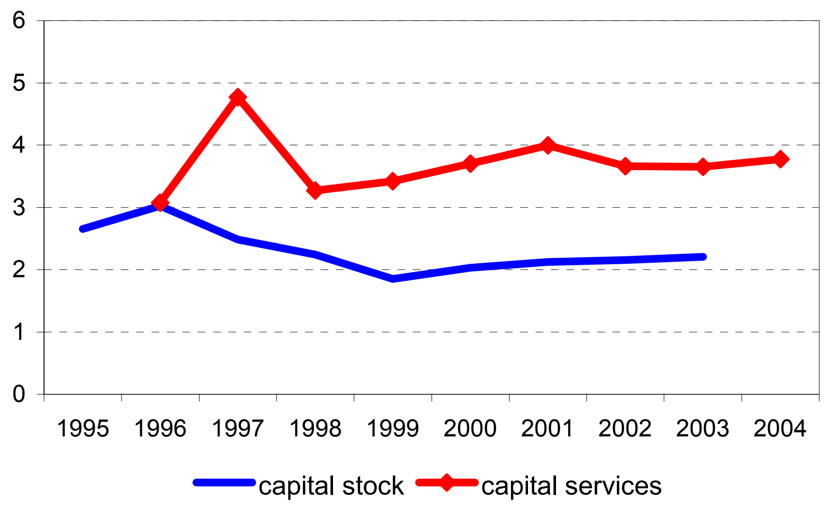

Table 1 presents details of the above result and compares the contributions of particular asset types to capital services growth (left pane) and net capital stock growth (right pane). It is apparent that the stock measure can underestimate the real growth of capital by more than one percentage point. Behind this difference lies mainly growth in transport equipment and other machinery as well as equipment assets, which are assigned more weight in the capital services measure. It can also be observed that while the contribution of computer software assets is negligible in the conventional measure, it is more significant in the new measure, where first it contributes quite negatively but then turns positive in the most recent period. This can be attributed primarily to the increased investment in computer software, which was rather weak in 1997-1998 and was not sufficient to cover the depreciation of these assets. The subsequent pickup in investment then resulted in the positive contribution of computer software to capital services growth.[92] The contribution of buildings, structures and dwellings, in contrast, is slightly downplayed by the measure of capital services.

[92] This pattern is slightly more pronounced if a variable depreciation rate is used.

Table 1: Growth rate of capital input – contributions by types of assets, percent and percentage points

	Capital services Yearly contributions by cost								Net capital stock Yearly contributions by value							
	Total	Dwellings	Other buildings and structures	Transport equipment	Other machinery and equipment	Cultivated assets	Computer software	Other intangible fixed assets	**Total**	Dwellings	Other buildings and structures	Transport equipment	Other machinery and equipment	Cultivated assets	Computer software	Other intangible fixed assets
1995									**2.7**	0.0	1.9	0.0	0.9	0.1	-0.1	-0.1
1996	**3.1**	0.0	1.3	0.0	2.5	0.1	-0.5	-0.2	**3.0**	0.0	1.6	0.2	1.3	0.1	0.0	-0.1
1997	**4.8**	0.0	1.1	0.5	3.5	0.1	-0.2	-0.2	**2.5**	0.0	1.4	0.1	1.0	0.0	-0.1	-0.1
1998	**3.3**	0.0	0.9	0.3	2.7	0.0	-0.5	-0.2	**2.2**	0.1	1.0	0.2	1.0	0.0	0.0	-0.1
1999	**3.4**	0.0	0.7	0.5	2.5	0.0	-0.1	-0.2	**1.9**	0.1	0.6	0.3	0.9	0.0	0.0	-0.1
2000	**3.7**	0.0	0.4	0.7	2.1	0.0	0.6	-0.2	**2.0**	0.0	0.4	0.5	1.1	0.0	0.0	0.0
2001	**4.0**	0.0	0.3	1.2	2.2	0.0	0.4	-0.1	**2.1**	0.0	0.6	0.6	0.9	0.0	0.0	0.0
2002	**3.7**	0.0	0.4	1.3	1.8	0.0	0.1	0.0	**2.2**	0.1	0.4	0.7	0.9	0.0	0.0	0.0
2003	**3.7**	0.1	0.3	1.5	1.7	0.0	0.1	-0.1	**2.2**	0.2	0.5	0.8	0.7	0.0	0.0	0.0
2004	**3.8**	0.1	0.4	1.6	1.3	0.0	0.4	0.0								
Average 1996-2003	**3.7**	0.0	0.7	0.7	2.4	0.0	0.0	-0.1	**2.3**	0.1	0.8	0.4	1.0	0.0	0.0	0.0

The main factors behind the differences between the two measures are highlighted in Table 2. The first column reports the average depreciation rates, the second and third columns compare the average weights of the asset groups in the measure. The average contributions in percentage points of asset groups to growth in net capital stock and in capital services, respectively, appear in the fourth and fifth columns, and in the last column the percentage difference between growth and contributions is reported. The difference in the weights is quite remarkable: while dwellings and other buildings and structures, i.e. assets with long service lives and relatively less technology involved, represent 80% of the total in the value of capital, in the (estimated) yearly payments for capital services they account for just above 50%. The weights and, hence, contributions of transport equipment, other machinery and equipment and other intangible assets are more than twice as high when the user cost is used for aggregation than when the share in the value of capital stock is used, and the contribution of computer software is approximately thirty times higher.

Table 2: Information in asset structure

	depreciation rate	average weight (%)		average contribution (p.p.)		difference
	yearly average % 1996-2002	in value *(net cap.stock)* 1994-2003	in user cost *(cap.services)* 1995-2004	by value *(nat cap.stock)* 1995-2003	by user cost *(cap.services)* 1996-2004	of contribution (p.p.)
Total	4.4	100.0	100.0	2.26	3.78	1.52
Tangible fixed assets	4.2	99.2	95.8	2.30	3.81	1.50
Dwellings	2.1	24.6	14.9	0.07	0.04	-0.03
Other buildings and structures	2.7	55.5	38.2	0.83	0.55	-0.27
Transport equipment	15.8	3.8	9.3	0.40	0.96	0.56
Other machinery and equipment	12.9	15.1	33.2	0.97	2.22	1.25
Cultivated assets	4.2	0.3	0.2	0.03	0.03	-0.01
Intangible fixed assets	33.9	0.8	4.2	-0.04	-0.03	0.01
Computer software	60.0	0.2	2.6	0.00	0.10	0.10
Other intangible fixed assets	19.9	0.5	1.6	-0.04	-0.13	-0.08

3.2. Information in industry structure

As described above, due to different sets of available statistical data, analysis of the industry breakdown of net capital stock was undertaken separately. Like the results presented for the asset breakdown, the use of the additional information in the breakdown into sixty industries significantly changes the measured growth of capital (Figure 2).

Figure 2: Growth rate of net capital stock and capital services, industry approach (%)

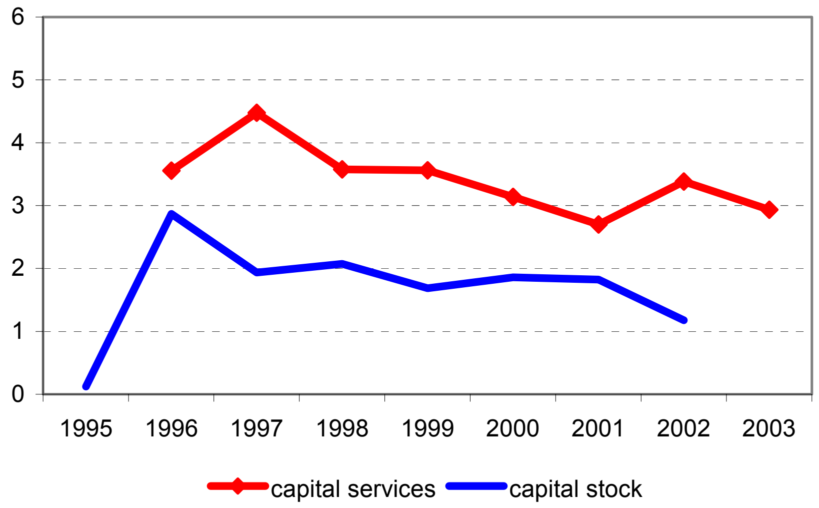

Table 3 shows how different the contributions of individual industries are if user costs are used as weights for the aggregation (left pane) or the shares in total value of capital are used as weights (right pane). For clarity, results for individual industries are aggregated into eight main groups; detailed results are available in the Appendix. Again the difference for the total growth of productive capital input exceeds one percentage point. The main difference between the two measures stems from the contributions of industry and transport. The highest relative increase of the contribution when user costs are used (observable also in Table 4) is for the transport industry. Within this contribution, there are significant positive and increased contributions in the sectors of post, telecommunications and land transport, but also a significant negative contribution from the sector of auxiliary operations in transport and travel agencies (see in Table A3). The net capital stock of the latter industry is formed by the transport infrastructure, which accounts for around 10 % of total net capital stock. The contribution of capital assets in industry also covers the assets in mining and extracting industries and the energy producing sector. The difference in contributions of capital assets in the first group of industries does not impose a large difference between the two measures of capital input. The contribution of capital in the energy producing sector, however, creates an almost 0.3 percentage point higher growth of capital input if measured by the growth in net capital. In manufacturing industries, the remarkable differences between the contributions weighted by user costs and share in value are mostly in favor of the measure of capital services. Contributing most to the difference is the manufacturing of motor vehicles and trailers, machinery and equipment, fabricated metal products, rubber and plastic production, chemicals and paper production.

Table 3: Growth rate of capital input – contributions by industry, percent and percentage points

	Capital services Yearly contributions by cost									Net capital stock Yearly contributions by value								
	Total	Agriculture and forestry	Industry	Construction	Trade, repair, hotels, rest	Transport	Financial intermediation	Real estate, rental, entrepreneurial activities	Public services	**Total**	Agriculture and forestry	Industry	Construction	Trade, repair, hotels, rest	Transport	Financial intermediation	Real estate, rental, entrepreneurial activities	Public services
1995										**0.1**	0.2	1.5	0.1	0.2	-0.5	0.3	-1.4	-0.3
1996	**3.6**	0.3	2.5	0.2	0.5	0.0	0.8	-0.5	-0.2	**2.9**	0.1	1.4	0.1	0.3	0.2	0.2	0.2	0.4
1997	**4.5**	0.2	2.3	0.1	0.6	0.7	0.3	0.0	0.3	**1.9**	-0.2	1.0	0.1	0.3	0.6	0.1	-0.1	0.0
1998	**3.6**	-0.2	1.8	0.2	0.3	1.4	0.2	-0.3	0.1	**2.1**	-0.1	0.9	0.1	0.2	0.3	0.0	0.3	0.2
1999	**3.6**	-0.1	1.6	0.2	0.4	1.0	0.1	0.2	0.2	**1.7**	0.0	0.9	0.5	0.3	-0.4	0.0	-0.1	0.5
2000	**3.1**	0.0	1.4	0.8	0.7	0.0	-0.1	0.0	0.4	**1.9**	-0.1	1.1	-0.6	0.0	0.6	0.0	-0.3	1.2
2001	**2.7**	-0.1	1.6	-0.7	0.0	0.9	0.0	-0.1	0.9	**1.8**	0.1	1.0	0.1	0.1	0.5	0.0	0.0	0.1
2002	**3.4**	0.1	1.8	0.1	0.3	0.9	0.1	0.0	0.2	**1.2**	0.0	0.7	0.1	0.3	-0.1	0.1	0.0	0.1
2003	**2.9**	0.1	1.3	0.1	0.9	0.0	0.2	0.1	0.4									
Average 1996-2002	**3.5**	0.0	1.8	0.1	0.4	0.7	0.2	-0.1	0.3	**1.9**	0.0	1.0	0.1	0.2	0.3	0.1	0.0	0.4

Table 4 provides additional details to the above results. The measure of capital services allocates significantly more weight to changes in capital intensity in almost all industries to the detriment of, in particular, real estate activities and some other services, i.e., categories that would also have either a negative or negligible contribution if the net capital stock measure were used. It can be observed that the average contribution of the transport industry is on average almost four times as high and the contribution of industry almost three times as high when user costs instead of value shares are used as weights. The contributions of financial intermediation and trade are more than twice as high and add to the difference between the two measures of capital input.

Table 4: The information in the industry structure

	depreciation rate yearly average % 1995-2002	average weight (%) in value *(net cap.stock)*	average weight (%) in user cost *(cap.services)*	average contribution (p.p.) by value *(net cap.stock)* 1995-2002	average contribution (p.p.) by user cost *(cap.services)* 1996-2003	difference of contribution (p.p.)
Total	4.4	100.0	100.0	1.69	3.42	1.72
Agriculture and forestry	5.7	2.6	3.7	0.01	0.03	0.02
Industry	6.5	19.6	30.0	1.06	1.77	0.70
Construction	7.6	1.7	2.3	0.06	0.12	0.06
Trade, repair, hotels, rest	7.0	6.2	11.2	0.22	0.45	0.23
Transport	5.2	16.6	20.7	0.16	0.61	0.45
Financial intermediation	10.6	1.5	3.2	0.09	0.20	0.11
Real estate, rental, entrepr.activities	2.8	28.2	9.4	-0.19	-0.07	0.12
Other services	3.0	23.5	19.6	0.28	0.30	0.02

It is important to note, however, that growth of net capital stock based on asset breakdown and industry breakdown is not the same. This is a problem of the deflator when constructing the net capital stock in constant replacement cost for asset groups. Obviously, errors in the underlying measure of the net capital stock of assets create differences in the estimated growth rate of capital services. Another source of the difference between the two measures of capital services is the degree of breakdown which was used for construction. Assuming no structural changes and average behavior in each group of assets can introduce a bias, which is in principle similar to that described in Part 2.

According to the presented results, growth of capital services was highest at the beginning of the analysed period, with a peak reaching 4.5% in 1997 and a slight decline afterwards towards the rate of 3%. This development reflects the investment boom of the years 1994-1996 (as a reflection of the first wave of foreign direct investment in the Czech Republic), but the rate of growth of capital services remained high despite the slump of economic activity in 1997 and 1998 and generally weak investment activity in the rest of the 1990s. Hanzlová (2001) analyses investment activity in the Czech Republic in the 1990s and finds that the investment activity of Czech companies in the second half of the 1990s consisted chiefly in infrastructure and restructuring investment, the infrastructure investment being crucial for the cultivation of the entrepreneurial environment but not having an immediate impact on the production capacity of the economy. Investment in machinery and equipment concentrated mostly on the industries of interest to foreign investors, and, in general, the high average age of capital assets (a legacy of the previous economic regime) did not decrease considerably. According to the report, replacement of capital stock was most intensive in the energy sector, telecommunications and production of dual-track vehicles. More pronounced investment in the information and communications technology producing sector emerged only in 2000 thanks to the investment activity of foreign-owned enterprises.[93]

Investment in information and communications technology in general was, on the other hand, probably dynamic already in the second half of the 1990s. According to Piatkowski (2003), ICT spending grew by rates above 5% at the beginning of the 1990s and further accelerated after 1996.[94] The author estimates that between 1995 and 2000, the share of net ICT real capital stock in total net capital stock increased from approximately 2% to 6%, which could account for about 0.7 percentage points on average of the output growth in the period. The Czech Statistical Office data on gross fixed capital formation by commodity show strong investment in radio, telephone and communications equipment (CPA group 32) and computer technology services (CPA group 72); the shares of these groups of commodities in total investment increased during 1995-2000 from below 1% to over 5% and from below 2% to over 3%, respectively. The share of office machinery and computers, on the other hand, remained approximately constant.[95]

4. Accounting for Czech economic growth

Good measurement of capital input into production is important for the analysis of other developments in the economy. For instance, the correct measurement of multi-factor productivity allows for the assessment of the effectiveness of investment. In times of dynamic development of information and communication technology, one should observe strong dynamics in MFP too, reflected in high labor productivity growth. In order to gauge the effect of the measurement of capital for MFP, we conduct a simple growth accounting exercise with a measure of capital based on stock and services measures. The difference in the underlying measure of capital input will be reflected in the ensuing measure of MFP.

Following Barro (1998), we carry out standard primal growth accounting using a neo-classical production function

[93] Development of technical infrastructure and information and communication technology diffusion between 1998-2004 in the Czech Republic is described by the Czech Statistical Office (2005).
[94] Expressed in USD. ICT spending includes investment as well as payments for services.
[95] The shares were calculated based on current prices data. The fast process of obsolescence of ICT assets implies fast decreases in prices which probably means that data in current prices underestimate the dynamism of these assets.

$$Y = F(A, K, L) \tag{12}$$

where aggregate output *Y* is a function of capital input *K*, labor input *L* and multi-factor productivity *A*. Differentiation with respect to time and dividing by *Y* allows us to separate the growth rate of output into the sum of the contribution of factor inputs and technological progress:

$$\frac{\dot{Y}}{Y} = g + \frac{F_K K}{Y}\frac{\dot{K}}{K} + \frac{F_L L}{Y}\frac{\dot{L}}{L} \tag{13}$$

where $F_K = \frac{\partial F}{\partial K}$ and $F_L = \frac{\partial F}{\partial L}$ are the marginal products of capital and labor, respectively, and $g = \frac{F_A A}{Y}\frac{\dot{A}}{A}$ is the growth to be ascribed to technological change. The latter is often also called the Solow residual, i.e. the part of economic growth that cannot be explained by the respective contributions of production inputs, and is interpreted as growth of multi-factor productivity (or the contribution thereof to economic growth).

If the price of capital service (*uk*) is equal to the social marginal product of capital, and wage (*w*) is equal that of labor, then $s_K = \frac{ukK}{Y}$ and $s_L = \frac{wL}{Y}$ are the respective shares of each factor remuneration in total product. In discrete time, the growth of output is then equal to the weighted sum of the growth rates of production inputs and MFP: [96]

$$\Delta \ln Y_t = g_t + s_{K,t}\Delta \ln K_t + s_{L,t}\Delta \ln L_t \tag{14}$$

Under the assumption of perfect competition in product and factor markets and constant returns to scale, the marginal products are reflected by rentals and wages. However, while labor remuneration is available from national accounts, the remuneration of capital (i.e. the price and volume of capital services) is not directly observable. As described before, this is because the services of capital goods are often not sold or rented, as the capital used in production is very often owned by the producer. Most of the transactions of renting capital services are hence not recorded and therefore not explicitly priced.

The share of capital remuneration in total output is thus very hard to obtain. However, national accounts provide a quantity of gross operational surplus that complements remuneration of labor to total output in current prices. Some growth accounting exercises thus adopt the approach of computing the rate of return to capital endogenously by computing it as a share of gross operating surplus in total value added (or as a complement to one of the ratio of total wage cost to value added).

Nevertheless, this approach can be imprecise for at least two reasons. First, the gross operating surplus cannot be fully attributed to fixed capital. It is a measure of business profits from normal operating activity and includes a so-called mixed income, i.e., income of self-employed persons and indirect business taxes. Secondly, in practice, the assumptions about constant returns to scale and competitive product markets need not hold. Relying on these assumptions may result in a bias in expressing the weights.[97]

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[96] The approximation of the Divisia index for discrete time can be done, e.g., by using a Thörnqvist index.

[97] The issue is discussed in Chapter II, Section 2.5 of this dissertation. A detailed analysis of the consequences of different assumptions on the production function and markets for MFP measures can be found in Schreyer (forthcoming).

Therefore, identically as in the benchmark model of Chapter II of this dissertation, the logic of capital services is followed here for expressing the remuneration of capital and the concept of user cost of capital is used. In this sense, a measure of capital remuneration is created based on total cost of capital, which is the product of the user cost of capital assets and the average net stock of these assets.

The weights of labor and capital respectively are then expressed by the following:

$$s_{L,t} = \frac{1}{2}\left(\frac{w_t L_t}{w_t L_t + uk_t K_t} + \frac{w_{t-1} L_{t-1}}{w_{t-1} L_{t-1} + uk_{t-1} K_{t-1}} \right), \quad \text{and}$$

$$s_{K,t} = \frac{1}{2}\left(\frac{uk_t K_t}{w_t L_t + uk_t K_t} + \frac{uk_{t-1} K_{t-1}}{w_{t-1} L_{t-1} + uk_{t-1} K_{t-1}} \right),$$

where $w_t L_t$ is total remuneration of labor computed as the product of average wage and total employment (including self-employment) in year *t* and $uk_t K_t$ is the total remuneration of capital computed as the sum over all industries of the product of user cost and net capital stock in each industry in year *t*.

As pointed out by Jorgenson and Griliches (1967), the quantity indexes of total input and total output have to be constructed from the quantities of each output and each input, respectively, using the relative shares of the value of each output in total output and shares of each input in total input as weights. Therefore, when plugging the aggregate measures of total output and inputs into growth accounting, one has to be careful whether this principle was taken into account when constructing the aggregate measures.

The measure of *Y* used in the following analysis is the gross domestic product expressed in constant prices of 1995.[98] This measure is constructed by the chain-linking method and therefore conforms to the above recommendation, that the weights of growth rates of each individual output should be updated each period. Similarly, the measure of *K*, capital services, as described above, has been constructed to take into account this principle, too.

As regards labor, the standard measure of this input should reflect the variability in total employment as well as developments in average hours worked. In addition, one should consider changes in the structure of employment to take into account changes in the productive capacity of labor. This can be done, for instance, by dividing total employment with respect to gender and education as was done, e.g., by OECD (2003). The total labor input would then be defined as follows:

$$d \ln L_t = \sum_j \frac{1}{2}\left(s_{jt-1} + s_{jt}\right) d \ln h_{jt}\,, \qquad (15)$$

where $s_{jt} = \frac{w_{jt} h_{jt}}{\sum_i w_{it} h_{it}}$, w_{jt} is the average wage for group *j* in year *t* and h_{jt} is the number of hours worked by group *j* in year *t*. The publicly available data do not allow a precise calculation of *d*ln*L* according to (13); however, our tentative computations suggest that for the Czech Republic in the period 1997-2004, the effect of structural changes in labor could be on average up to 0.5 percentage points to add to the growth of total labor input

[98] The concept of OECD (2004 and 2001b) is followed by using GDP for the measurement of MFP at the aggregate level.

measured by total number of hours worked in the economy.[99] The composition effect is thus not accounted for in the measure of labor, which is then computed as the product of total employment and average hours worked[100] for each year. The measure of MFP thus contains the effect of improving the productivity of labor stemming from the shift of its composition towards more productive (and higher paid) workers.

Table 5 depicts the effect of employing capital services measures (as constructed based on the industry and asset breakdown) in the growth accounting exercise for the Czech economy. The results are in line with the finding above that the measure of capital based on capital services supports higher contributions of capital to production than the measure based on net capital stock if the structure of capital changes towards more productive assets. It demonstrates the fact that the measure of capital services uses the correct set of weights that correspond to user cost and thus do not undervalue the contribution of short-lived capital assets. The measure of capital services also contains the effect of structural changes within the existing capital towards more or less productive use, which is also a contribution that should be recognized as related to capital and not to MFP in a growth accounting exercise. In our case, the calculated MFP hence should include minimum growth effects from capital. But, as mentioned above, it can include a considerable contribution from the changes in the quality of labor input.

Table 5: Decomposition of total output growth (growth in %, contributions in percentage points)

	gross domestic product	employment	average hours worked	**based on net capital stock**		**based on capital services (industry breakdown)**		**based on capital services (asset breakdown)**	
				capital	TFP	capital	TFP	capital	TFP
1996	3.9	0.1	0.0	1.2	2.6	1.2	2.6	1.2	2.6
1997	-0.7	-0.4	0.0	0.8	-1.2	1.9	-2.2	2.0	-2.4
1998	-0.8	-0.9	0.2	0.8	-1.0	1.4	-1.6	1.3	-1.4
1999	1.3	-1.3	0.4	0.6	1.6	1.3	0.9	1.3	1.0
2000	3.6	-0.4	0.1	0.7	3.2	1.2	2.7	1.4	2.5
2001	2.4	0.2	-2.8	0.7	4.3	1.0	4.0	1.5	3.6
2002	1.9	0.5	-0.6	0.4	1.6	1.2	0.8	1.3	0.7
2003	3.5	-0.5	-0.3			0.9	3.4	1.1	3.2
average 1996-2002	1.7	-0.3	-0.4	0.8	1.6	1.3	1.0	1.4	0.9

Using the experimental measure of capital services in the growth accounting exercise results in a rather significant reduction to the measured rate of growth of multi-factor productivity by 0.6-0.7 percentage points on average in the period 1996-2002, i.e. by approximately 35-40%. This result, that using the measure of capital services leads to reduction in MFP in a period of dynamic development of shorter-lived capital assets, is roughly in line with other findings in the literature. Schreyer (2003), for instance, who compares the MFP measures based on net capital stock and net capital services for

[99] The size of the effect was computed based on (13) with eight groups of labor (broken down by gender and four education groups). It was assumed that the changes in average hours worked are identical across labor groups and that the wages of the group in the education class ISCED 4 (post-secondary non-tertiary) are identical to the wages earned by workers with GCE (they are reported as higher; however, corresponding data on employment by education are not available).

[100] The measure of average hours worked was taken from OECD (2006).

Australia, France and the United States, also finds a reduction in MFP when the capital services measure is used to account for capital input, though this reduction is less pronounced than found here for the Czech Republic.[101]

5. Conclusion

This paper constructs an experimental measure of capital services, which should in theory better account for productive capital input than a simple measure of net capital stock. It is shown that there is additional information in the standard published data on capital that can be used for this purpose. The experimental measure of capital services is based on the assumption that the officially published data on net stock of capital assets in replacement cost reflect well the productive capacity of the existing capital. In order to calculate the growth of capital services in each year, the growth rate of the productive stock of each group of capital assets is assigned a weight that reflects the user cost of those assets, i.e. rentals. Two versions of a measure of capital services have been computed, one based on the breakdown by type of asset and the other based on breakdown by industry. Both of them indicate that the standard measure of net capital stock, when used as an input into the production function, underestimates the growth of capital input by more than one percentage point, which can result in an overestimation of multi-factor productivity in a growth accounting exercise.

The measure still remains imprecise in several respects. Some limitations come from the method; the most important is that the suggested measure reflects more the potential contribution of existing capital to production than the actual one. Other limitations are caused by the use of the underlying data; in particular, the measure would be much more precise if a vintage effect could be added to the constructed measure. Also the quality of the measure would clearly increase if the contribution of information and communication technology assets could be accounted for separately. For the time being, however, the experimental measure of capital services is a clear improvement over the measure of net capital stock if the contribution of capital to production is to be described.

[101] For the period 1995-2001, the difference ranges from 0.3 to 0.6 percentage points.

6. References

Ahmad, N., F. Lequiller, P. Marianna, D. Pilat, P. Schreyer and A. Wolfl (2003): "Comparing Labour Productivity Growth in the OECD Area: the Role of Measurement", OECD Statistics Directorate Working Paper 2003/5.

Australian Bureau of Statistics (2000): Australian National Accounts: Concepts, Sources and Methods (Chapter 16), www.abs.gov.au.

Barro, R. J. (1998): "Notes on Growth Accounting", NBER Working Paper 6654.

Beffy, P.-O., P. Ollivaud, P. Richardson and F. Sédillot (2006): "New OECD Methods for Supply-side and Medium-term Assessments: A Capital Services Approach", OECD ECO Working Paper No. 482.

Czech Statistical Office (2004): Balance of Non-Financial Assets, 1995-2002, publication 5208-04.

Czech Statistical Office (2005): Czech Information Society in Figures 2005.

Dybczak, K., V. Flek, D. Hájková, and J. Hurník (2006): "Supply-Side Performance and Structure in the Czech Republic (1995–2005)", CNB Working Paper 4/2006.

Eurostat (1997): "The Capital Stock in the European Union - Structural Diagnosis and Analytical Aspects", Eurostat, Luxembourg.

Eurostat (2005): ESA 1995 Home Page, http://forum.europa.eu.int/irc/dsis/nfaccount/info/data/esa95/esa95-new.htm

Griliches, Z., and D.W. Jorgenson (1966): "Sources of Measured Productivity Change: Capital Input", *American Economic Review*, Vol. 56, Issue 1/2 (March 1966), pp. 50-61.

Hájek M. (2005): "Ekonomický růst a souhrnná produktivita faktorů v České Republice, 1992-2004 " (Economic Growth and Total Factor Productivity in the Czech Republic, 1992-2004), Working Paper No. 4, CSE-CSEM, Prague.

Hájková, D. (2006): "The Capital Input into Czech Production: An Experimental Measure of Capital Services", CERGE-EI Discussion Paper 168.

Hanzlová, D. (2001): "Analýza vývoje hrubých hmotných investic v průběhu 90. let" ("Analysis of the development of gross fixed investment in the 1990s"), Czech Statistical Office.

Hurník, J., and D. Navrátil (2005): "Potential Output in the Czech Republic: A Production Function Approach", *Prague Economic Papers* (3), pp. 253-266.

Inklaar, R., M. O'Mahony, C. Robinson and M. Timmer (2003): "Productivity and Competitiveness in the EU and the US", in: M. O'Mahony and B. van Ark eds.: *EU Productivity and Competitiveness: An Industry Perspective*, European Commission.

Jorgenson, D.W., F. M. Gollop and B. M. Fraumeni (1987): *Productivity and U.S. Economic Growth*, Harvard University Press.

Jorgenson, D.W., and Z. Griliches (1967): "The Explanation of Productivity Change", *The Review of Economic Studies*, 34/3, pp.249-283.

Jorgenson, D.W. (1995): *Productivity*, Volumes I and II, MIT Press.

Meinen, G., P. Verbiest and P.-P. de Wolf (1998): "Perpetual Inventory Method: Service Lives, Discard Patterns and Depreciation Methods", Statistics Netherlands.

Lízal, L. (1999): "Depreciation Rates in a Transition Economy: Evidence from Czech Panel Data" *Prague Economic Papers* (3), pp. 261-277.

OECD (2001a): *Measuring Capital – OECD Manual*, Paris.

OECD (2001b): *Measuring Productivity – OECD Manual*, Paris.

OECD (2003): *The Sources of Economic Growth in the OECD Countries*, Paris.

OECD (2004): "OECD Productivity Database: Calculation of Multi-factor Productivity Growth", http://www.oecd.org/dataoecd/31/9/29880777.pdf

OECD (2006): *OECD Factbook 2006: Economic, Environmental and Social Statistics*. Paris??

Oulton, N., and S. Srinivasan (2005): "Productivity Growth and the Role of ICT in the United Kingdom: An Industry View, 1970-2000", CEP Discussion Paper No 681.

Piatkowski, M. (2003): "Does ICT Investment Matter for Growth and Labor Productivity in Transition Economies?", TIGER Working Paper Series, No. 47.

Romer, P. M. (1990): "Endogenous Technological Change", *Journal of Political Economy*, 98, pp. 71-102.

Schreyer, P. (2003): "Capital Stocks, Capital Services and Multi-factor Productivity Measures", OECD Economic Studies No. 37, pp. 163-184.

Schreyer, P. (forthcoming): "Measuring Multi-factor Productivity when Rates of Return are Exogenous", in: W. E. Diewert, B. M. Balk, D. Fixler, K. J. Fox and A. O. Nakamura (eds.), Price and Productivity Measurement, Volumes 1 and 2, Trafford Press.

Schreyer, P., E. Bignon and J. Dupont (2003): "OECD Capital Services Estimates: Methodology and First Results", Statistics Directorate Working Paper 2003/6, OECD, Paris.

Schwerdt, D., and J. Turunen (2006): "Growth in Euro Area Labour Quality", CEPR Discussion Paper No. 5509.

Sixta, J. (2004): "The Influence of the Revision of Consumption of Fixed Capital on GDP", Proceedings from the International Statistical Conference, Prague Sept. 6-7, 2004, http://www.czso.cz/sif/conference2004.nsf/i/the_influence_of_the_revision_of_consumption_of_fixed_capital_on_gdp.

Thörnqvist, L. (1936): "The Bank of Finland's Consumption Price Index" Bank of Finland, Monthly Bulletin No.10, pp. 1-8.

U.S. Bureau of Labor Statistics (1983): "Trends in Multifactor Productivity", 1948-81, BLS Bulletin 2178.

U.S. Bureau of Labor Statistics (2004): "Changes in the Composition of Labor for BLS Multifactor Productivity Measures", http://www.bls.gov/web/mprlabor.pdf.

U.S. Bureau of Labor Statistics (2006): "Overview of Capital Inputs for BLS Multifactor Productivity Measures", http://www.bls.gov/mfp/mprcaptl.pdf.

Vijselaar, F., and R. M. Albers (2002): "New Technologies and Productivity Growth in the Euro Area", ECB Working Paper No. 122.

Appendix 1: Additional details of calculation

Table A.1: The eight groups in which industry breakdown is presented (NACE classification)

	Sectors	Subsectors
Agriculture and forestry	A+B	01-05
Industry	C+D+E	10-41
Construction	F	45
Trade, repair, hotels, restaurants	G+H	50-55
Transport	I	60-64
Financial intermediation	J	65-67
Real estate, rental, entrepreneurial activities	K	70-74
Other services	L+M+N+O+P+Q	75-93
Total	A-Q	01-93

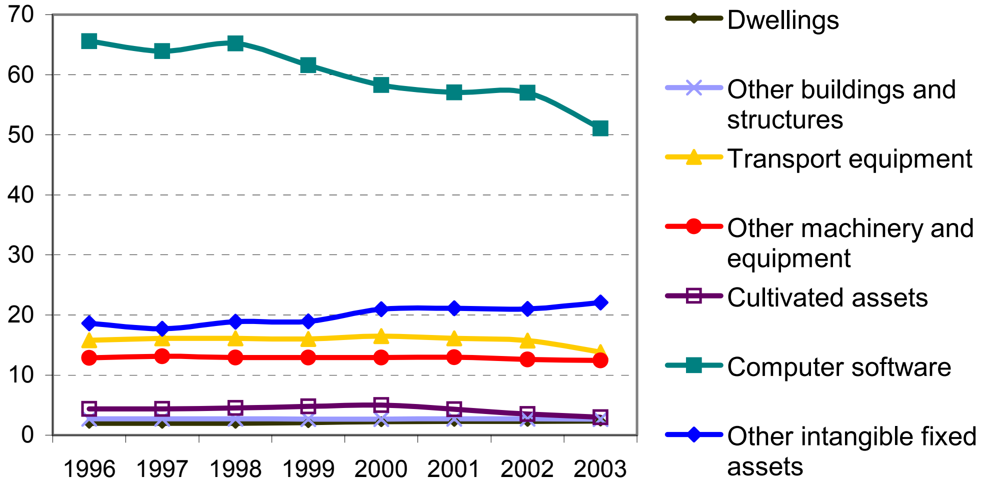
Table A.2: Growth rates of measures of capital input (% year on year)

	Capital stock (net stock const. repl. cost)	**Capital services** based on breakdown by asset type	industry
1996	2.9	3.1	3.6
1997	1.9	4.8	4.5
1998	2.1	3.3	3.6
1999	1.7	3.4	3.6
2000	1.9	3.7	3.1
2001	1.8	4.0	2.7
2002	1.2	3.7	3.4
2003		3.7	2.9

Table A.3: Information on industry structure - detail

		depreciation rate yearly average % 1995-2002	average share (%) in net capital stock (1995 replac.cost) 1995-2002	average share (%) in cost of capital 1996-2003	average contribution (p.p.) by value *(cap.stock)* 1995-2002	average contribution (p.p.) by user cost *(cap.services)* 1996-2003	% difference of contribution
TOTAL		4.4	100.0	100.0	1.69	3.42	102
01	Agriculture	6.0	2.1	3.1	0.03	0.05	63
02	Forestry	4.2	0.4	0.5	-0.02	-0.02	3
05	Fishing	4.3	0.0	0.0	0.00	0.00	-2
10	Mining of coal	5.7	1.1	1.6	0.02	0.03	55
11	Extraction of petroleum, natur. gas	4.4	0.0	0.0	0.00	0.01	53
12	Mining of uranium	4.0	0.1	0.1	0.00	0.00	4
13	Mining of metal ores	4.6	0.0	0.0	0.00	0.00	-714
14	Other mining and quarrying	9.0	0.1	0.3	0.01	0.01	99
15	Manuf. of food prod. and beverages	7.0	1.6	2.5	0.05	0.09	61
16	Manufacture of tobacco products	8.1	0.1	0.2	0.00	0.02	276
17	Manufacture of textiles	7.6	0.5	0.8	0.02	0.03	70
18	Manuf. of wearing apparel; fur	7.4	0.1	0.2	0.00	0.00	77
19	Manuf. of luggage and footwear	6.9	0.1	0.1	0.00	0.00	38
20	Manuf. of wood except furniture	7.4	0.4	0.6	0.02	0.03	67
21	Manuf. of pulp, paper and paper prod.	7.1	0.4	0.7	0.02	0.04	78
22	Publishing, printing	8.4	0.4	0.7	0.02	0.04	82
23	Manuf. of coke, refined petroleum prod.	6.5	0.3	0.5	0.02	0.03	50
24	Manuf. of chemicals and chem. prod.	6.9	1.0	1.6	0.05	0.08	61
25	Manuf. of rubber and plastic prod.	7.9	0.5	0.9	0.05	0.09	83
26	Manuf. of other non-metalic mineral prod.	6.6	1.3	2.0	0.06	0.10	61
27	Manufacture of basic metals	6.7	1.0	1.6	0.04	0.07	70
28	Manuf. of fabricated metal products	7.0	0.9	1.4	0.06	0.10	67
29	Manuf. of machinery and equip. n.e.c.	6.7	1.0	1.5	0.05	0.08	63
30	Manuf. of office machinery and comp.	10.1	0.0	0.0	0.01	0.02	239
31	Manuf. of electr. mach.and appar. n.e.c.	8.6	0.5	0.8	0.05	0.09	93
32	Manufacture of radio, television	8.3	0.2	0.3	0.02	0.04	95
33	Manuf. of medical and optical instr.	7.2	0.2	0.2	0.01	0.02	67
34	Manuf. of motor vehicles, trailers	7.4	1.3	2.2	0.15	0.27	84
35	Manuf. of other transport equipment	6.8	0.2	0.4	0.00	0.00	76
36	Manuf. of furniture; manuf. n.e.c.	7.0	0.3	0.5	0.02	0.03	58
37	Recycling	7.9	0.1	0.1	0.00	0.00	85
40	Electr.,gas,steam and hot water supply	5.5	4.4	5.9	0.30	0.43	45
41	Collection and distribution of water	3.3	1.5	1.3	0.01	0.01	-6
45	Construction	7.5	1.7	2.4	0.06	0.12	96
50	Sale,maint. and repair of motor veh.	7.3	0.8	1.5	0.04	0.07	81
51	Wholesale trade	8.4	2.2	4.5	0.10	0.19	102
52	Retail trade, repair serv.	8.1	1.7	3.3	0.09	0.19	114
55	Hotels,restaurants	3.8	1.5	1.3	-0.01	-0.01	-24
60	Land transport	5.9	3.6	5.1	0.18	0.26	51
61	Water transport	9.3	0.0	0.1	0.00	0.00	40
62	Air transport	8.3	0.1	0.2	0.01	0.04	154
63	Travel agency services	4.6	10.6	10.9	-0.37	-0.35	-5
64	Post and telecommunication	7.9	2.3	3.7	0.35	0.67	92
65	Financial intermediation	11.2	1.3	2.6	0.08	0.19	133
66	Insurance and pension funding	8.0	0.2	0.3	0.01	0.01	48
67	Activities auxiliary to fin.interm.	8.7	0.1	0.1	0.00	0.00	82
70	Real estate activities	2.3	25.3	7.9	-0.19	-0.10	-50
71	Renting of machinery and equipment	9.9	0.2	0.4	0.02	0.04	128
72	Computer and related activities	12.8	0.2	0.4	0.01	0.02	124
73	Research and development	3.5	0.4	0.4	-0.01	0.00	-9
74	Other business activities	7.2	2.0	2.6	-0.02	-0.02	26
75	Public administration and defence	2.6	10.2	6.7	0.22	0.19	-14
80	Education	2.4	6.6	5.6	0.04	0.04	-6
85	Health and social work	4.1	2.3	2.7	0.06	0.08	41
90	Sewage and refuse disposal	3.5	2.3	2.1	-0.05	-0.03	-35
91	Activities of membership organisation	3.5	0.3	0.3	0.01	0.01	-10
92	Recreation,cult. and sporting activities	5.8	1.7	2.0	0.00	0.01	-3914
93	Other service activities	5.4	0.1	0.2	-0.01	0.00	-63

Graph A.1: Development in depreciation rates by asset type



Note: Depreciation rates are computed as the ratio of consumption of fixed capital and the average net stock of fixed capital in the respective year, both in current prices.

Table A.4: Capital services based on constant and time-variable rate of depreciation (breakdown by asset type)

	Capital services (constant depreciation) Yearly contributions by cost								Capital services (variable depreciation) Yearly contributions by value							
	Total	Dwellings	Other buildings and structures	Transport equipment	Other machinery and equipment	Cultivated assets	Computer software	Other intangible fixed assets	**Total**	Dwellings	Other buildings and structures	Transport equipment	Other machinery and equipment	Cultivated assets	Computer software	Other intangible fixed assets
1996	**3.1**	0.0	1.3	0.0	2.5	0.1	-0.5	-0.2	**2.8**	0.0	1.3	-0.1	2.4	0.1	-0.8	-0.2
1997	**4.8**	0.0	1.1	0.5	3.5	0.1	-0.2	-0.2	**4.7**	0.0	1.0	0.5	3.4	0.1	-0.3	-0.1
1998	**3.3**	0.0	0.9	0.3	2.7	0.0	-0.5	-0.2	**3.2**	0.0	0.9	0.3	2.7	0.0	-0.6	-0.2
1999	**3.4**	0.0	0.7	0.5	2.5	0.0	-0.1	-0.2	**3.5**	0.1	0.7	0.5	2.4	0.0	-0.1	-0.2
2000	**3.7**	0.0	0.4	0.7	2.1	0.0	0.6	-0.2	**3.8**	0.0	0.4	0.7	2.1	0.0	0.8	-0.2
2001	**4.0**	0.0	0.3	1.2	2.2	0.0	0.4	-0.1	**4.1**	0.0	0.3	1.2	2.2	0.0	0.5	-0.1
2002	**3.7**	0.0	0.4	1.3	1.8	0.0	0.1	0.0	**3.7**	0.0	0.4	1.3	1.9	0.0	0.2	-0.1
2003	**3.7**	0.1	0.3	1.5	1.7	0.0	0.1	-0.1	**3.8**	0.1	0.3	1.5	1.8	0.0	0.2	-0.1
2004	**3.8**	0.1	0.4	1.6	1.3	0.0	0.4	0.0	**3.8**	0.1	0.4	1.6	1.4	0.0	0.4	-0.1
Average 1996-2004	**3.7**	0.0	0.6	0.8	2.3	0.0	0.0	-0.1	**3.7**	0.0	0.7	0.8	2.3	0.0	0.0	-0.1