PAPER

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Productivity growth at the sectoral level: measurement and projections

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Abstract

Global simulation models are increasingly used to assess future scenarios and the impact of policies related to food security, land use and climate change. A crucial element in these studies are assumptions on productivity change and technical progress, the key drivers of long-run economic growth and structural change. However, despite their importance, these assumptions are often simplistic or rather ad hoc. This paper addresses this issue by presenting sector and country specific projections for labour productivity till the year 2050 for seven economic regions in the world.

Introduction

Policy makers frequently rely on global outlooks and scenario studies to gain insights on future developments related to major global and highly complex issues such as food security, climate change, biodiversity and land use change. Prime examples or the OECD Environmental Outlook, the OECD-FAO agricultural Outlook and the IPCC Special Report on Emissions Scenarios (SRES). In many of these reports multi-country multi-sector simulation models are used to quantify future global economic development as well as the impact of certain policies on economic growth using a variety of scenarios. A key input for these models are assumptions on future productivity growth and its principal component, technical change, which are the main drivers of long-run economic development and structural transformation.

Assumptions on how productivity change will differ across sectors and countries will have substantial impact on the outcomes of the models. For example, and increase in agricultural labour productivity relative to that of other sectors will have an impact on the economy through a number of channels. Through intermediate and final demand linkages it will not only increase the demand for agricultural products but also for other industrial outputs and services. At the same time, it improves international competitiveness resulting in a reduction of food imports and increased exports. Finally, the use of more labour saving technologies might lead to a shift in employment from agriculture to manufacturing.[1] In order to provide realistic projections of economic development it is therefore essential that global simulation models implement sectoral productivity forecasts that are historically valid and empirically founded.

In a recent paper Van Meijl (Forthcoming) compared the sensitivity of five global computable general equilibrium models to assumptions on technological change. In most of the models, the assumptions on future productivity change are rather ad hoc or simplistic due to lack of information. For example, it is frequently stated that technological change is identical across sectors and countries, something which is not in line with the empirical literature on innovation and growth. Using detailed case studies, scholars in the field of innovation sciences have demonstrated the existence of 'technological trajectories' (Dosi, 1982; Pavitt, 1984; Breschi et al., 2000) that may differ considerably between sectors, depending on the underlying knowledge base, opportunities for innovation and demand factors. Another strand of literature found strong heterogeneity in total factor productivity change across sectors in both time and space (Bernard and Jones, 1996a; O'Mahony and Timmer, 2009). Also several models that are reviewed in the study by Van Meijl (Forthcoming) use advanced productivity forecasts for the agricultural sector while relative naïve assumptions were used for manufacturing and services. In many economies, also including developing countries, these sectors make up the largest part of GDP. Through general equilibrium effects and backward and forward linkages, technical progress in manufacturing and services will have considerable impact on agricultural growth structural change and trade. Hence, the forecasting of technical change should not be easily neglected and deserves considerable attention.

The aim of this paper is to address these issues and present forecasts for labour productivity change at the sectoral level that can be used in multi-country and multi-sector models to improve long-run economic projections and scenarios studies. The forecasts cover 9 individual economic sectors that together span the total economy till the year 2050. Results are presented for eight important economic regions, including advanced, emerging and developing economies. To prepare the projections, we

[1] There exists a considerable amount of research that analysis the impact agricultural productivity growth on industrialisation and economic development. See for example Gollin, Parente and Rogerson (2002, 2007) and Alvarez-Cuadrado and Poschke (2011).

closely follow the approach of Nin *et al.* (2005) and Ludena *et al.* (2007), who decompose historical data on inputs and outputs into a movement of the technical frontier (technical change) and movements towards the frontier (catch up) for the crop and livestock sectors. The distinction between these two elements of productivity growth allows us to account for the limitations to catch up when countries approach the frontier. Something which cannot be addressed in simple extrapolations of productivity trends. The historical analysis is based on a new database with value added and labour data compiled by Timmer and De Vries (2009) and McMillan and Rodrik (2011). Results of this study can be used as input for global and national CGE models and integrated assessment models to analyse future growth and development.

The paper is divided into three parts. First, a brief review of the literature on economic growth, technical change and catch up, in particular focussing on patterns of sectoral productivity change development across time and space. The second part elaborates on the historical analysis of productivity growth. It describes the database we used, the decomposition methodology and the results. The third part focuses on the labour productivity projections. The approach to prepare the forecasts is summarized and the final projections are presented. Finally, we end with conclusions.

Catching up and convergence at the sector level

Economic growth and development is a highly dynamic phenomenon, which often has been characterised as a process of 'catching up, forging ahead and falling behind' (Abramovitz, 1986; also see Fagerberg and Verspagen, 2002). The 'catch up' hypothesis commonly refers to the idea that in the long run countries with a relatively low level of productivity will exhibit faster (productivity) growth than countries that operate at higher levels of labour productivity, all else equal. The rationale behind this hypothesis is that technologically backward countries (i.e. low-income countries) carry the potential for rapid advance because they have the opportunity benefit from the diffusion of a backlog of technologies that already have been developed by technologically leading countries (i.e. high-income countries). The further away a country is located from the technology frontier, the greater the potential for catch-up and the faster the expected growth in productivity growth, leading to convergence. Catch up is, however, inherently self-limiting and the rate of productivity growth is expected to decline as following countries approach the frontier and managed to imitate and assimilate the majority of existing technologies. Productivity growth of leading countries is determined by the rate of innovation – the development and implementation of technologies that are new to the world. Innovation results in an outward shift of the technology frontier and productivity divergence. Eventually, the global pattern of productivity change is determined by the opposing forces of innovation and diffusion.

The empirical investigation of the 'catch up' hypothesis as well as the related presumption that productivity levels of countries will converge has received considerable attention. Due to the lack of data most studies have investigated aggregate labour or total labour productivity patterns (for an overview see Baumol et al., 1994). Nonetheless, there are also exist a limited number of papers that adopt a sectoral approach which are relevant for the subject of this study. The seminal work is by Bernard and Jones (1996a, 1996b), who estimate total factor productivity for fourteen OECD countries and six sectors for the period 1970 to 1987. They find that a strong tendency towards convergence in in labour productivity and total factor productivity for most of the sectors, in particular services, but no evidence for convergence in the manufacturing sector. Inklaar and Timmer (2009) extent the analysis by using an expanded dataset up to 2005, more sectoral detail and industry level PPPs (also see

Sørensen and Schjerning, 2008; Van Biesebroeck, 2009). They confirm the findings of Bernard and Jones and find convergence in services but not in manufacturing. Heterogeneity is even larger when a more disaggregated sectoral classification is used. Castellacci *et al.* (2010) apply quantile regression techniques to analyse convergence in labour productivity for different sub-samples and sub-periods using data for a larger group of countries also including Latin America and Asian economies. They find that sector-level convergence is limited to 'growth' miracle economies in the sample while other countries exhibit a pattern of divergent productivity patterns. Recently, Rodrik (2011) used the UNIDO INDSTAT2 database to analyse labour productivity convergence for ISIC 2-digit level manufacturing sectors in a sample of over 100 countries. In contrast to the other studies, he finds that productivity in manufacturing is converging across countries and is not conditional to country specific characteristics. He explains his finding by arguing that technology transfer and upgrading is more likely in manufacturing than in agriculture and services sectors.

In sum, the literature finds mixed evidence of convergence at the sector level with considerable heterogeneity in convergence across sectors. The literature also shows that the results are very sensitive to sample coverage, data construction and estimation strategy. This study utilizes the concepts of technical change and catch up as a basis for making sectoral productivity projections.

Productivity growth: 1961-2005

Data

The analysis of global technical change and catching up at the disaggregated level has been hampered by lack of detailed sector data that is available over a long time span and for a wide range of countries. Typically, the available databases cover a high number of sectors at the 3 to 5 level digit in advanced economies (e.g. Inklaar and Timmer, 2009) or describe only a few broad sectors, such as agriculture and manufacturing, for a larger sample that also includes developing economies (e.g. Martin and Mitra, 2001). For this paper, we use the sector database that was originally developed by Timmer and De Vries (2009) and recently has been expanded by McMillan and Rodrik (2011). The database presents internationally comparable information on value added and persons employed for nine main sectors in the economy (See annex). The data were drawn from a number of national sources, including: national accounts, population surveys, business surveys and labour force surveys. Value added figures expressed in local currency at 2000 prices are converted to dollars using 2000 PPP exchange rates in order to make international comparisons. The database covers 38 economies of which twenty-nine are developing countries and nine are high-income countries. For most countries complete data is available for the period 1960-2005 but for Sub-Saharan countries, China and Turkey data is limited to the period 1990-2005.[2]

The advantage of the sector database over other datasets that have been used in previous literature is the global coverage, including advanced economies and a number of developing countries from Africa, Latin America and Asia as well as a complete economic coverage (i.e. all sectors together comprise total GDP), which is essential to make the link with CGE models. A major disadvantage of the database is that it does not present data on other inputs than labour. We are therefore only able to present an analysis of partial productivity change (see discussion below).

[2] For some countries data is available before 1960 but this is not always complete. For several countries that were added to the 10-sector database by McMillan and Rodrik (2011), information is available after 2005. For consistency reasons we limit the analysis to the period 1960-2005. The data are publicly available through: http://www.hks.harvard.edu/fs/drodrik/Research%20papers/Employment_VA_data_f4.dta [Accessed 11-04-2013].

Decomposition of productivity growth

In order to make projections on future productivity growth we start by analysing past patterns of technical change and catch up. We use the methodology of Nin et al. (2005; also see Färe et al., 1994), which decomposes productivity growth in the two components of our interest: (1) a shift of the technical frontier (i.e. innovation) and (2) a countries' movement towards the frontier (i.e. catching up/diffusion). Note that due to data limitations – the lack of capital stock and other input data at the sector level – we can only use a partial measure of productivity, namely labour productivity. Preferably we would have used an index of total factor productivity to inform future trends in technical change and catch up. Total factor productivity accounts for changes in all inputs simultaneously and is therefore able to separate the accumulation and substitution of inputs from technical change which is not possible with a partial measure such as labour productivity. Differences between labour productivity and total factor productivity tend to be the largest in capital intensive industries such as mining, construction and public utilities and smallest in services (Bernard and Jones, 1996a). This limitation has to be born in mind when using the results of our analysis. These limitations notwithstanding, we are of the opinion that offers an improvement to the present modelling of future sectoral technical change which does not take into account catching up and convergence.

Figure 1 illustrates the decomposition of labour productivity into its two components. With a single input l (labour) and a single output v (value added), technology is represented by the production frontier Ft in period t and by frontier Ft+1 in period t+1.The frontier reflects the maximum feasible output at each level of input for a given period t. The location of the frontier is determined by the countries with the highest labour productivity in a certain year, in this example country A in period t and country B in period t+1. These countries can be regarded as 'best practice' and are regarded as technically efficient. Figure x also shows the production points of country C that produces ot output (value added) with lt labour in period t and ot+1 output with lt+1 labour in period t+1. Labour productivity for this country in year t and t+1 is defined as LPt=ot/lt and LPt+1=ot+1/lt+1, respectively. However, taking into account the production frontier output could have been increased to ot* in period t and o*t+1 in period t+1 with productivity of Ft=ot*/lt and Ft+1=ot+1*/lt+1 for each periods, respectively. Country C therefore is not technically efficient in both periods but has the potential to improve performance. Growth in labour productivity country C is defined as LPGt,t+1=LPt+1/LPt, which is greater than one between t and t+1if productivity is increasing over time and less than one if productivity is decreasing. Labour productivity growth can be decomposed in a catching up and technical change component by multiplying the right hand side of the labour productivity growth equation by (Ft+1/Ft)(Ft/Ft+1)=1 with F being frontier productivity as defined above. This can be rearranged to:[3]

$$LPG_{t,t+1} = \left[\frac{LP_{t+1}/F_{t+1}}{LP_t/F_t}\right]\left[\frac{F_{t+1}}{F_t}\right] \qquad (1)$$

The first term on the right hand side of equation 1 is the efficiency component (EFF), which measures catching up (or falling behind). It indicates the rate at which the target country is approaching or moving away from the frontier. This is the case because LPt+1/Ft+1 and LPt/Ft measure the distance

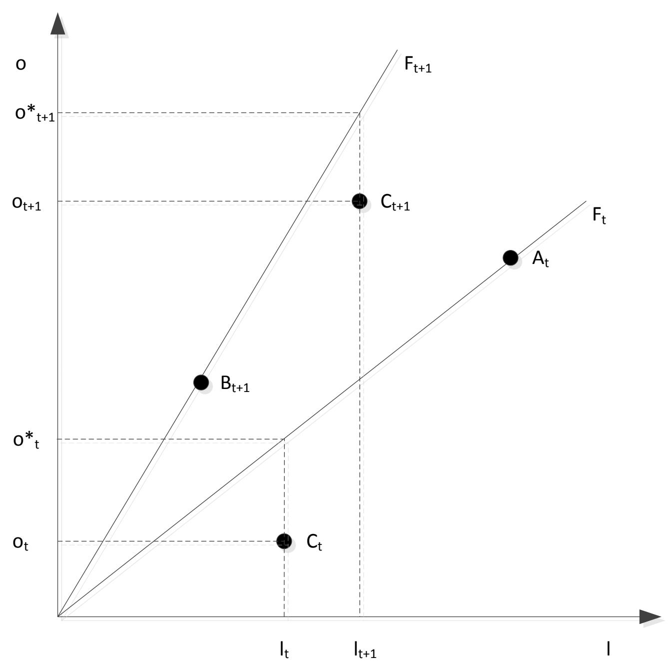
[3] The decomposition is the identical to the Malmquist total factor productivity index, proposed by Fare et al. (1994), which can be used when information on multiple inputs and outputs is available. See Ludena et al. (2007) for an example. In this case, the technical change component is simplified because we consider a technology with only one input and one output, and constant returns to scale. All computations are done using R applying the Data Envelopment Analysis package FEAR (Wilson, 2008) in R.

to the frontier (i.e. technical efficiency) in period t and t+1, respectively. If countries are catching up to the frontier and technical efficiency improves, LPG will be larger than one. The second term in equation 1 is an index of technical change (TCH) and measures a shift of the technical frontier over time. Technical progress will result in an index exceeding one.

Following Nin *et al.* (2005), we assume constant returns to scale in production. This implies that the catch up component captures both 'pure' and 'scale' efficiency gains. As we are predominantly interested in obtaining a broad measure of technical change to make projections and there is no information available to make assumptions on changes in scale efficiency in the future, we do not consider variable returns to scale in our analysis.[4] The assumption of constant returns to scale also implies that the shift of the frontier (technical change) between period t and t+1is independent of inputs and therefore equal for all countries for any given sector.

Finally, we use a 'cumulative' or 'sequential' production frontier to estimate technical change (see Tulkens and Vanden Eeckaut, 1995 for a discussion). More specifically, this approach assumes that 'what was possible in the past remains always possible in the future'. By including all data up to and year t for the construction of the frontier in year t, we eliminate the possibility of technical regress (the frontier moving backwards). The occurrence of technical regress or 'forgetting' is not realistic from the perspective of the theory of catch up in which latecomer countries are able to benefit from the diffusion of all available technologies that are in use by technological leaders. The same approach is used by Nin et al. (2003), Ludena *et al.* (2007) and Los and Timmer (2005), in studies on technological change.

Figure 1: productivity growth and decomposition

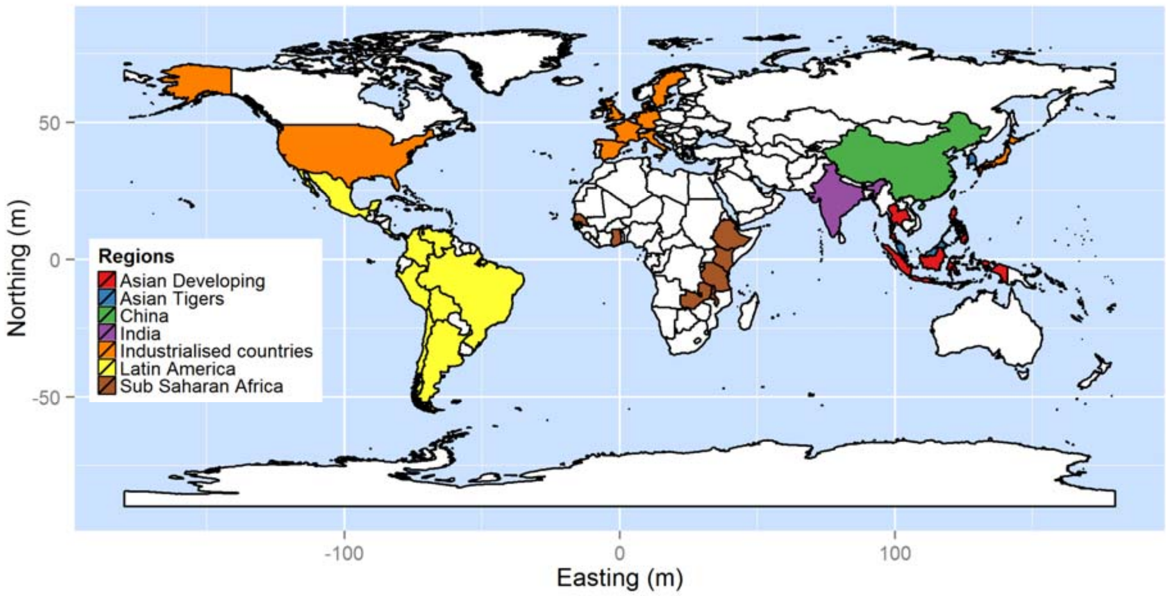


[4] See Fare et al. (1994) for a decomposition of efficiency growth into 'pure' and 'scale' efficiency.

Historical analysis

The results of our decomposition analysis are summarised in Table 1. We report figures for labour productivity (LPG) growth and its two components: efficiency change (EFF) and technical change (TCH), for two periods: 1961-1985 and 1986-2005 to order to examine changes over time. We focus on seven major regions of the world (Figure 2). The country groupings are constructed conform our expectations on productivity growth and catch up. Industrialised countries composed of the USA, Japan and European countries are technological leaders, while countries, such as Brazil, China, India, and the Asian Tiger countries are expected to benefit from technology diffusion resulting in rapid productivity growth. On the other hand, for developing countries in Sub Saharan Africa, Asia and perhaps Latin America technology diffusion and assimilation is probably problematic, possibly leading to falling behind.

Figure 2: Regional aggregation



Note: Data on Nigeria, South Africa and Turkey are not used in the analysis (see text).

Following Ludena *et al.* (2007) we include the aggregate regions as separate observations in our decomposition analysis by aggregating input and output of individual countries within regions. This means that productivity growth and its components are directly estimated for selected country groupings together with estimates of individual countries that identify the technological frontier.[5] The advantage of this approach is that extremes in the data are reduced or eliminated.

The analysis is conducted for seven sectors, namely: agriculture; manufacturing; construction; wholesale and retail trade; transport, storage and communications; finance and insurance; and personal and government services. We also conducted the analysis for two other sectors for which data is available (mining and public utilities) but decided not to report the results because we regard them as

[5] Note that aggregate regional labour productivity (LP) can be decomposed into:

$$LP = \frac{VA}{L} = \sum_{i=1}^{n} \frac{va_i \times l_i}{l_i \times L} = \sum_{i=1}^{n} \frac{va_i}{l_i} \times s_i = \sum_{i=1}^{n} lp_i \times s_i$$

where va_i is value added, l_i is labour and s_i represents the share of country i in total aggregate regional labour, which means that employment is implicitly used as weighting factor to compute productivity at the aggregate regional level.

problematic. In the case of the mining sector, labour productivity trends are highly erratic and seem to be distorted by the extreme performance of a few countries that are characterised by a very large oil and petrol sector (e.g. Nigeria and Venezuela). Taking into account resource dependencies and related capital intensity, it is unlikely that other countries will ever be able to reach the same level of productivity. Similarly, for the public utilities sector we find labour productivity growth that is much higher than in any of the other sectors for almost all developing and emerging economies in the sample. We suspect that this is partly caused by a process of modernisation and expansion in the electricity, gas and water supply sectors in these countries that also involved considerable capital accumulation. The growth of capital stock cannot be distinguished from technical change in a partial measure of productivity and creates a bias, in particular in capital intensive sectors such as public utilities.

It is well known that output and employment data are sensitive to short run fluctuations and cyclical movements. As our focus is on long-term trends we apply the commonly used Hodrick-Prescott (1997) filter to smooth the data before estimating LPG, TCH and EFF.[6]

The results of the historical decomposition analysis are summarised in Table 1. It shows the average annual change in LPG and EFF for the eight focus regions and seven sectors in our analysis. It also presents the global rate of TCH. As discussed above, shift of the (sectoral) frontier is a global phenomenon and therefore technical change is the same for all countries in the sample. Labour productivity growth is defined as the combination of global level technical change and country specific technical efficiency change (e.g. catching or falling behind). For reference, we also include the decomposition results for the total economy (total). The total economy is defined as all sectors for which we data is available and therefore also includes the mining and public utilities sectors. The analysis is conducted by using total economy value added and labour, implicitly using labour shares as weights. In this way, the results can directly be compared with productivity and technical change analysis that use aggregate economy data from other sources. LPG, EFF and TCH is presented for two historical periods: 1961-1990 and 1991-2005 to provide insights into historical dynamics. The cut-off point is determined by data availability as we lack long time series for SSA and China.

It is interesting to start with a comparison of the TCH figures between sectors, which give an impression of global technological dynamics. The agriculture and manufacturing sectors are the by far the most dynamic of all sectors, showing average annual rates of technological change of between 2.5 and 4.5 percent in both sub-periods. With around 3.5 percent, technological progress has been high but stable over the last 45 years in agriculture while it increased with almost two percent point from 2.7 to 4.2 percent in manufacturing. Technological advancement is also relatively high in the transport, storage and communications with around 2.5 percent per year whereas it has been very low in the remaining sectors: construction; wholesale and retail trade; finance and insurance; and personal and government services. Striking is the finding that there has not been any technical progress for construction and finance and insurance for the period 1990-2005, indicating that labour productivity levels for this past 15 years have not surpassed the level in earlier years.

These findings are in line with other studies that investigated technical change at the sectoral level. For instance, various studies found very high rates of labour and total factor productivity growth for agriculture, which is frequently higher than in the manufacturing sector (Jorgenson and Gollop, 1992; Martin and Mitra, 2001). Recently, Jorgenson and Timmer (2011), using a new database with detailed information on sectoral output and productivity for high number of sectors in OECD countries, found that that performance in the services sector is very heterogeneous. Finance and insurance, and personal

[6] In accordance with Ravn and Uhlig (2002) we set λ equal to 6.25 for annual data.

and government services exhibit low or no productivity improvements while trade and transportation services have been very dynamic, with rapid productivity growth.

Next, we turn to the discussion of the LPG, EFF and TCH components by region, starting with the industrialised countries. Productivity growth has been highest for agriculture, manufacturing, and wholesale and retail trade in both historical periods. LPG is predominantly driven by TCH, while EFF is low. This is conform expectations all industrialised countries are producing on the frontier (in most cases the USA) or very close to the frontier and therefore opportunities to catch up are limited. For some several sectors in the most recent period EFF is negative, which suggests that several industrialised countries are longer able to keep up with the technological frontier and are falling behind.

For China only data is available for the period 1990-2005. As would be expected from a rapidly modernising economy like China, labour productivity change is very high (on average almost 9 percent for the total economy). The decomposition shows that growth is driven by technology diffusion (on average 7.06 percent for the total economy), illustrated by the very high EFF scores. Only in the agricultural sector, catching up has been limited with EFF being just over 1 percent.

In comparison to China, the performance of India has been much more moderate . Between 1961 and 1990, LPG for the country was only around 1.2 percent, with above average productivity growth in agriculture, manufacturing, and wholesale and retail trade. After 1990, LPG accelerated in almost all sectors with the major exception of the finance sector which shows a decrease in LPG and EFF.

The Asian Tiger countries have experienced a period of profound structural change and economic development over the last decades (World Bank, 1993; Lall, 1996) which is also reflected by the productivity estimates. LPG has been consistently high in almost all sectors with the exclusion of the financial services sector and construction) for both sub-periods. An interesting finding is that LPG has been mainly caused by technology diffusion and assimilation in the period 1961-1990 while in the most recent period, TCH has been the main driver, indication that opportunities for catching up become exhausted.

The Asian Tigers are followed by a second group of countries we have termed Asian developing economies, including Indonesia, the Philippines and Thailand. The results are very mixed, both across sectors and over time, in particular for the period 1961-1990. We find a strikingly high LPG and EFF figures (8.12 and 7.19 percent, respectively) for the financial sector which is mainly caused by Indonesia. This might be an artefact of the data. In the most recent period, overall performance of the Asian developing economies is deteriorating. Five out of the seven sectors are falling away from the frontier, while the other sectors only marginally catch up.

There is evidence that Brazil has gone through a rapid phase of economic development becoming increasingly important as producer of global biofuels, food and feedstock, which warrants an in depth investigation. For this reason we present separate figures for Brazil and the other Latin American countries. Overall, LPG is very disappointing in both periods. In contrast to expectations, Brazil does not experience catching up and exhibits negative EFF for most countries. Between 1990 and 2005 only agriculture and construction show signs of catch up.

LPG and EFF results for Latin America are very similar to those found for Brazil. The evidence indicates that Latin American countries are not benefitting from technology diffusion resulting in negative EFF rates in all sectors over the last six decades. For some sectors, performance is decreasing some much, even resulting in negative LPG rates, suggesting that labour productivity is decreasing over time.

Finally, we present decomposition results for Sub Saharan Africa. We decided not to include Nigeria and South Africa in the group although we have data for these countries. Including Nigeria, generates a strong bias in the analysis because value added and employment are, respectively, around 75 percent and 60 percent (average for 1990-2005) of the total of all the Sub Saharan countries in the sample. We are of the opinion that, taking into account its oil-dominated economy and sheer size, Nigeria is not representative for Sub Saharan Africa and therefore it would be better to exclude it from the analysis. For similar reasons we exclude South Africa, which is ranked as an upper-middle income country by the World Bank in 2012, from the Sub Saharan aggregate. The negative figures for EFF indicate Sub Saharan Africa is falling away from the technological frontier in all sectors. Apart from agriculture, and transport, storage and communications sectors, this has resulted in deteriorating labour productivity for the period 1990-2005.

Table 1: Productivity growth and components

	1961-1990			1991-2005			2006-2050		
	LPG	EFF	TCH	LPG	EFF	TCH	LPG	EFF	TCH
Industrialised countries									
agr	4.78	1.30	3.45	3.37	-0.07	3.47	3.43	-0.02	3.46
con	0.80	0.62	0.18	-0.75	-0.75	0.00	-1.05	-1.17	0.12
cspsgs	0.49	0.02	0.48	0.04	-0.39	0.44	-0.63	-1.09	0.47
fire	0.37	-0.57	0.95	1.14	1.14	0.00	1.32	0.68	0.63
man	3.76	1.07	2.66	3.68	-0.80	4.52	1.74	-1.49	3.28
tsc	3.39	1.66	1.71	2.96	-0.24	3.22	2.37	0.15	2.22
wrt	2.31	2.07	0.23	2.17	0.39	1.85	1.41	0.63	0.77
sum	2.36	1.17	1.17	1.59	-0.15	1.74	1.17	-0.19	1.36
China									
agr	-	-	-	4.61	1.14	3.47	4.11	0.63	3.46
con	-	-	-	5.70	5.70	0.00	3.96	3.84	0.12
cspsgs	-	-	-	7.49	7.02	0.44	4.58	4.10	0.47
fire	-	-	-	6.16	6.16	0.00	1.72	1.08	0.63
man	-	-	-	12.20	7.39	4.52	7.00	3.60	3.28
tsc	-	-	-	7.01	3.69	3.22	5.40	3.12	2.22
wrt	-	-	-	4.04	2.20	1.85	3.11	2.32	0.77
sum	-	-	-	8.91	7.06	1.74	5.46	4.04	1.36
India									
agr	0.47	-2.86	3.45	1.44	-1.93	3.47	1.48	-1.91	3.46
con	1.60	1.41	0.18	1.14	1.14	0.00	-0.18	-0.30	0.12
cspsgs	3.08	2.59	0.48	6.43	5.97	0.44	3.42	2.94	0.47
fire	4.11	3.20	0.95	-3.10	-3.10	0.00	-4.86	-5.45	0.63
man	3.13	0.46	2.66	3.96	-0.56	4.52	1.59	-1.64	3.28
tsc	2.29	0.58	1.71	6.39	3.05	3.22	4.22	1.96	2.22
wrt	1.27	1.03	0.23	4.48	2.61	1.85	2.96	2.18	0.77

sum	1.94	0.76	1.17	4.26	2.47	1.74	3.17	1.79	1.36
Asian Tigers									
agr	4.83	1.31	3.45	4.29	0.82	3.47	4.23	0.75	3.46
con	4.79	4.76	0.18	0.44	0.44	0.00	0.38	0.26	0.12
cspsgs	1.52	1.05	0.48	1.03	0.60	0.44	0.89	0.43	0.47
fire	1.26	0.54	0.95	-0.27	-0.27	0.00	0.28	-0.35	0.63
man	6.34	3.65	2.66	6.35	1.76	4.52	4.55	1.23	3.28
tsc	6.50	4.56	1.71	5.24	1.98	3.22	3.05	0.81	2.22
wrt	5.80	5.54	0.23	3.02	1.21	1.85	2.29	1.51	0.77
sum	5.48	4.46	1.17	3.75	1.98	1.74	2.38	1.00	1.36
	1961-1990			1991-2005			2006-2050		
	LPG	EFF	TCH	LPG	EFF	TCH	LPG	EFF	TCH
Asian developing countries									
agr	3.47	0.05	3.45	2.60	-0.79	3.47	2.59	-0.83	3.46
con	-0.68	-0.86	0.18	-1.64	-1.64	0.00	-1.49	-1.60	0.12
cspsgs	-0.11	-0.59	0.48	1.78	1.34	0.44	0.95	0.48	0.47
fire	8.21	7.19	0.95	0.44	0.44	0.00	-1.14	-1.76	0.63
man	3.30	0.64	2.66	2.78	-1.66	4.52	1.82	-1.42	3.28
tsc	-0.21	-1.88	1.71	1.15	-2.02	3.22	0.86	-1.32	2.22
wrt	1.96	1.73	0.23	-0.07	-1.85	1.85	-1.81	-2.56	0.77
sum	4.13	2.93	1.17	2.44	0.69	1.74	1.53	0.16	1.36
Brazil									
agr	2.86	-0.55	3.45	4.17	0.69	3.47	4.87	1.37	3.46
con	0.85	0.68	0.18	0.25	0.25	0.00	0.29	0.17	0.12
cspsgs	-0.04	-0.50	0.48	0.19	-0.24	0.44	0.27	-0.19	0.47
fire	0.90	-0.04	0.95	-1.98	-1.98	0.00	-1.52	-2.14	0.63
man	1.26	-1.34	2.66	1.48	-2.89	4.52	-0.98	-4.13	3.28
tsc	4.10	2.35	1.71	-0.88	-3.96	3.22	-2.17	-4.29	2.22
wrt	-0.82	-1.06	0.23	-1.22	-2.94	1.85	-2.04	-2.79	0.77
sum	2.56	1.38	1.17	0.33	-1.39	1.74	-0.14	-1.48	1.36
Latin America									
agr	1.73	-1.63	3.45	2.31	-1.09	3.47	2.39	-1.03	3.46
con	-0.75	-0.93	0.18	-0.15	-0.15	0.00	-0.64	-0.76	0.12
cspsgs	-0.32	-0.79	0.48	0.29	-0.14	0.44	0.05	-0.41	0.47
fire	0.95	0.00	0.95	-1.59	-1.59	0.00	-1.55	-2.17	0.63
man	1.08	-1.53	2.66	2.27	-2.14	4.52	0.46	-2.73	3.28
tsc	1.32	-0.38	1.71	1.94	-1.23	3.22	1.17	-1.02	2.22
wrt	-1.62	-1.85	0.23	-0.77	-2.53	1.85	-2.34	-3.08	0.77
sum	0.65	-0.51	1.17	1.03	-0.70	1.74	0.42	-0.93	1.36

Sub Saharan Africa									
agr	-	-	-	1.79	-1.61	3.47	2.14	-1.27	3.46
con	-	-	-	-1.81	-1.81	0.00	-2.69	-2.81	0.12
cspsgs	-	-	-	-2.81	-3.23	0.44	-4.00	-4.45	0.47
fire	-	-	-	-0.29	-0.29	0.00	-0.57	-1.19	0.63
man	-	-	-	-4.26	-8.40	4.52	-6.30	-9.28	3.28
tsc	-	-	-	2.32	-0.85	3.22	2.04	-0.18	2.22
wrt	-	-	-	-3.41	-5.16	1.85	-4.89	-5.62	0.77
sum	-	-	-	0.70	-1.02	1.74	0.37	-0.98	1.36

Productivity projections: 2005-2050

Modelling of technical change and catch up

The historical analysis of labour productivity growth in the seven target regions forms the starting point for the construction of future productivity growth. Our analysis demonstrates that productivity growth consists of two components: technical change and diffusion (catching up), which behave differently over time. Without sector specific knowledge on future R&D expenditures or bio-physical and technical limitations of production, it is difficult to make assumptions on future technical change other than the continuation of the historical trend.[7] On the other hand, as has been pointed out above, the process of catching up to the frontier is inherently limited. Eventually countries like China that show rapid catch up, will reach the frontier and future growth will be constrained by the outward movement of the frontier.

In order to project the catch up component of productivity growth, we assume that it can be modelled as a diffusion process of new technologies. Studies have shown that the cumulative adoption path of new products and processes follows and S-shaped curve (Griliches, 1957; Geroski, 2000). In our case this implies that technical efficiency of latecomer countries improves slowly in the beginning because it takes time to adopt technologies from leading countries. In the subsequent phase, the technology gap is closed rapidly as more technologies are absorbed, followed by a phase of slower efficiency growth when countries approach the frontier and opportunities to transfer existing technologies become exhausted.

We follow Nin *et al.* (2005) and Ludena *et al*. (2007) and model catching up for each of the regions in the sample using a logistical functional form:

$$Z_{it} = \frac{K_t}{1 + e^{-\alpha - \beta t}} \tag{2}$$

where Zit denotes the efficiency level of region i in year t. Kt is the maximum efficiency level that a region can reach in the long run, which is equal to 1 (100 percent technically efficient) and constant over time. β is a measure of the speed of catching up. A higher value of β denotes a steeper S-shaped function and therefore faster catching up. α is a constant that positions the curve on the time scale. The parameters of the logistical function are estimated using linear regression using the following transformation of the observed technical efficiency scores:

[7] See Evenson and Rosegrant (1995) for projections using expert knowledge and Van Ittersum *et al.* (2013) for an approach to assess the biophysical limits to agricultural productivity.

$$Y_{it} = log\left(\frac{Z_{it}}{K_t - Z_{it}}\right) = \alpha + \beta t \quad (3)$$

Positive and significant values of β for a region will be taken as evidence that the region is catching up to the frontier. Negative and significant values denote falling behind the technical frontier.

To account for the existence of different periods of catching up and productivity growth in the past, which might cause differences in the slope and intercept of the S-shaped curve, we test for structural change in technical efficiency trend. In previous studies (Ludena et al., 2007; Nin et al., 2005) Chow tests are used to find structural breaks in the historical data. However, this test can only be used if the timing of the change is known at forehand. In our case, this information is not available nor would it be feasible to conduct in-depth research to collect such information given the large number of countries and sectors for which we aim to prepare projections. There exists a number of approaches that have been specifically developed to identify multiple structural changes in time series without having prior information (see (Hansen, 2001) for an overview). Here we apply the method proposed by Bai and Perron (1998, 2003), which use a dynamic programming algorithm to compute the global minimizers of the residual sum of squares, which correspond with breakpoints in the data.[8] To algorithm requires the specification of the minimum number of years between structural break points (and the beginning and end points of the data). We set this to 15 years which we regard as sufficiently long to constructs future projections. This implies that for countries for which data coverage is 15 years or less (mainly Sub Saharan African countries and China) no structural changes are assumed.[9]

Apart from the catch up part, we also need to make projections for the technical change component of productivity change. As no information is available we simply assume that the technical progress for each of the sectors continues as in the past (Table 1). Finally, we calculate future labour productivity growth by multiplying the projections for technical efficiency change with technical change in line with equation 1.

Productivity projection results

The last three columns of Table 1 summarise the productivity projections for the period 2006-2050 by focus region. As has been mentioned above, technical change is assumed to grow at the same rate as in the past. TCH is therefore the average of the values in the periods 1961-1990 and 1991-2005, and for each of the sectors is the same for all countries in the sample.

We start by looking at the labour productivity forecasts for industrialised countries. For all sectors the growth rate is lower or similar than in the previous periods. Like in the previous period, several sectors in some of the industrialised countries continue to fall behind, illustrated by the negative EFF values. Comparing the periods: 1961-1990, 1991-2005 and 2006-2050, we observe a long term trend of decreasing labour productivity throughout the economy (2.36 percent, 1.59 percent and 1.17 percent, respectively for the three periods for the total economy) that converges to the rate technological change. This is in accordance with our view that opportunities to catch up diminish once economies, such as the group of industrialised countries, approach the technological frontier.

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[8] The package 'strucchange' in R was used to conduct the structural change analysis .

[9] We also experimented using F-tests. The advantage of this approach is that it does not require any information on the length of the structural change period. The disadvantage is that it is only able to identify one single break in the series. In most cases the breakyears that are identified overlap but differences remain. As our timeseries span more than four decades and multiple breaks are easily possible, we prefer the Bai and Perron (1998, 2003), approach.

The pattern of productivity change that is observed for China resembles that of the Asian Tigers countries in the past. Labour productivity keeps on growing in all sectors with rates between 1.71 percent (financial services) and 7 percent (manufacturing). However, in comparison with the period before 1990, productivity growth is lower in all sectors mainly because of lower EFF. Catching up is clearly slowing down as the technology gap becomes smaller over time. A closer look at the technical efficiency scores reveals that opportunities for technology transfer are not exhausted yet. Only in personal services, financial services and manufacturing technical efficiency is more than 75 percent, while other sectors operate around 50 percent of the frontier. An interesting exception is agriculture, for benefits relatively much less from technological catch up. This contradicts the findings of Ludena *et al.* (2007) who find relative high levels of EFF. A potential explanation for this difference might be the different measures for productivity used (i.e. labour productivity versus total factor productivity) and deserves further research. With the present rate of productivity growth, China will need on average, depending on the sector, between X and X years to catch up to the frontier.

India's productivity performance in the future remains mixed. Several sectors, including personal services, transport and trade show strong performance and positive EFF while productivity of other sectors is low or even negative, notable in the financial services sector. On average, LPG (3.17 percent) and EFF are positive for the total economy.

As has been described above, the Asian Tiger economies went through a phase of rapid modernisation in the period 1961-1990, similar to the phase China is in now, but catching up has been slowing down since. We forecast this to continue in the future as the technology gap becomes smaller. EFF is predicted to become lower for all sectors (except trade services) but remains positive (except for financial services) as there are still opportunities for catch up towards 2050. In fact, technical efficiency is between 40 and 60 percent for most sectors in 2005, surpassing the 70 percent in four sectors in 2050.

Productivity growth of the Asian development countries contrasts sharply with that of the Asian Tigers. Performance is expected to remain poor in the future for almost all sectors. Apart from personal services, the technology gap with the frontier is growing over time as indicated by the negative EFF values.

Finally, also in Latin America (including Brazil) and Sub Saharan Africa, the projections indicate continuous falling away from the frontier instead of catch up in nearly all sectors. Moreover, in many sectors, labour productivity continues to decrease over time. The only major exception is the agricultural sector in Brazil, for which EFF (1.37 percent) and LPG (4.87 percent) are projected to grow in the future. The overall poor performance of Brazil contradicts with the most recent growth experience which is overwhelmingly positive.

Another useful way of summarising our results is by using graphs that depict both historical productivity patterns and future projections (Figure 3-10). The figures display the cumulative labour productivity for the seven sectors and the total economy for the period between 1961 (1991 in case of China and Sub Saharan Africa) and 2050. In contrast with a standard annual index, the cumulative index represents the growth of labour productivity from at each point of time relative to the value in the base year. This type of index can directly be used in dynamic CGE models to model technological 'shocks' over a certain time period, which is the common approach in such models.

The figures confirm the large heterogeneity across sectors over time in each region that also has been found in convergence literature discussed above. Even within the same country or group of countries that share similar characteristics, some sectors are much more dynamic than others. As can be seen in most of the figures, this will result in strongly diverging labour productivity rates between sectors in the long run. This demonstrates that measuring and projecting productivity at the aggregate country level is misleading and might result in biased estimates.

Three sectors stand out in terms of labour productivity growth: agriculture, manufacturing and transport services. In the Industrialised countries, Asian Tigers and Latin America labour productivity growth is rapidly accelerating in these three sectors, resulting in highest cumulative productivity index in the year 2050. In the other regions, at least two of the three sectors exhibit the best performance. For a large part, these results are determined by the high rate of technological change that characterises these sectors and which also has been found in other productivity studies.

Figure 3: Cumulative productivity growth – Industrialised countries (1961-2050)

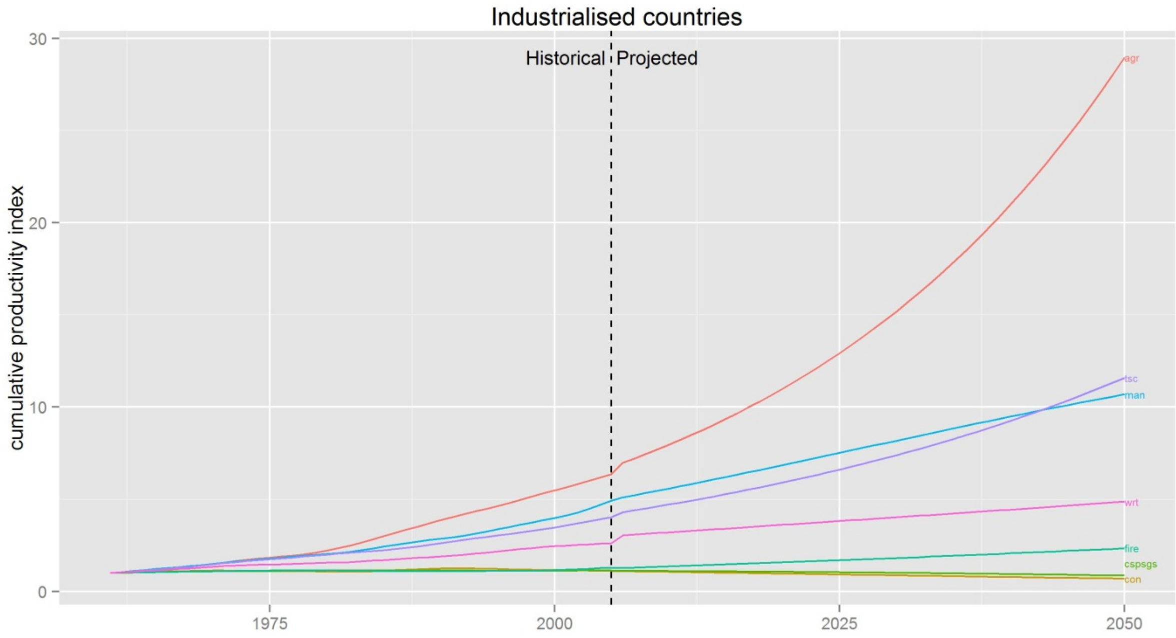


Figure 4: Cumulative productivity growth – China (1991-2050)

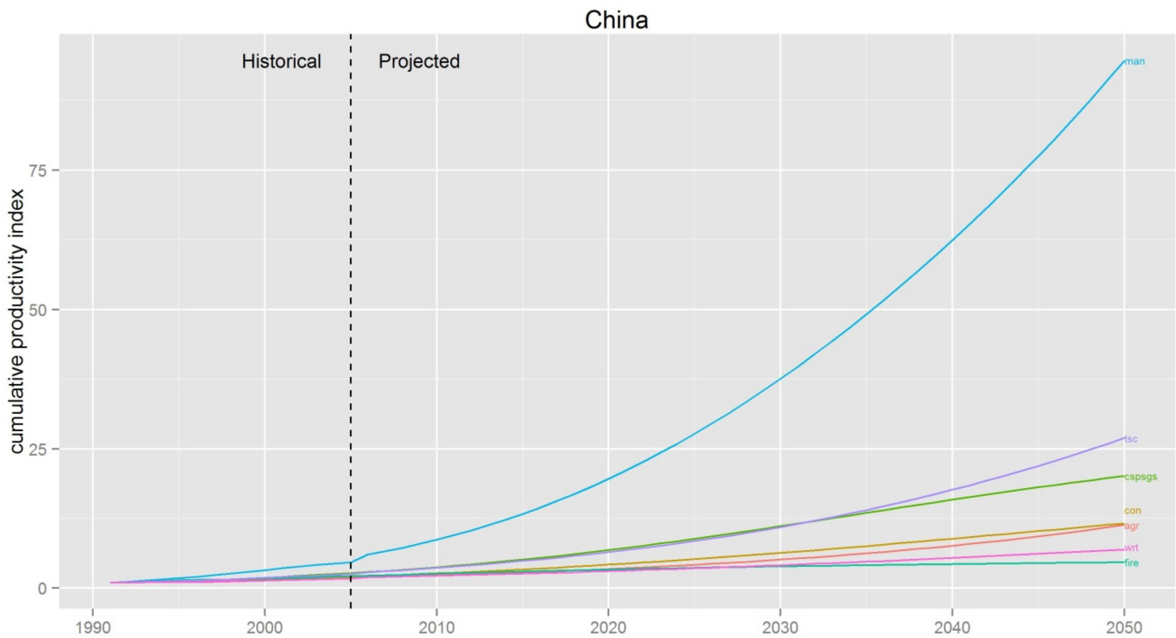


Figure 5: Cumulative productivity growth – India (1961-2050)

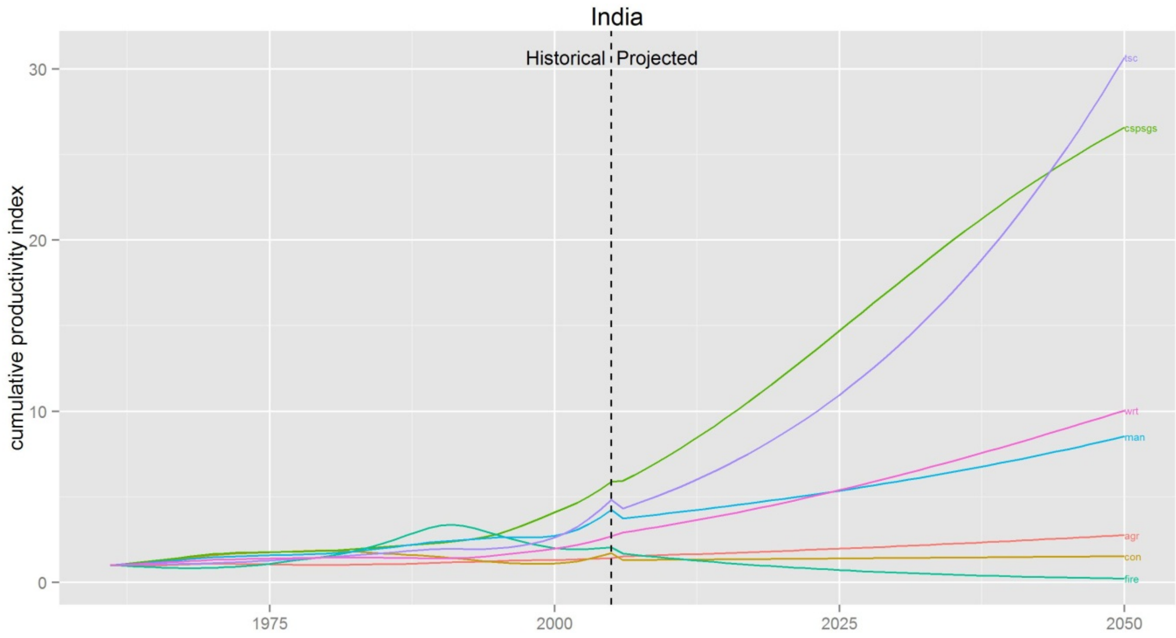


Figure 6: Cumulative productivity growth – Asian Tigers (1961-2050)

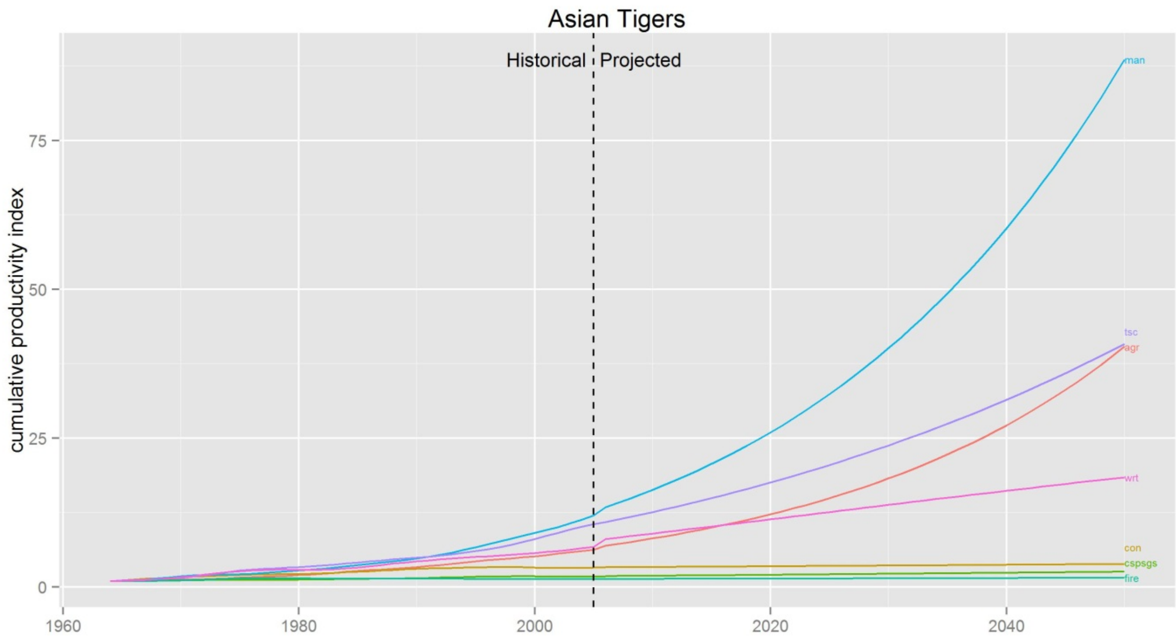


Figure 7: Cumulative productivity growth – Asian developing economies (1961-2050)

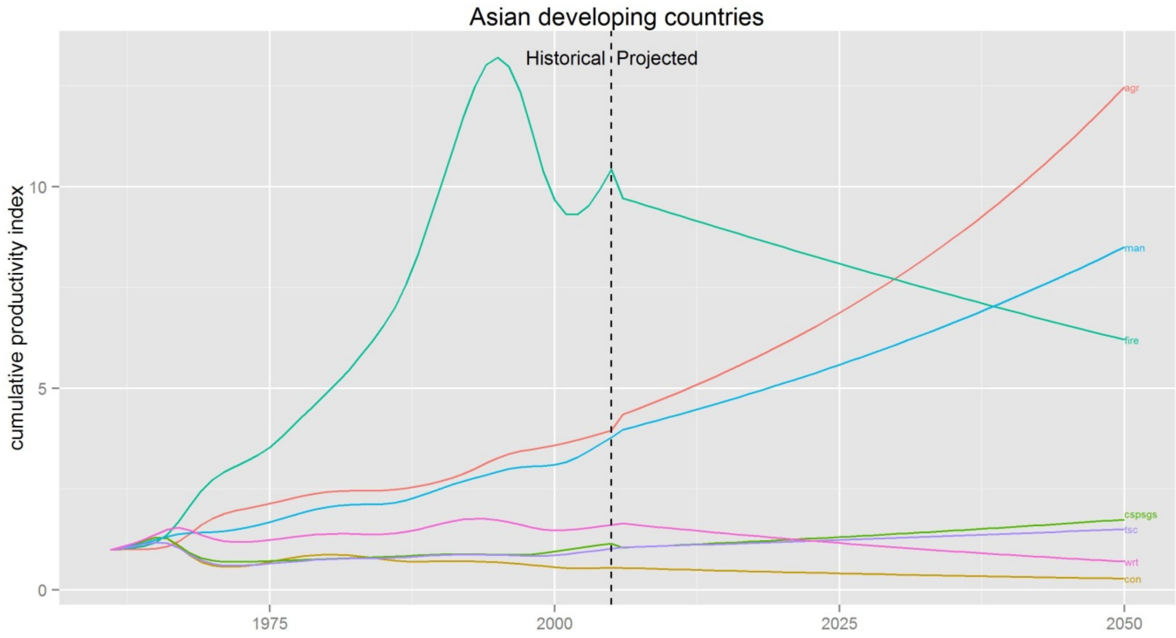


Figure 8: Cumulative productivity growth – Brazil (1961-2050)

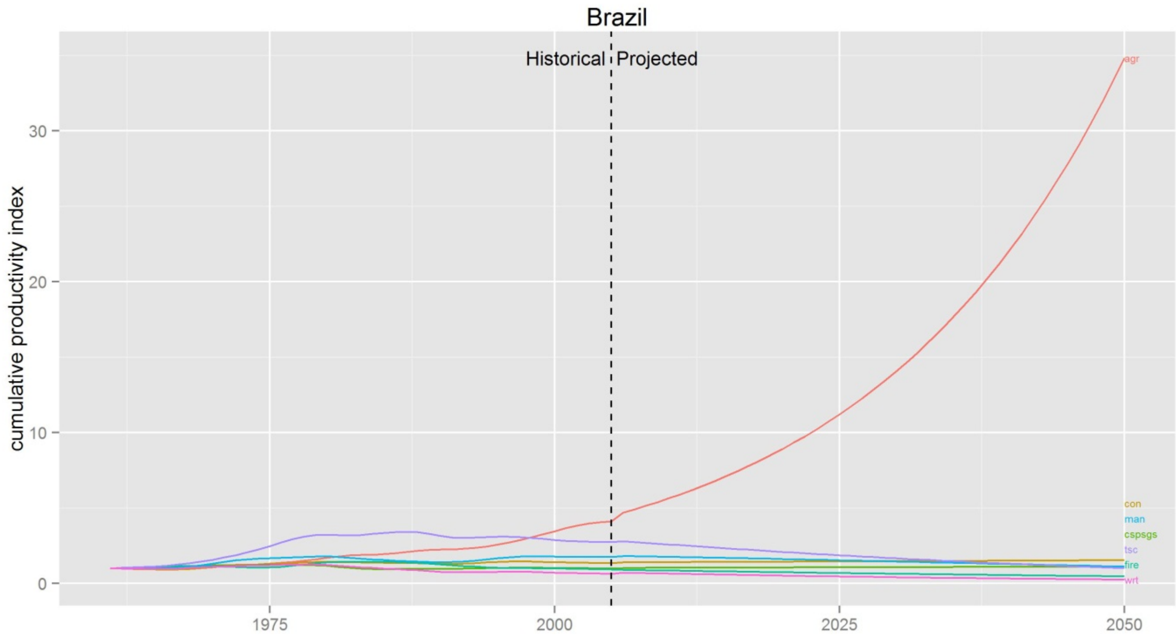


Figure 9: Cumulative productivity growth – Latin America (1961-2050)

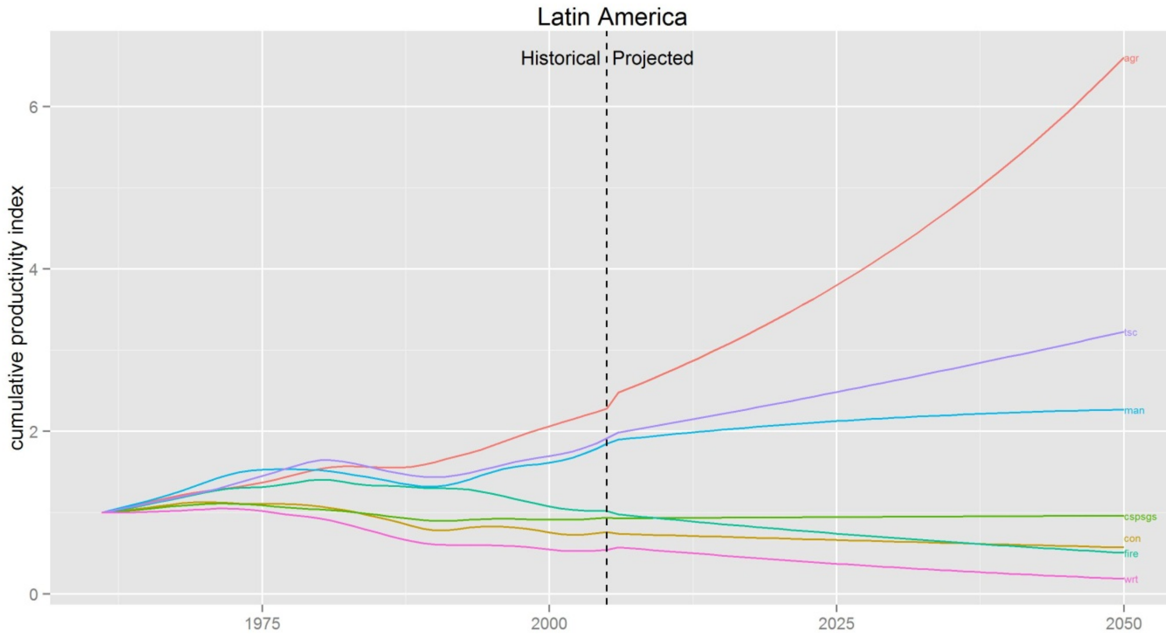
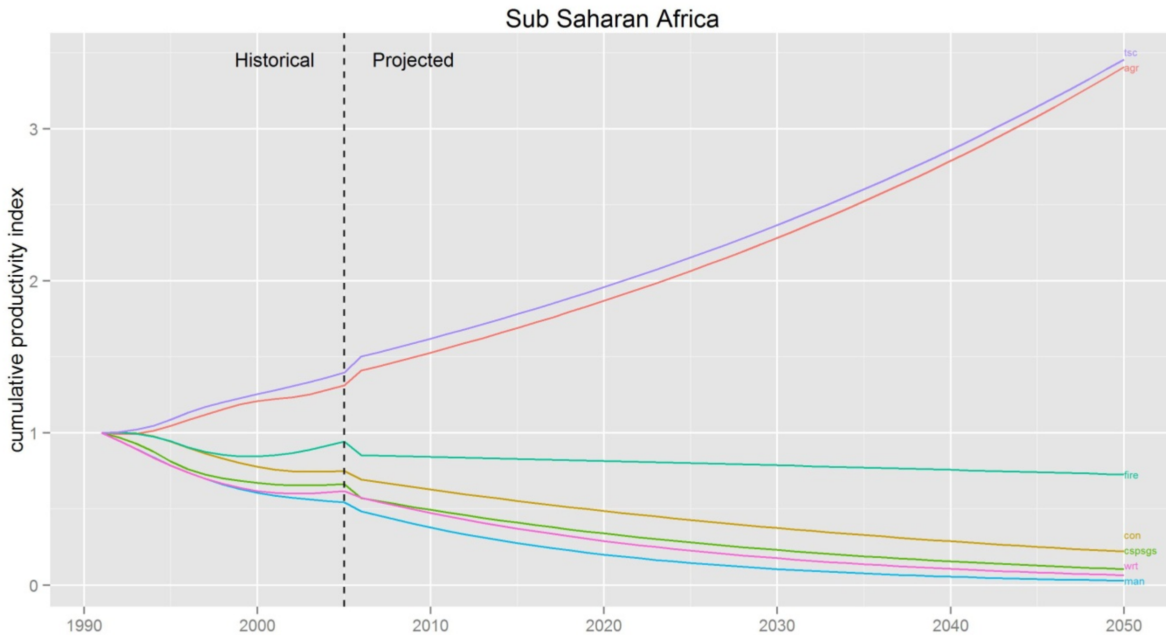


Figure 10: Cumulative productivity growth – Sub Saharan Africa (1991-2050)



Conclusions

Future assessments of food security, changes in land use and international trade depend heavily on assumptions of productivity growth and technical change. However, in most CGE models that are used to make such assessments, the empirical foundations of productivity growth and technical change are weak, often involving ad hoc assumptions or partial improvements.

In this paper we present productivity forecasts for nine individual sectors, together representing the total economy, for eight key regions in the world up to 2050. The forecasts are based on an analysis of historical labour productivity patterns and separately account for a shift of the technological frontier and catching up towards the frontier. In line with other research, we find that agriculture, manufacturing and trade sectors exhibit the highest rate of technological change. The analysis also shows that some regions operate at or near the frontier (Industrialised countries), while others are in the process of catching up (the Asian Tigers and China), show mixed performance across sectors (India, Asian Developing countries and Brazil) or are falling behind (Latin America and Sub Saharan Africa). These insights are combined to prepare the final productivity projections for each sector and country.

Differences in productivity across sectors shape the future structure of individual economies. A well-known stylized fact is the shift of output and labour from agriculture towards manufacturing when agricultural productivity increases (Kuznets, 1971). Differences in sectoral labour producticity across countries will determine international competitiveness. Together these effects shape the global patterns of international trade, income distribution, food security and land use. However, to assess the processes in detail a global simulation model is required. Future research will incorporate our productivity results in a multi-country multi-sector CGE model to analyse the impact of technical change and productivity growth on global change.

Although we feel our approach is a substantial improvement to the present state of the art of technical change modelling, which often adopts a rather ad hoc approach, it is important to highlight several limitations. Like previous work to analyse sectoral technical change in a multiple country setting, this study is hampered by data issues. First, although our database covers major regions in the global economy, including several BRICS countries, no projections could be made for Eastern Europe, Central Asia (including Russia), North Africa and the Middle East (except Turkey), which make up a considerable part of the global economy. Moreover, the Eastern European countries and Russia have undergone substantial transformation in the past twenty years and are therefore difficult to compare with other regions. hence, a separate analysis of productivity growth and catch up would have been desirable for this group of countries.

Secondly, with 15 years the time covered for China and Sub Saharan Africa is relatively short. It is doubtful if this period capture the full dynamics of catch up or falling behind. Thirdly , a major issue is the lack of input data, most importantly sector level capital stock. As a consequence we are only able to analyse and project labour productivity. This is clearly a biased measure as it tends to confound factor accumulation and technical change, which might be severe in capital intensive sectors. Having data on capital stock will allow for the distinction between capital accumulation and total factor productivity, the preferred measure of technological change.

Finally, another data problem is related with the conversion of output data in national currencies into comparable units. Sørensen (2001) and Sørensen and Schjerning (2008) argue that aggregate GDP PPPs, which are also applied in this study, are not appropriate as conversion factors for measuring productivity at the sectoral level. They show that relative measures of productivity depend critically on the choice of PPP base year. The bias is particularly strong in the manufacturing sector but is not found for services. This implies that our results for manufacturing should be interpreted with caution.

At the moment several initiatives are ongoing to address this data issues, which might make it possible to enhance the analysis in the future.[10]

[10] Recently, a new project has been initiated to improve and expand the McMillan and Rodrik database, the key source of information in this paper. In particularly, an effort will be made to improve the coverage of historical value added and employment data for Sub Saharan Africa. The project is funded under the DFID-ESRC Growth Programme. For more information see: http://www.esrc.ac.uk/my-esrc/grants/ES.J009601.1/read [accessed 10-04-2013]. In addition, as part of the World KLEMS project, information on output and inputs (including capital stock), and possibly PPPs, at the detailed sectoral level will be gathered for a number of important developing and transition economies. More information can be found on the following website: http://www.worldklems.net/ [accessed 10-04-2013]

Annex 1: List of sectors

Agriculture (also includes hunting, forestry and fishing)	agr	A+B
Manufacturing	man	D
Construction	con	F
Wholesale and retail trade (also includes hotels and restaurants)	wrt	G+H
Transport, storage and communications	tsc	I
Finance and insurance (also includes real estate and business services)	fire	J+K
Personal and government services (also includes community and social services)	cspsgs	O+P+Q+L+M+N
Total economy	sum	-

Note: Total economy also includes data on mining (C) and public utilities (E). These sectors are not analysed separately.

Annex 2: Country classification

1.	*Industrialised countries:* Denmark, France, Italy, Japan, Netherlands, Spain, Sweden, United Kingdom, USA.
2.	*Brazil*
3.	*Latin America:* Argentina, Bolivia, Chile, Colombia, Costa Rica, Mexico, Peru, Venezuela
4.	*India*
5.	*China*
6.	*Asian Tigers:* Hong Kong, South Korea, Malaysia, Singapore, Taiwan
7.	*Asia Developing:* Indonesia, Philippines, Thailand
8.	*Sub Saharan Africa:* Ethiopia, Ghana, Kenya, Malawi, Mauritius, Senegal, Zambia

Annex 2: Logistic function parameters and breakyears by sector and country

[To be added]

Note: parameters are estimated for the period from the break year to 2005.

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