



Ca' Foscari
University
of Venice

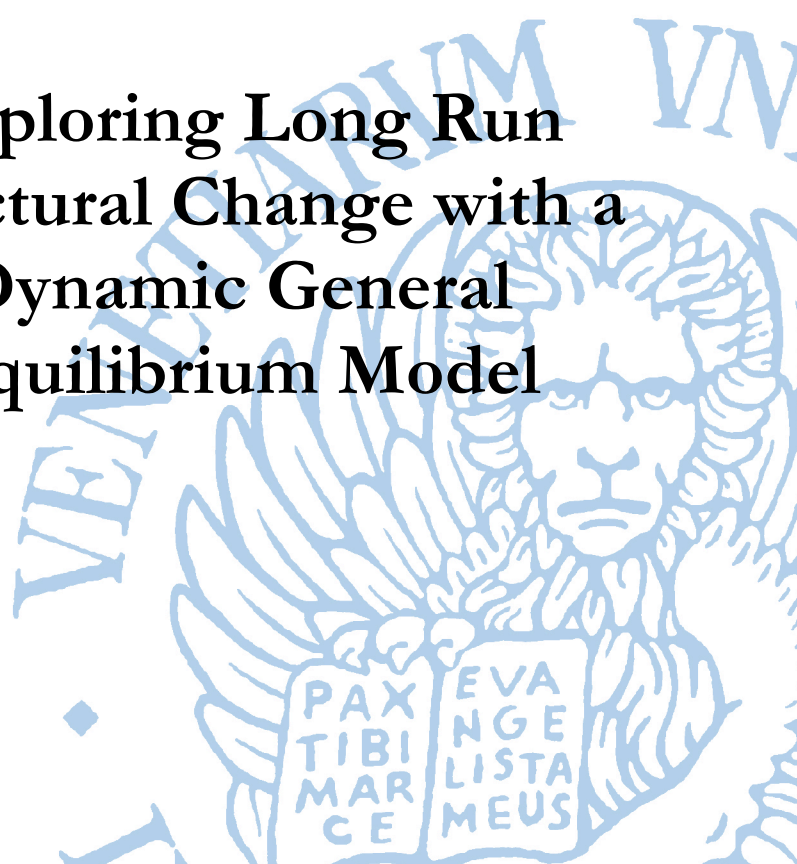
**Department
of Economics**

Working Paper

**Wolfgang Britz
and
Roberto Roson**

**Exploring Long Run
Structural Change with a
Dynamic General
Equilibrium Model**

ISSN: 1827-3580
No. 12/WP/2018





Exploring Long Run Structural Change with a Dynamic General Equilibrium Model

Wolfgang Britz

Institute for Food and Resource Economics, University of Bonn

Roberto Roson

Ca' Foscari University of Venice; IEFE Bocconi University, Milan

Abstract

In this paper we present a computable general equilibrium model (G-RDEM), specifically designed for the generation of long run scenarios of economic development, featuring a non-homothetic demand system, endogenous saving rates, differentiated industrial productivity growth, interest payments on foreign debt and time-varying input-output coefficients. To the best of our knowledge, this is the first model of this kind. We illustrate how parameters of the five modules of structural change have been estimated, and we test the model by comparing its results with those obtained by a more conventional recursive dynamic CGE model. Both models are driven by the same GDP and population data, exogenously provided by the IPCC Shared Socio-economic Pathway 3. GDP levels determine the endogenous productivity parameters. Population affects the definition of per capita income, which in turn affects the household demand system and the variation of input-output coefficients. Information on the demographic structure is also employed to modify the aggregate saving rate parameters. It is found that the two models do produce different findings, both globally and at the regional and industrial level. Understanding the origins of such differences sheds some light on how mechanisms of structural change operate in the long run.

Keywords

Computable General Equilibrium models, Long-run economic scenarios, Structural change

JEL Codes

C68, C82, C88, D58, E17, F43, O11, O40

Address for correspondence:

Roberto Roson
Department of Economics
Ca' Foscari University of Venice
Cannaregio 873, Fondamenta S.Giobbe
30121 Venezia - Italy
Phone: (+39) 041 2349147
Fax: (+39) 041 2349176
e-mail: roson@unive.it

This Working Paper is published under the auspices of the Department of Economics of the Ca' Foscari University of Venice. Opinions expressed herein are those of the authors and not those of the Department. The Working Paper series is designed to divulge preliminary or incomplete work, circulated to favour discussion and comments. Citation of this paper should consider its provisional character.

Exploring Long Run Structural Change with a Dynamic General Equilibrium Model

Wolfgang Britz*
Roberto Roson†

Abstract

In this paper we present a computable general equilibrium model (G-RDEM), specifically designed for the generation of long run scenarios of economic development, featuring a non-homothetic demand system, endogenous saving rates, differentiated industrial productivity growth, interest payments on foreign debt and time-varying input-output coefficients. To the best of our knowledge, this is the first model of this kind. We illustrate how parameters of the five modules of structural change have been estimated, and we test the model by comparing its results with those obtained by a more conventional recursive dynamic CGE model. Both models are driven by the same GDP and population data, exogenously provided by the IPCC Shared Socio-economic Pathway 3. GDP levels determine the endogenous productivity parameters. Population affects the definition of per capita income, which in turn affects the household demand system and the variation of input-output coefficients. Information on the demographic structure is also employed to modify the aggregate saving rate parameters. It is found that the two models do produce different findings, both globally and at the regional and industrial level. Understanding the origins of such differences sheds some light on how mechanisms of structural change operate in the long run.

Keywords:

Computable General Equilibrium models, Long-run economic scenarios, Structural change.

JEL Codes:

C68, C82, C88, D58, E17, F43, O11, O40.

*Institute for Food and Resource Economics, University of Bonn. E-mail: wolfgang.britz@ilr.uni-bonn.de.

†Ca' Foscari University, Venice, and IEFÉ Bocconi University, Milan. E-mail: roson@unive.it.

1 Introduction

Structural change refers to the variation over time of the productive structure of an economy, of its endowments of primary resources (including human capital), as well of its trade and demand patterns. A vast literature on the determinants and implications of structural change exists (Matsuyama, 2016). Quite often, rather than focusing on the full input-output structure of a certain economic system, studies take a somewhat narrow view, where structural change is only identified with the changing composition of output or employment. These works typically relate structural change to economic development (e.g., Chen et al. 2011; Castellacci et al. 2014; Üngör 2013; de Vries et al. 2015; Rodrik 2016; Haraguchi et al. 2017), or to changes in aggregate productivity (e.g., Fagerberg 2000; Sorensen 2001; Duarte and Restuccia 2010; McMillan and Rodrik 2011; Young 2014; Vu 2017; Padilla-Pérez et al. 2017).

A further distinction can be traced in terms of main determinants of structural change. Some studies emphasize the role of demand-side effects, due to different income elasticities and non-linear Engel curves (Matsuyama, 2002; Comin et al., 2015; Roson and van der Mensbrugghe, 2018), possibly linking them to international trade and comparative advantage (Fieler, 2011; Caron and Markusen, 2014; Matsuyama, 2017). Other studies stress the role of supply-side drivers, due to productivity differentials among factors and industries (Bernard and Jones, 1996; Hansen, 2001; Griffith et al., 2004; Buera et al., 2015). The latter often assess the existence and relevance of the so-called “Baumol’s disease” (Baumol, 1986; Triplett and Bosworth, 2006; Young, 2014), which posits the existence of a sluggish sector (services), whose products are weakly substitutable in the economy.

Whenever relative prices matter, be it for comparative advantage or relative productivity, the appropriate modeling framework is general equilibrium. This also offers the additional benefit of assessing multiple processes of structural change, simultaneously or separately. An interesting effort in this direction is the recent contribution by Swiecki (2017). In that paper, a general equilibrium model is specified, combining four forces of structural change in a common framework: (i) sector-biased technological progress, (ii) non-homothetic tastes, (iii) international trade and (iv) changing wedges between factor costs across sectors. The model is calibrated using data for 45 countries over the period 1970–2005, and counterfactual simulations are employed to systematically assess the relative importance of the four mechanisms. Sector-biased technological change turns out to be the most important one, especially for understanding the decline of manufacturing labor share and the corresponding growth in services in developed countries. On the other hand, non-homothetic preferences are key to account for the movement of labor out of agriculture, which matters primarily for poorer countries.

The research we present in this paper is quite similar in spirit, but our methodological approach departs from Swiecki (2017) in several fundamental aspects. First, we refrain from developing our own general equilibrium model, extending instead a well known and tested Computable General Equilibrium

(CGE) model of the world economy. This is because we regard the Swiecki model as too restrictive to capture some important aspect of structural change, especially in the long run. That model includes only three sectors and one (homogeneous) primary factor: labor, whereas we distinguish instead among capital, land, natural resources and different labor categories, while allowing for very high level of industrial detail. Swiecki’s model is formulated as a sequence of temporary equilibria, where physical investment, capital and debt accumulation are not accounted for, contrary to our framework. Finally, compared to more standard CGE analyses, international trade in Swiecki (2017) is sketchy, where frictions are included as iceberg costs, and the trade balance is in equilibrium in all countries in all periods. These differences clearly reflect different aims: whereas our framework is developed for long-run forward looking analysis, based on a detailed, recent dataset of the global economy, Swiecki simulates and compares ex-post, in a setting where data availability is far more restricted.

By employing a dependable CGE core in our model, we link our analysis to the vast field of applied CGE modeling, which provides a wealth of information, much beyond industrial shares, including, for instance: terms of trade, equivalent variations, environmental impacts, public sector balances, etc.. That allows us to conduct a broad evaluation of structural change, so far a rather uncharted territory in CGE modeling (Rose, 1995).

We are aware that the utilization of a CGE framework also brings some disadvantages, though. Even a relatively standard CGE model is very data demanding and includes hundreds of equations and accounting identities. A complete description of the model structure, the underlying data and closure rules adopted in the simulation experiments is not feasible or useful in a scientific paper. Because of the model complexity and its “readiness” a skeptical reader may be induced to think that we are dealing with it as a “black box”. In other words, getting numerical output without a proper critical assessment of the model assumptions, and without being able to trace out the key economic mechanisms producing the results. We respond to this potential critique by adopting (but only as a starting point) a very well documented and tested CGE model, for which post-simulation and sensitivity analysis tools are available. This is the standard GTAP model¹, with parameters calibrated on the basis of the latest GTAP release of a global Social Accounting Matrix. The usage of this model will be better described in the following section.

Another problem with CGE models is that they were not conceived and designed for economic analysis in the medium and long run. Rather, they were intended for short-term policy assessment, like simulating the effects of a fiscal reform, or the implementation of a trade agreement. This explains why most parameters are usually “calibrated” to a relatively recent Social Accounting Matrix (or Input Output Table), such that the observed structure of an economic system is taken as a benchmark, from which counterfactual experiments are conducted. But, of course, when the economy is analyzed at a longer time horizon, the current economic structure, as estimated from some past national accounts,

¹<http://www.gtap.org>.

is no more a valid reference.

Since a conventional CGE model is of little help in analyzing structural change in the long run, we develop our own model, specifically designed for this purpose, which we term GTAP-derived Recursive Dynamic Extended Model (G-RDEM). We start from the standard GTAP model, which is used to define a temporal general equilibrium state of the world economy for each time period considered. The sequence of temporal equilibria is linked through endogenous capital accumulation and productivity growth, in a recursive dynamic fashion. More importantly, we introduce five new features, which we regard as key drivers of structural adjustment²: (a) a non-homothetic demand system for household consumption; (b) parameters of productivity growth which allow for different “speeds” among sectors; (c) non-constant aggregate propensity to save in the economies; (d) interest payments on past cumulated foreign debt; (e) time-varying industrial cost structures. We estimate relationships and parameters for these five elements by means of econometric methods, as illustrated in the next section.

We use the G-RDEM model to define (and examine) a scenario of global economic development, on the basis of given projections of national income and population growth. This also constitutes a major point of departure from the approach followed in several studies in the literature where, rather than looking at the future, structural change is seen as an observed phenomenon of the past.

Our work is motivated by an emerging demand for the construction of internally consistent and sufficiently detailed scenarios of long-run economic development. Most of this demand stems from research on climate change policy and impacts, coordinated world-wide by the Intergovernmental Panel of Climate Change (IPCC), a UN-backed international network of scientists from different disciplines, including economics. Much of the work of IPCC is based on “Integrated Assessment Models”, combining physical and socio-economic modeling, where the latter component is often based on a CGE specification (e.g., Van der Mensbrugge, 2017). The assessment of climate change policy and impacts requires the definition of long run scenarios for both the climate and economic systems. Global Circulation Models, forecasting the evolution of climate in the world, were in the past fed by reference scenarios (SRES), providing information on human-induced emissions of greenhouse gases, reflecting in turn specific hypotheses of economic development (Riahi et al., 2007). Starting from the 5th Assessment Report (Pachauri et al., 2014), the IPCC has promoted the constructions of two separate groups of scenarios: Representative Concentration Paths (RCP), which are based on physical GHGs concentration targets (Van Vuuren et al., 2014), and Shared Socio-economic Pathways (SSP), which specifically defines assumptions of development in terms of GDP, demographic structure, education and urbanization rates (Riahi et al., 2017). SSP scenarios are increasingly being adopted not only in the context of climate change, but in a variety of other research fields, requiring an extended time perspective, for

²Other mechanisms, like international trade and comparative advantage, are naturally endogenous in a CGE setting.

instance in contrasting economic growth and availability of natural resources, like water (Roson and Damania, 2017), or assessing the future risk of hunger (Hasegawa et al., 2015).

The five SSPs are based on narratives describing alternative socio-economic developments. To translate these qualitative storylines into quantitative information, to be possibly used in subsequent numerical analyses, some more aggregate models are employed under assumptions broadly consistent with the narratives. For instance, Dellink et al. (2017) describe how the OECD ENV-Growth model was used to derive (per capita) GDP projections on a country basis. The methodology is based on a convergence process and places emphasis on some key drivers of economic growth in the long run: population, total factor productivity, physical capital, employment and human capital, and energy and fossil fuel resources (specifically oil and gas).

In many modeling exercises, however, knowing a possible future level of GDP may not be enough. Often, the scenario need to be defined at a finer disaggregation level, and here is where multisectoral models like CGEs may come into play. Here, a given GDP projection is often taken as exogenous while allowing a CGE model to endogenously compute the corresponding TFP productivity. The result would be an hypothetical general equilibrium state for the economy (with explicitation of production volumes, relative prices, etc.), consistent with the constraint of GDP being set at the pre-defined level. Yet, it is clear that the economic structure emerging from such simulation with a standard CGE would be quite implausible, as most of the structural parameters of the CGE model have been inherited from calibration on past data (and kept unchanged), whereas the several structural change processes affecting the economy in the future have not been taken into account. This is why a special CGE model like G-RDEM, specifically constructed for the generation of long term scenarios and baselines, is necessary.

We describe the characteristics of the G-RDEM model in the next section, where we also illustrate how the parameter values for the various modules have been estimated. The model is then employed, in the third section, to generate a quite detailed scenario for the world economy, based on population and GDP projections from SSP3, up to the year 2050. To understand how the various mechanisms of structural change operate and affect the results, the scenario generation exercise is conducted in several rounds, through the activation of all or only one of the structural change modules at a time. The results are subsequently processed and contrasted, to highlight the role, characteristics, and implications of the various processes. Some conclusions will follow.

2 The G-RDEM Model Structure

2.1 GTAP Model and Data

Since CGE models provide a detailed account of multiple and interrelated markets, their development calls for a large effort in terms of data collection, integra-

tion and parameters' estimation. The Global Trade Analysis Project (GTAP) is an international consortium and a global network of researchers, founded in the early '90s with the aim of providing a standardized reference data set (mainly) for CGE applications, intended to reduce their fixed setup cost while making it easier their comparison and reproducibility. GTAP realizes a global Social Accounting Matrix (normally every 3-4 years), by harmonizing multiple data sources, mainly input-output tables and bi-lateral trade series. The latest available GTAP 9 release considers 57 industries in 140 countries and regions, referring to the year 2011.³

In addition to the data set, a ready-to-use "standard" comparative static CGE model is offered, with parameters calibrated on the global SAM, accompanied by a free simulation software. The structure of the GTAP model is fully described in Hertel and Tsigas (1997).⁴ Some minor changes have been introduced recently (Itakura and Hertel, 2001; Corong et al., 2017). The reason for providing a reference model as a complement to the data base is related to the possibility of adopting a unifying approach when addressing a wide range of different policy issues, as shown in Hertel (1997).⁵ Indeed, the model can be tailored to the various needs by appropriately aggregating regions and industries, but also by selecting suitable behavioral closure rules.⁶

Some basic assumptions of the model are canonical: industries are modeled through representative, cost-minimizing firms with constant returns to scale and zero profits; households maximize utility under a budget constraint; revenues are obtained by selling services of primary factors; all macroeconomic identities hold, etc. Some other assumptions are less common, in particular:

- Utility of the representative household is implicitly defined as a Constant Differences in Elasticity (CDE) function (Hanoch, 1975). This function allows for (rather limited) differences in income elasticities among consumed goods and services.
- Aggregate savings are a constant share of national income. Savings are virtually collected by a global bank and redistributed as physical investments, without the need to match national savings to investments, therefore to have the trade balance in equilibrium.
- Trade and transport margins in international commerce are handled similarly, by means of virtual global transport and trade agents.

The standard GTAP model has not only being used in different applications, but it has served as a starting point for several extensions, which sometimes require the construction of additional data and satellite accounts, which are also provided (at least in part) by the GTAP consortium. Several variants are

³Data is available also for 2004 and 2007.

⁴For a concise graphical exposition, see Brockmeier (2001).

⁵This book can now be freely downloaded at:

http://www.gtap.agecon.purdue.edu/products/gtap_book.asp

⁶For instance, nominal wages can be fixed exogenously, by making endogenous the labor demand (therefore unemployment).

now available, e.g.: GTAP-E for energy markets and CO2 emissions (Burniaux and Truong, 2002), GTAP-M for domestic margins (Peterson, 2006), GTAP-AEZ for land use and agro-ecological zones (Lee et al., 2009), GTAP-W for water (Calzadilla et al., 2011), GTAP-HET for firm heterogeneity (Akgul et al., 2016). Sometimes, the model extensions involve quite substantial departures from the neoclassical paradigm of perfectly competitive markets, introducing, e.g.: monopolistic competition (Swaminathan and Hertel, 1996), economies of scale (Francois, 1998), oligopolistic industries (Roson, 2006).

The model we present and apply in this paper (G-RDEM⁷) follows this practice by adopting the standard GTAP model for the definition of a series of intra-periodal equilibria, but also extends that model dynamically and introduces a number of modifications in its formulation, to better capture some trends in long-term structural adjustment.

2.2 From Comparative Statics to Recursive Dynamics

The standard GTAP model is a classic CGE, allowing the realization of comparative statics exercises. This means that an initial general equilibrium state, consistent with trade flows as observed in the calibration SAM, is perturbed by modifying some exogenous variables (e.g., tax rates, productivity parameters, etc.). Therefore, like in any basic CGE model, there is no explicit time dimension.

Although a dynamic variant of the GTAP model does exist (Ianchovichina and Walmsley, 2012), the simplest way of making the model dynamic is by framing it as a chain of temporal general equilibria. This can be simply done by making the (exogenous) capital stock at time t dependent on (endogenous) investments at time $t-1$.⁸ When there is no intertemporal optimization, this approach is often termed “recursive dynamics”. In general, that extension alone will not generate a realistic path of economic growth.⁹ This is why the usual methodology for the calibration of this kind of models entails the generation of a “baseline”, obtained by exogenously imposing GDP levels at each period, while making endogenous some productivity parameter. Counterfactual simulations are then obtained by setting the resulting productivity parameter to exogenous, and over-imposing shocks to other parameters, possibly time-dependent. This means that the model dynamics is partly endogenous (capital accumulation) and partly exogenous (productivity growth), whereas the CGE model is essentially used here only to split down the economic structure, on the basis of given projections of macroeconomic variables.

⁷G-RDEM is integrated in the open-source and flexible CGEBox modelling platform. For details, see Britz and Roson (2018).

⁸Of course, several alternatives are possible. For instance, van der Mensbrugge (2008) considers “vintages” of capital stocks and allocation of new capital among industries as dependent on relative returns.

⁹There are several reasons for this. One reason, for example, is the assumption of exactly one year lag for the transformation of investments in fresh new capital, which may not hold in the real world.

In the rest of the paper, we employ the recursive dynamic variant of the standard GTAP model (which we call RecDyn) as a comparative benchmark for our G-RDEM model. Both models are driven by the same population and GDP scenario, as defined in the Share Socio-economic Pathway number 3.

2.3 Introducing a Non-Homothetic Demand System

The relationship between consumption level and income (also known as Engel curve) can be complex and non-linear. Consequently, modeling a time-varying and income-dependent structure of household consumption implies introducing a sufficiently sophisticated demand system in the CGE framework, capable of capturing what Matsuyama (2016) terms “Generalized Engel Law”: the fact that budget shares in consumption expenditure do not vary monotonically over time at progressively higher income levels.

Following Roson and van der Mensbrugghe (2018), we implement an empirically estimated AIDADS demand system into the G-RDEM model, for broad product groups. The AIDADS is An Implicit, Directly Additive Demand System (Rimmer and Powell, 1992). It can be understood as a generalization of a Linear Expenditure System, where marginal budget shares are not fixed, but are a linear combination of two vectors, depicting the marginal budget structure at very low and very high utility (income) levels. The demand for good i is expressed as:

$$q_i = \gamma_i + \phi_i \frac{y - \sum_j p_j \gamma_j}{p_i} \quad (1)$$

where y is total income or expenditure, γ_i is a parameter depicting the constant in the Marshallian demands and ϕ_i is the marginal budget share (which in a LES would be a fixed parameter) given by:

$$\phi_i = \frac{\alpha_i + \beta_i e^u}{1 + e^u} \quad (2)$$

where α_i, β_i are parameters and u is the *implicitly* defined, *cardinal* utility function. The following conditions hold:

$$\lim_{u \rightarrow -\infty} \phi_i = \alpha_i \quad (3)$$

$$\lim_{u \rightarrow \infty} \phi_i = \beta_i \quad (4)$$

$$\alpha_i < \phi_i < \beta_i \quad (5)$$

$$\lim_{y \rightarrow \infty} \frac{p_i q_i}{y} = \phi_i = \beta_i \quad (6)$$

Expenditure shares therefore stabilize at the level β_i in the long run, although at different “speeds”. It is not possible to get a closed form solution for the utility

level u , which must then be estimated numerically, alongside the parameters α_i, β_i and γ_i . A number of constraints must also be taken into account, to ensure regularity conditions for the system (Powell et al., 2002). Cranfield (1999) shows how to use maximum likelihood methods for estimation, employing also bootstrapping techniques to get parameters statistics (e.g., confidence intervals) and maximum entropy for multiple demands, disaggregated in terms of per-capita income.

We first econometrically estimated $\alpha_i, \beta_i, \gamma_i$ and u using data from the International Comparison Program (ICP, 2015), for ten broader expenditure categories (food, beverages and tobacco, clothing, housing, furniture, transportation, recreation, communication, health, education). The integration in the CGE model requires mapping the parameter estimates to the commodity resolution of the model. The demand system is calibrated against the benchmark data of regional household consumption, from the GTAP v.9 data set. To this purpose, we regressed the utility levels u from our findings to total per capita consumption expenditure y in each region. That allows us to estimate (from (2)) the marginal budget shares in the calibration point. We then discarded the previously estimated γ_i and instead solve (1) for γ_i at given q, y, p and the calibrated marginal budget shares. In the case that this implies a negative γ_i , we use a penalty minimization approach, which minimizes the difference between the estimated α_i, β_i and the “corrected” ones, such that all γ_i turn out to be positive.¹⁰

2.4 Introducing Differentiated Productivity Growth

Productivity does not vary uniformly among industries and sectors. Harberger (1998) points out that the whole dynamics of economic progress actually resembles the growth process of “mushrooms”, rather than the steady rise of “yeast”. Indeed, differential productivity growth is one key factor of structural change in the economic systems, and probably the most important one (Swiecki, 2017). Several implications of different growth rates have been investigated in the literature, e.g.: relevance and empirics of the so-called “Baumol’s disease” (Baumol, 1986; Triplett and Bosworth, 2003; Young, 2014); specialization and international trade (McMillan and Rodrik, 2011; Caron and Markusen, 2014); “premature deindustrialization” (Rodrik, 2016); interactions between human capital, growth and structural change (Teixeira and Queirós, 2016).

To introduce differentiated productivity growth in the G-RDEM model, we build on Roson (2018), who estimated trends in labor productivity, using the Groeningen GGDC 10-Sector Database (de Vries et al., 2015). In that study, some trends and country specific dummies for labor productivity (VA/employment) are estimated. Results are subsequently employed in a cluster analysis, where three groups of countries with similar characteristics are identified. Table 1 shows some of the findings used to obtain parameters for G-RDEM.

¹⁰For more information, see Britz and Roson (2018).

Table 1: Average labor productivity growth rates

Cluster	AGR	MAN	SER	TOT
<i>Rising</i>	6.23	11.43	5.65	8
<i>Steady</i>	7	7.88	5	5.93
<i>Lagging</i>	5.17	5.32	2.34	3.16

The last column in Table 1 (*TOT*) displays the average (yearly) growth rate in labor productivity in each group of countries. It refers to value added per worker or hour, so it accounts for capital deepening and similar effects. Interestingly, the differences among industries depends on how fast an economy is growing.

In the development of the G-RDEM model we are not concerned about labor productivity in itself, but rather on the relative differences among the three broad sectors of Agriculture, Manufacturing and Services. To this end, a correspondence between the three clusters and the annual GDP growth rates used in the SSPs was established, and the ratio of each sector productivity rate, relative the slowest growing sector, which is Services, was computed. A quadratic interpolation between the three multipliers and the references GDP growth rates was undertaken for each industry, thereby getting a quadratic polynomial relationship between a sectoral productivity shifter (ratio between industry growth rate and the corresponding one in the Services) and GDP annual growth.

2.5 Making the Aggregate Saving Rate Variable

Individual saving behavior depends on expected future income, risk and bequest motives. Therefore, aggregate savings rates are related to the demographic structure, as explained by the life cycle theory, with individuals or households saving or dissaving at various stages of life. In particular, two variables are found to be especially relevant in the empirical literature: the youth and old dependency ratios, that are the shares of (nonworking) youth and aged people in total population. However, saving behavior is also influenced by social and institutional characteristics, which are very specific to the different economies: pension and health systems, family links, etc.

In the process of construction of baseline scenarios, projections of future population are normally available, alongside data on GDP. In some cases, as it is for the Shared Socio-economic Pathways, estimates regarding the age structure of population are also provided. Quite naturally, then, a model like G-RDEM should have a mechanism for making aggregate saving rates variable over subsequent periods, and consistent with the given scenario of income and population.

One strand of literature (e.g., Kirsanova and Sefton, 2007), works with micro-economic survey data. These papers explicitly account for factors such as demography, welfare state, retirement behavior, borrowing constraints, income distribution over a lifetime and its uncertainty, as well as capital gains. While

they give robust evidence that those factors indeed explain the saving behavior of individuals or households, data limitations typically allow to offer results for only one or a small group of countries. Another approach in the literature, which is at the basis of the method implemented in G-RDEM, employs cross-sectional analyses over countries. Most of these works do take the lifecycle hypothesis into account (although indirectly) and find that larger proportions of the young and the elderly compared to persons in working age (dependency ratios) generally decrease the saving rate (Doshi, 1994; Masson et al., 1998; Loayza et al., 2000).

We carried out our own cross-section estimation, using GTAP 9 and other data used in our modeling framework, to overcome any potential divergence in definitions, measurement units etc.. The reader might note that we face a potential endogeneity issue: higher rates of GDP growth require increased capital accumulation, thus larger net investments and consequently higher saving rates. The saving rate and GDP growth are hence structurally dependent. However, this is not an issue of major concern in this context, since we are not integrating the estimated equation into the model, but only updating saving rates, given GDP projections. Hence, our aim is solely to ensure that correlation, not causation, is properly accounted for.

The distribution of the national aggregate saving shares in the GTAP 9 data set reveals a large spread, as shown in Figure 1. We regressed those saving rates with OLS against the following explanatory variables:

- Population composition by age group from the IIASA repository for 2010 (Lutz et al., 2017)
- GDP growth per capita from 2010 to 2011, in PPPs, from the OECD Env. Growth Model data base as found in the IIASA repository
- Foreign savings (trade balance) relative to regional income, from the GTAP 9 data base

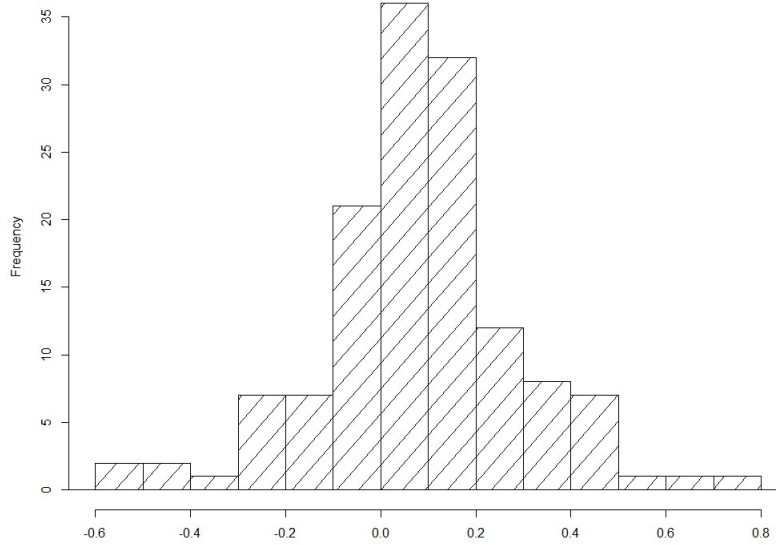
We also tested, as a potential explanatory variable, the share of government consumption on regional income, but we did not find a statistically significant relation.

We found a very good fit for our sectional analysis, with R^2 at 92% and all variables (with the exception of the young dependency rate) statistically significant at 0.1%. The young DR is nonetheless significant at the 5% level. All variables have the expected sign: dependency ratios decrease the saving rates, as postulated by the life cycle hypothesis, while a higher income per capita and a higher growth rate increase the saving rate. A positive trade surplus (i.e., negative foreign savings) also tends to increase the saving rates.

We have not directly used the fitted values in the G-RDEM model, though, since we would then have neglected any unexplained additional factors, which could imply large changes in the saving rates from the benchmark in some countries. Thus, we use relative changes in the estimates¹¹ to update the saving

¹¹We neglect foreign savings at this stage, to avoid outlier cases such as oil exporting countries (high saving rates) as well as some other countries, often developing ones, with very low saving rates.

Figure 1: Distribution of aggregate savings rates in GTAP 9



rates in the model.¹²

2.6 Introducing Debt Dynamics

The standard GTAP model includes a module for the allocation of foreign savings, which could be interpreted as direct investments. The key variable is the regional current return on capital ($rorc_r$), defined as:

$$rorc_r = \frac{p_{c,r} [1 - \bar{\kappa}_r]}{p_{i,r}} - \overline{fdepr} \quad (7)$$

where $p_{c,r}$ is the endogenous price of capital services in region r , $p_{i,r}$ is the endogenous price (cost) of producing a composite investment good, $\bar{\kappa}_r$ is the exogenous tax rate on capital earnings and \overline{fdepr} the exogenous depreciation rate.

The future expected return on capital ($rore_r$) is formulated as:

$$rore_r = rorc_r \left(\frac{k_{s,r}}{k_{e,r}} \right)^{\overline{rorFlex}} \quad (8)$$

where $k_{s,r}$ and $k_{e,r}$ are start and end of period capital stocks, respectively. Since at the end of the period the capital stock is augmented by the flow of real

¹²For more information, see Britz and Roson (2018).

investments, the denominator in the ratio is normally larger than the numerator. The parameter *rorFlex* drives the sensitivity to relative real returns. If it is set to zero, expectations are static. For higher values, any increase of investments at time t reduces expected returns at time $t+1$, thereby providing a mechanism of decreasing marginal returns (expected).

An arbitrage condition ensures that the risk-adjusted expected return is globally equalized:

$$r_{ore_r} \overline{risk_r} = r_{org} \quad (9)$$

Therefore, foreign net investments are allocated so that (8) and (9) hold.

We introduce in G-RDEM a system of non-bilateral flows of income transfers, due to interest payments on cumulated foreign debt.¹³

$$captrans_{r,t} = r_{orc_{r,t}} \cdot \sum_{tt < t} fsav_{r,tt} \quad (10)$$

The given interest payments on the stock of foreign debt enter the equation defining the regional income, in addition to the factor and tax income. They are positive for a country which was in the past a lender and negative for past debtors.

A practical issue emerged when the mechanism above was applied to some special circumstances, where foreign savings account for a large share of investments or total final consumption. Examples are some developing countries, receiving large amounts of development aid or remittances, but also some “tax havens”. In such cases, we noticed that the mechanism above can lead, after some periods, to a situation where regional income gets unrealistically small. To avoid such extremes, while allowing for the existence of capital inflows or outflows determined by factors other than expected returns, we introduced a regional share parameter, such that only part of the debt may actually be served.¹⁴

2.7 Allowing for Time-Varying Industrial Cost Structures

Parameters of the production function, applied to the representative firm in each regional industry, are calibrated on the observed cost structures of the base year SAM. Therefore, changing cost structures, or input-output coefficients, would amount to changing parameters in the production function. This would be equivalent to adopting a different technology for the production of goods and services in the various regional industries.

An alternative interpretation is possible, though. In fact, even at a relatively fine level of disaggregation, each industry comprises many differentiated goods, which could well have diverse income elasticities. As a consequence, as the economy grows, the average industrial cost structure may vary even if the production technologies for individual goods stay the same. Already Arrow (1959)

¹³These flows, which could be positive or negative, are balanced in such a way that their sum over all regions is zero in each period.

¹⁴Such share parameters are set case-by-case, on the basis of informed guesses.

decomposed changes in input-output coefficients into variations due to real disposable income and variations due to technology and tastes. Other studies in this tradition are: McGilvray and Simpson (1969), Skolka (1989), Casler et al. (1991), Sawyer (1992), Israilevich et al. (1997).

The relevance of this composition effect is an empirical question, which we have addressed here by checking the existence of a relationship between regional cost shares and an index of per-capita income¹⁵ in the GTAP 9 data set. We tested our hypothesis using a sectional approach where, to keep the analysis manageable, we first aggregated to 10 sectors, while keeping the maximum spatial detail of 140 countries and regions. We then regressed the intermediate input-output coefficients on the log of the per capita income index in each country, including only cost shares observations with a median of at least 1%. This leaves 65 series out of the potential 100 (10x10 input-output matrix).

If input-output coefficients change in the process of economic development, we should find regression coefficients associated with per capita income with a low significance level of being zero. In fact, out of the 65 coefficients with a cost share of at least 1%, more than 40 turn out to have probabilities of being zero lower than 1%, which supports the hypothesis of a relation with per capita income. The actual estimation procedure uses a Mean-Absolute Deviation as a robust estimator, which is not very sensitive to outliers. It uses sectoral output as a weight, assuming that larger sectors are statistically better monitored and reported.¹⁶

The estimates have been introduced in G-RDEM as functions, updating input-output coefficients (therefore parameters of the industrial production functions), from one time period to the next.

3 A Numerical Assessment

In order to contrast the findings from the G-RDEM model with those of a more conventional model, lacking the specific features we have introduced to capture long run structural change, we performed a series of numerical simulation exercises. We adopted the GTAP RecDyn model as a benchmark, as it is a simple multiperiod extension of the standard, comparative static GTAP model. For all cases, we consider an aggregation which includes all the 57 industries in the GTAP database, while the regions are aggregated into 10 macroregions.¹⁷

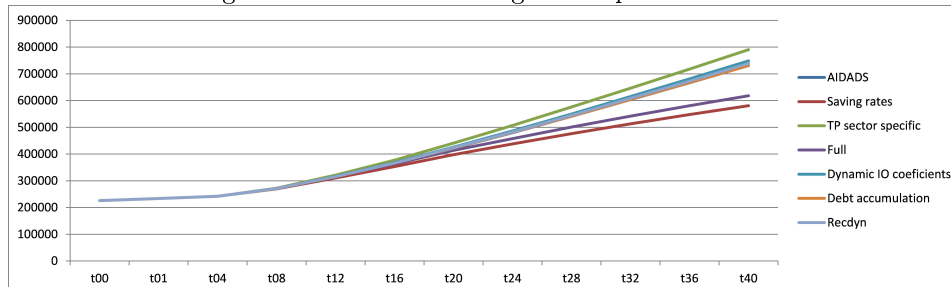
In the following, we briefly describe how the simulations have been realized. Then, we present the results, by distinguishing the global aggregate effects from those related to the industrial composition in the various economies.

¹⁵Economies are not closed in our system. Therefore, the index was built through trade weighted aggregation of per-capita incomes.

¹⁶For more information, see Britz and Roson (2018).

¹⁷Oceania, EastAsia, SEAsia, SouthAsia, NAmerica, LatinAmer, EU_28, MENA (Middle East and North Africa), SSA (Sub-Saharan Africa), RestofWorld.

Figure 2: Evolution of the global capital stock



3.1 Simulation Strategy

By selecting the various characteristics in G-RDEM, we can obtain seven different model configurations: (1) the complete G-RDEM implementation with all its five features (AIDADS demand system, productivity shifters, updated saving rates, updated I-O coefficients, debt accumulation); (2) five versions of G-RDEM, having only one of those modules active, and (3) the GTAP Recursive Dynamic variant, where only capital accumulation is considered and the demand system is a CDE (Constant Differences in Elasticity).

The seven model versions are used to build seven corresponding scenarios, that are time series of macroeconomic variables. All variants are driven by the same GDP and population data exogenously provided by SSP3. GDP levels determine the endogenous productivity parameters. Population affects the definition of per capita income, which in turn affects the household demand system and the variation of input-output coefficients. Information on the demographic structure is also employed to modify the aggregate saving rate parameters.

3.2 Global Results

The various features we introduced in G-RDEM generate some findings which apply worldwide, across all regional economies. For instance, Figure 2 displays the evolution of the global capital stock.

As it can be readily seen, the smallest growth in the capital stock is obtained when saving rates are varied from their benchmark levels, meaning that, on average, savings are less and capital accumulation slower. That reflects mainly the impact of higher dependency rates in the age structure of population. Globally, however, savings must match investments, so that investments must also be smaller. Remember that regional GDP in each year is fixed to the same level in all model variants. Since investments are one component of the GDP, keeping the latter unchanged implies that other components, like private and public consumption, must expand. This is confirmed in Figure 3, showing the evolution of private household consumption.

Consumption levels, however, are also affected by other effects. In particular, we found that interest payments on foreign debt reduce consumption, and

Figure 3: Global private household consumption

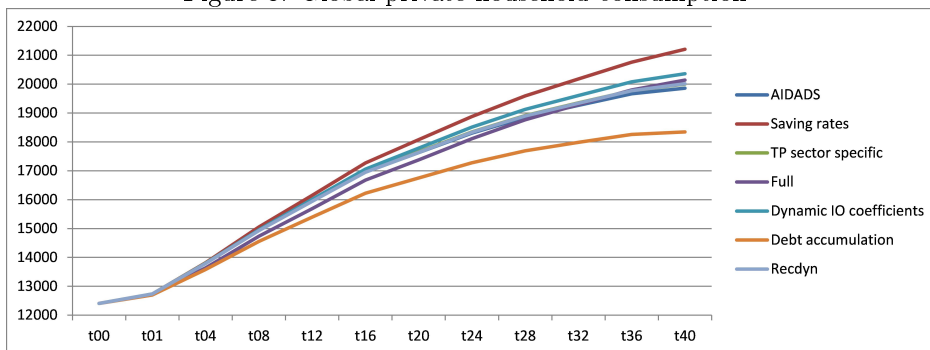
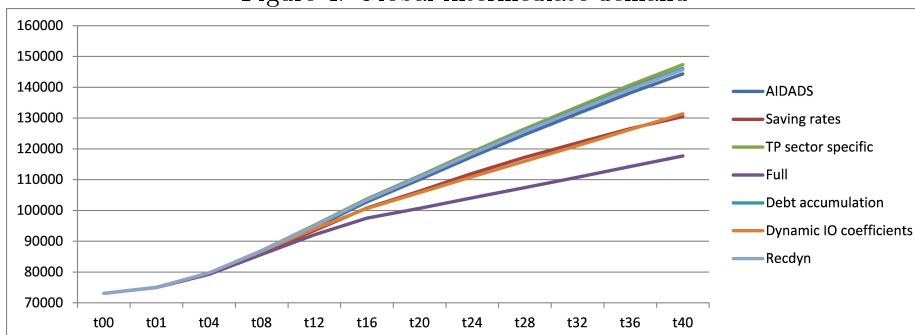


Figure 4: Global intermediate demand



when both endogenous saving rates and foreign debt are jointly considered, the differences between G-RDEM and the benchmark recursive dynamic GTAP model are not very significant, at least in terms of global aggregate private consumption.

A similar kind of effect occurs on the supply side. Since GDP can also be defined as the value of primary resources in the economy, if the capital stock shrinks then this reduction must be compensated through higher productivity, as other primary resources stocks are not endogenous. We also found that the complete G-RDEM model generates a considerably smaller increase in intermediate demand than GTAP-RecDyn. This seems to be primarily due to two mechanisms: (a) lower saving rates imply higher TFP growth, therefore less intermediate factors; (b) changing cost shares, which on average reduce the amount of intermediates. Figure 4 shows how global demand for intermediate factors evolves.

Table 2: Euclidean distances

<i>Full</i>	AIDADS	debt	I-O upd.	savrate	tfp	<i>RecDyn</i>	
338.2	342.2	349.6	375.9	270.1	360.8	344.8	Oceania
5575.7	4873.1	5188.3	5419.8	4237.6	5972.4	5014.8	EastAsia
906.0	1036.4	1096.8	1013.7	820.8	1214.5	1065.4	SEAsia
1422.0	1569.0	1631.6	1597.8	1323.3	1944.7	1613.9	SouthAsia
2922.8	2945.6	2851.0	3628.8	2319.6	3246.7	2953.3	Namerica
917.9	1155.6	1174.7	1109.6	888.0	1258.5	1172.5	LatinAmer
2346.7	2769.6	2762.9	3435.7	1747.1	2868.0	2732.9	EU_28
426.9	514.3	534.0	496.1	401.1	566.7	521.1	MENA
761.2	856.1	860.5	815.5	646.1	988.2	841.7	SSA
1362.6	1801.7	1946.3	1765.1	1281.5	1887.2	1862.4	RestWorld

3.3 Structural Change and Its Determinants

To analyze issues of structural change we focus, among the many macroeconomic variables generated by a CGE model, on the industrial real value added $V_i^{r,t}$ in region r at time t . More precisely, $V_i^{r,t}$ is the aggregate composite of primary factors employed in industry i , which is the equivalent of labor employment in models where only labor is the primary factor. Since there are 57 industries considered in our simulation experiments, the structure of each regional economy at some period is identified by a vector with 57 elements. To measure how much the regional structure change from the calibration year (2011) to the final year (2050) it is possible to compute an Euclidean distance:

$$D^r = \sqrt{\sum_i \left(V_i^{r,2050} - V_i^{r,2011} \right)^2} \quad (11)$$

Notice that D^r measures both the absolute variation of the total real value added in a region, which also depends on the size of the regional economy, and the variability of the industrial shares.¹⁸ Table 2 presents the Euclidean distances, computed for all regions in the seven model variants.

Since we are interested in knowing how much the various features we have introduced in G-RDEM generate different results with respect to the GTAP-RecDyn benchmark, the variation in Euclidean distance relative to the RecDyn one can be readily calculated, as shown in Table 3. We can see that the two models produce very different findings for Rest of the World, Middle East and North Africa, Latin America, but also for Europe and South-East Asia. On the other hand, differences are minimal for the cases of North America and Oceania.

To further distinguish the contribution due to variations in the aggregate, from the one due to the varying industrial composition, it is possible to check (Table 4) the relative variation in total regional value added (primary factors)

¹⁸In this sense, it differs from measures like the Norm of Absolute Values (NAV) index (Vu, 2017).

Table 3: Relative variations in Euclidean distance

<i>Full</i>	AIDADS	debt	I-O upd.	savrate	tfp	
-1.89%	-0.74%	1.41%	9.04%	-21.66%	4.65%	Oceania
11.18%	-2.83%	3.46%	8.07%	-15.50%	19.10%	EastAsia
-14.96%	-2.72%	2.95%	-4.86%	-22.96%	14.00%	SEAsia
-11.89%	-2.78%	1.10%	-1.00%	-18.01%	20.50%	SouthAsia
-1.03%	-0.26%	-3.46%	22.87%	-21.46%	9.93%	Namerica
-21.72%	-1.44%	0.19%	-5.37%	-24.26%	7.34%	LatinAmer
-14.13%	1.34%	1.10%	25.71%	-36.07%	4.94%	EU_28
-18.09%	-1.30%	2.46%	-4.80%	-23.04%	8.74%	MENA
-9.56%	1.71%	2.24%	-3.11%	-23.24%	17.41%	SSA
-26.84%	-3.26%	4.51%	-5.22%	-31.19%	1.33%	RestWorld

Table 4: Relative variations in total real value added

<i>Full</i>	AIDADS	debt	I-O upd.	savrate	tfp	
-27.48%	-1.43%	1.39%	-12.23%	-23.64%	2.92%	Oceania
-15.96%	-1.33%	2.34%	-1.47%	-25.73%	14.26%	EastAsia
-20.85%	-0.46%	2.27%	-0.95%	-28.05%	9.46%	SEAsia
-15.12%	-0.57%	1.38%	-0.62%	-24.14%	14.36%	SouthAsia
-28.66%	-1.71%	0.14%	-10.77%	-26.53%	7.70%	Namerica
-24.70%	-1.20%	1.56%	-2.31%	-28.35%	5.75%	LatinAmer
-35.89%	-1.42%	1.83%	-1.01%	-37.26%	2.16%	EU_28
-18.24%	0.18%	2.14%	-1.63%	-25.46%	8.48%	MENA
-15.82%	-0.07%	1.87%	-1.48%	-23.60%	10.67%	SSA
-31.59%	-1.43%	3.16%	-3.53%	-32.69%	1.80%	RestWorld

composite, again with respect to RecDyn. The numbers in Table 4 highlight how strong the effects discussed in the previous section are, at the regional level (compare them with Figure 2). For instance, lower savings imply less capital accumulation, therefore a lower stock of primary resources (compensated by higher productivity).

Table 5 presents the differences between numbers in Table 3 and numbers in Table 4. Therefore, it broadly illustrates how variations in industrial shares contribute to the overall divergence. Very significant changes in the industrial mix are detected in Oceania, East Asia, North America and Europe. Interestingly, in terms of Euclidean distance of G-RDEM from GTAP-RecDyn, these changes offset the lower growth in the stock of primary resources for Oceania and North America.

Which industries, in which regions, are affected by the most relevant variations? Tables 6 and 7 display the difference between the share of each of the 57 industries in the regional aggregate of primary factors in 2050 and the same share in the calibration year 2011, as obtained by the complete G-RDEM model. Changes lower than -2% or greater than +2% are highlighted in bold. Notice

Table 5: Differences in relative variations

<i>Full</i>	AIDADS	debt	I-O upd.	savrate	tfp	
25.59%	0.69%	0.01%	21.27%	1.98%	1.73%	Oceania
27.15%	-1.49%	1.12%	9.54%	10.23%	4.83%	EastAsia
5.89%	-2.26%	0.68%	-3.91%	5.09%	4.54%	SEAsia
3.23%	-2.21%	-0.28%	-0.37%	6.14%	6.14%	SouthAsia
27.62%	1.45%	-3.60%	33.64%	5.07%	2.23%	Namerica
2.99%	-0.24%	-1.37%	-3.05%	4.09%	1.59%	LatinAmer
21.76%	2.76%	-0.73%	26.73%	1.19%	2.78%	EU_28
0.15%	-1.48%	0.33%	-3.17%	2.42%	0.26%	MENA
6.25%	1.78%	0.37%	-1.63%	0.36%	6.74%	SSA
4.76%	-1.83%	1.34%	-1.69%	1.50%	-0.47%	RestWorld

that absolute, not relative, differences are shown. As a consequence, larger values are likely to be found for those industries which are comparatively large, in terms of value added share in the regional economy.

Shares of all industries in the agricultural sector decline, the most in South Asia and Africa for Vegetables and Fruits. This effect is driven by the very low income elasticity of agricultural products which, in our AIDADS demand system, primarily affects some developing countries.

Coal production significantly absorbs less resources, especially in Africa and Rest of the World (which includes several energy exporters, like Russia). The main determinant here appears to be the higher energy efficiency of some production processes, reducing the amount of intermediate energy factors per unit of output.

Some significant variations can be detected in the shares of Construction, which are clearly related to changes in investments. We can see both increases and decreases, as total investments are not only globally diminished, but also differently distributed. The large increment in North America and Europe, on one hand, and the decrease in South Asia and Sub-Saharan Africa, on the other hand, suggests a relationship with income per capita. Indeed, we found that such relationship indirectly operates through changes in relative prices and productivity. This is because GDP projections in the SSP3 scenario are based on hypotheses of progressive convergence. Poorer countries grow more, but this translates into significant gains in productivity. South Asia, MENA and SSA are, in fact, the three regions with the largest decrease in the relative producer price for Constructions, whereas North America and Europe (being mature, slow growing economies) are the regions where the decrease is smallest. This effect is further amplified by the differential variation in industrial productivity. Therefore, much less resources are employed in Constructions in the fast growing economies, thereby reducing its share in the value added composite, and vice versa.

Shares of what is call the “Trade” industry in GTAP (all retail sales including automotive fuel; wholesale trade and commission trade; hotel and restaurants;

Table 6: Absolute differences in industrial shares in the full G-RDEM model 2011-2050 (I)

	Oceania	EastAsia	SEAsia	SouthAsia	Namerica	LatinAmer	EU_28	MENA	SSA	RestWorld
Paddy rice	-0.01%	-0.42%	-1.28%	-0.83%	0.01%	-0.05%	0.00%	-0.15%	-0.44%	-0.02%
Wheat	-0.15%	-0.09%	0.00%	-0.65%	0.02%	-0.07%	-0.09%	-0.66%	-0.08%	-0.15%
Cereal grains nec	0.01%	-0.16%	-0.20%	-0.09%	-0.07%	-0.15%	-0.03%	-0.35%	-1.25%	-0.10%
Vegetables, fruit, nuts	-0.10%	-1.12%	-1.38%	-2.41%	-0.09%	-0.28%	-0.19%	-2.02%	-3.01%	-0.57%
Oil seeds	-0.02%	-0.16%	-0.75%	-0.59%	0.00%	-0.23%	-0.04%	-0.13%	-0.59%	-0.05%
Sugar cane, sugar beet	-0.01%	-0.03%	-0.12%	-0.39%	-0.01%	-0.18%	-0.01%	-0.08%	-0.08%	-0.02%
Plant-based fibers	0.03%	-0.06%	-0.01%	-0.45%	0.01%	-0.02%	0.00%	-0.13%	-0.06%	-0.02%
Crops nec	-0.08%	-0.04%	-0.87%	-1.73%	-0.02%	-0.26%	-0.16%	-0.09%	-0.79%	-0.03%
Cattle,sheep,goats,horses	-0.36%	-0.23%	-0.17%	-0.16%	-0.06%	-0.22%	-0.10%	-0.17%	-0.43%	-0.09%
Animal products nec	-0.08%	-0.59%	-0.39%	-0.33%	-0.03%	-0.22%	-0.12%	-0.25%	-0.14%	-0.10%
Raw milk	-0.14%	-0.05%	0.00%	-1.78%	0.04%	-0.14%	-0.07%	-0.25%	-0.09%	-0.16%
Wool, silk-worm cocoons	-0.04%	-0.04%	0.00%	-0.03%	0.00%	0.03%	0.00%	0.00%	0.00%	0.01%
Forestry	-0.12%	-0.29%	-0.36%	-0.33%	-0.19%	-0.03%	-0.18%	0.04%	-0.26%	-0.05%
Fishing	-0.04%	-0.40%	-0.76%	-0.27%	-0.01%	-0.10%	-0.03%	-0.15%	-0.40%	-0.07%
Coal	-0.32%	-0.39%	-0.78%	-0.08%	-0.06%	-0.04%	-0.03%	0.01%	-0.06%	-0.15%
Oil	-0.19%	-0.21%	-1.19%	-0.25%	-0.33%	-1.05%	-0.09%	-6.28%	-3.44%	-4.85%
Gas	0.17%	0.01%	-0.13%	-0.05%	-0.03%	0.01%	-0.03%	-0.83%	-0.14%	-0.34%
Minerals nec	-1.70%	-0.60%	-0.79%	-0.38%	-0.13%	-0.74%	-0.08%	-0.77%	-0.74%	-0.34%
Meat: cattle,sheep,goats,horse	0.07%	-0.05%	-0.06%	0.01%	0.10%	-0.13%	0.02%	-0.24%	-0.52%	-0.12%
Meat products nec	-0.09%	0.01%	-0.16%	-0.01%	-0.09%	-0.06%	-0.19%	-0.10%	-0.10%	-0.04%
Vegetable oils and fats	-0.01%	-0.04%	-0.47%	-0.07%	-0.01%	-0.05%	-0.06%	0.00%	0.01%	-0.02%
Dairy products	0.01%	-0.01%	-0.05%	-0.36%	0.02%	-0.11%	-0.06%	-0.29%	-0.03%	-0.13%
Processed rice	0.00%	-0.04%	-0.13%	-0.57%	0.01%	-0.07%	0.00%	0.00%	0.00%	-0.01%
Sugar	-0.07%	-0.01%	-0.10%	-0.08%	-0.01%	-0.05%	-0.04%	-0.02%	-0.05%	-0.01%
Food products nec	-0.29%	-0.02%	-0.58%	-0.16%	-0.17%	-0.24%	-0.49%	-0.08%	-0.46%	-0.16%
Beverages and tobacco products	0.03%	0.23%	0.25%	0.10%	0.09%	0.09%	-0.07%	0.08%	0.08%	0.14%
Textiles	-0.01%	-0.32%	-0.14%	0.13%	0.03%	-0.08%	-0.09%	0.05%	0.18%	-0.04%
Wearing apparel	0.00%	0.04%	0.08%	0.12%	0.03%	-0.01%	-0.09%	-0.08%	-0.01%	0.03%

Table 7: Absolute differences in industrial shares in the full G-RDEM model 2011-2050 (II)

	Oceania	EastAsia	SEAsia	SouthAsia	Namerica	LatinAmer	EU_28	MENA	SSA	RestWorld
Leather products	0.00%	0.02%	-0.09%	0.01%	0.01%	0.01%	-0.06%	-0.07%	0.05%	-0.01%
Wood products	0.14%	-0.10%	-0.23%	-0.03%	0.06%	-0.06%	0.07%	-0.12%	-0.11%	-0.09%
Paper products, publishing	0.53%	-0.28%	0.33%	0.47%	0.15%	0.06%	0.30%	0.35%	0.26%	0.05%
Petroleum, coal products	-0.14%	0.30%	0.06%	-0.12%	-0.22%	0.16%	-0.25%	0.18%	-0.01%	0.41%
Chemical,rubber,plastic prods	-0.27%	-1.25%	-1.18%	0.73%	-0.26%	-0.36%	-0.96%	0.44%	0.38%	-0.55%
Mineral products nec	-0.28%	-0.55%	-0.19%	0.06%	-0.35%	-0.06%	-0.47%	-0.09%	-0.13%	-0.17%
Ferrous metals	-0.06%	-1.16%	0.05%	0.26%	-0.08%	-0.10%	-0.09%	0.08%	0.05%	-0.40%
Metals nec	-0.14%	-0.29%	-0.19%	0.01%	-0.29%	-0.24%	-0.29%	-0.13%	-0.04%	-0.51%
Metal products	-0.17%	0.12%	-0.27%	-0.17%	-0.24%	0.01%	-0.54%	-0.03%	-0.13%	-0.08%
Motor vehicles and parts	-0.12%	-0.10%	0.27%	0.09%	-0.22%	0.08%	-0.46%	0.14%	0.36%	0.08%
Transport equipment nec	-0.06%	-0.18%	0.00%	0.14%	0.01%	0.02%	-0.09%	0.04%	0.39%	-0.13%
Electronic equipment	-0.28%	-1.25%	-0.31%	0.37%	-0.20%	-0.08%	-0.37%	0.00%	0.17%	-0.22%
Machinery and equipment nec	-0.24%	-0.94%	0.52%	0.75%	-0.26%	0.22%	-0.91%	0.37%	0.36%	-0.56%
Manufactures nec	-0.14%	-0.35%	0.01%	-0.09%	-0.12%	-0.04%	-0.36%	0.10%	0.05%	-0.25%
Electricity	-0.26%	0.55%	0.30%	-0.17%	-0.36%	0.23%	-0.51%	0.73%	0.17%	0.63%
Gas manufacture, distribution	-0.02%	0.02%	-0.42%	0.05%	-0.05%	-0.02%	0.02%	-0.11%	0.03%	-0.16%
Water	-0.16%	0.04%	0.13%	0.10%	-0.13%	0.07%	-0.01%	0.13%	0.18%	0.15%
Construction	1.70%	-0.80%	-1.28%	-2.72%	2.40%	-0.11%	3.06%	-1.90%	-2.32%	-0.25%
Trade	5.49%	-4.40%	-1.13%	2.38%	5.11%	-2.18%	6.35%	1.38%	2.75%	-1.01%
Transport nec	-1.25%	0.53%	1.14%	0.91%	-0.23%	0.49%	-0.32%	1.11%	0.46%	0.76%
Sea transport	0.02%	-0.42%	-0.15%	-0.14%	0.04%	-0.02%	0.17%	0.02%	0.07%	-0.10%
Air transport	0.70%	-0.06%	-0.02%	0.12%	1.00%	-0.01%	0.62%	0.04%	0.12%	-0.04%
Communication	-0.17%	1.18%	0.00%	0.32%	0.02%	0.65%	-0.48%	0.94%	0.33%	0.78%
Financial services nec	0.25%	0.01%	2.45%	3.59%	-0.27%	0.56%	1.27%	2.51%	3.08%	1.24%
Insurance	0.65%	-0.34%	0.22%	0.30%	0.66%	-0.16%	1.12%	0.02%	0.76%	-0.06%
Business services nec	-3.24%	5.77%	1.88%	0.20%	-2.96%	2.59%	-2.83%	2.32%	1.88%	3.44%
Recreation and other services	-2.13%	1.35%	0.93%	0.55%	-2.80%	0.80%	-2.18%	1.53%	0.67%	1.37%
Pub.Admin/Defence/Health/Educat	-0.80%	1.84%	0.22%	-1.76%	-2.42%	-0.48%	-3.45%	0.34%	-0.10%	0.99%
Dwellings	3.04%	5.71%	6.80%	5.47%	2.87%	2.40%	3.00%	2.65%	3.17%	2.75%

repairs of motor vehicles and personal and household goods) also vary significantly, but with different directions. In this case, it is difficult to identify a dominant force, because much of the demand for Trade services is an indirect one, coming from other sectors, so that the variation in Trade activities is related in a complex way to the overall evolution in the structure of the regional economy.

Relative prices and reduced productivity growth also explain why the shares of Financial Services get larger in some regions, with the exception of South Asia. Indeed, South East Asia and Africa is where the relative cost of Financial Services increases.

A clear pattern emerges for the shares of Business, Recreational and other services, where mature economies of Oceania, North America and Europe reduce the relative amount of primary resources devoted to them, whereas the shares increment in the other regions. This is due to two overlapping mechanisms. Oceania, North America and Europe are the three mature economies with the largest shares of Business, Recreational and other services in the initial year 2011. Therefore, one aspect of the catching up process by the developing economies is the expansion of this sector. In addition, production costs decrease very significantly in Oceania, America and Europe, which allows to save there on the utilization of primary resources.

Finally, Dwellings shares get larger in all regions, despite non negligible gains in productivity. As Dwellings mainly affect final consumption, the main driver here is the high income elasticity.

4 Conclusions

Nobody knows what the economic structure will look like in the relatively distant future, what new technologies could emerge and what discontinuous variations will affect trade and consumption patterns. What we do know, nonetheless, is that a number of slow processes are ongoing, which have affected the economic structure in the past and will keep affecting it in the future. Therefore, the construction of an internally coherent scenario of economic development (which is actually not about forecasting) cannot ignore them.

In this paper we have presented G-RDEM, a computable general equilibrium model specifically designed to this purpose, featuring a non-homothetic demand system, endogenous saving rates, differentiated industrial productivity growth, interest payments on foreign debt and time-varying input-output coefficients. To the best of our knowledge, this is the first model of this kind. We therefore believe that this work may pave the way to several interesting developments and new applications.

Indeed, such a modeling tool is much needed, especially for interdisciplinary long-term studies, requiring a sufficient level of detail in economic data, like in the assessment of climate change policies and impacts. G-RDEM further eases such more focused applications, as it can be flexibly combined with specialized modules such as GTAP-AEZ, which depicts land use, or GTAP-E, for

more detail in the energy sector. Once a long-run scenario has been defined, counterfactual “what-if” experiments could then be conducted in the usual way, that is by exogenously changing some parameters in the system. In turn, these variations may regard “typical” simulation parameters, such as tax rates, or may directly simulate some structural change shocks, like the introduction of new technologies, not available or not diffused at the time when the structural parameters of the model were estimated.

We have contrasted findings from our model from those obtained by a more conventional CGE model, and we did this by forcing both models to follow a given trajectory of GDP levels, as defined by the IPCC SSP3 scenario. We noticed that this may have some relevant implications. For instance, the lower capital accumulation in G-RDEM has to be compensated by higher total factor productivity, to keep up with the GDP growth. It should be noticed, however, that this is only one among the many possible ways that external information can drive the two models. One alternative, for example, could have been adopting the same TFP trajectory, rather than the same GDP.

It is possible to switch “on” or “off” each one of the five “special structural change features” of the G-RDEM model. Indeed, we have also run the model with only one module active at a time, in order to verify the contribution of each of the five mechanisms to the overall results. We found no dominant effect. Some forces shape the global outcomes, some others produce implications which are most relevant at the regional or industrial scale. Other effects may also critically depend on some closure assumptions, or implementation details.

References

- Akgul, Z., Villoria, N. B., and Hertel, T. W. (2016). Gtap-het: Introducing firm heterogeneity into the gtap model. *Journal of Global Economic Analysis*, 1(1):111–180.
- Arrow, K. J. (1959). *A time series analysis of interindustry demands*, volume 17. North-Holland Publ.
- Baumol, W. J. (1986). Productivity Growth, Convergence and Welfare: What the Long-Run Data Show. *The American Economic Review*, 76(5):1072–1085.
- Bernard, A. B. and Jones, C. I. (1996). Comparing Apples to Oranges : Productivity Convergence and Measurement Across Industries and Countries. *American Economic Review*, 86(5):1216–1238.
- Britz, W. and Roson, R. (2018). G-rdem: A gtap-based recursive dynamic cge model for long-term baseline generation and analysis. *Ca’Foscari University Dept. of Economics Working Paper 11/2018*.
- Brockmeier, M. (2001). A graphical exposition of the gtap model. *GTAP Technical Papers*, page 5.

- Buera, F. J., Kaboski, J. P., and Rogerson, R. (2015). Skill Biased Structural Change. *NBER Working Paper*, 21165.
- Burniaux, J.-M. and Truong, T. P. (2002). Gtap-e: an energy-environmental version of the gtap model.
- Calzadilla, A., Rehdanz, K., Tol, R. S., et al. (2011). The gtap-w model: Accounting for water use in agriculture. Technical report, Kiel Working Paper.
- Caron, J. and Markusen, J. R. (2014). International Trade Puzzles: a Solution Linking Production and Preferences. *The Quarterly Journal of Economics*, pages 1501–1552.
- Casler, S. D., Afrasiabi, A., and McCauley, M. (1991). Decomposing change in energy input-output coefficients. *Resources and energy*, 13(1):95–109.
- Castellacci, F., Los, B., and de Vries, G. J. (2014). Sectoral productivity trends: convergence islands in oceans of non-convergence. *Journal of Evolutionary Economics*, 24:983–1007.
- Chen, S., Jefferson, G. H., and Zhang, J. (2011). Structural change, productivity growth and industrial transformation in China. *China Economic Review*, 22(1):133–150.
- Comin, D. A., Lashkari, D., and Mestieri, M. (2015). Structural Change with Long-run Income and Price Effects. *National Bureau of Economic Research Working Paper Series*, No. 21595.
- Corong, E. L., Hertel, T. W., McDougall, R., Tsigas, M. E., and van der Mensbrugghe, D. (2017). The standard gtap model, version 7. *Journal of Global Economic Analysis*, 2(1):1–119.
- Cranfield, J. A. L. (1999). *Aggregating non-linear consumer demands: A maximum entropy approach*. PhD thesis, Purdue University.
- de Vries, G., Timmer, M., and de Vries, K. (2015). Patterns of structural change in developing countries. In Weiss, J. and Tribe, M., editors, *Routledge Handbook of Industry and Development*, pages 65–83. Routledge.
- Dellink, R., Chateau, J., Lanzi, E., and Magné, B. (2017). Long-term economic growth projections in the shared socioeconomic pathways. *Global Environmental Change*, 42:200–214.
- Doshi, K. (1994). Determinants of the saving rate: an international comparison. *Contemporary Economic Policy*, 12(1):37–45.
- Duarte, M. and Restuccia, D. (2010). The role of the structural transformation in aggregate productivity. *The Quarterly Journal of Economics*, 125:129–173.

- Fagerberg, J. (2000). Technological progress, structural change and productivity growth: a comparative study. *Structural Change and Economic Dynamics*, 11(4):393–411.
- Fieler, A. C. (2011). Nonhomotheticity and Bilateral Trade: Evidence and a Quantitative Explanation. *Econometrica*, 79(4):1069–1101.
- Francois, J. (1998). Scale economies and imperfect competition in the gtap model.
- Griffith, R., Redding, S., and Reenen, J. V. (2004). Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries. *The Review of Economics and Statistics*, 86(4):883–895.
- Hanoch, G. (1975). Production and demand models with direct or indirect implicit additivity. *Econometrica: Journal of the Econometric Society*, pages 395–419.
- Hansen, B. E. (2001). The New Econometrics of Structural Change: Dating Breaks in U.S. Labor productivity. *Journal of Economic Perspectives*, 15(4):117–128.
- Haraguchi, N., Cheng, C. F., and Smeets, E. (2017). The importance of manufacturing in economic development: Has this changed? *World Development*, 93:293–315.
- Harberger, A. C. (1998). A Vision of the Growth Process. *The American Economic Review*, 88(1):1–32.
- Hasegawa, T., Fujimori, S., Takahashi, K., and Masui, T. (2015). Scenarios for the risk of hunger in the twenty-first century using shared socioeconomic pathways. *Environmental Research Letters*, 10(1):014010.
- Hertel, T. W. (1997). *Global trade analysis: modeling and applications*. Cambridge university press.
- Hertel, T. W. and Tsigas, M. E. (1997). Structure of GTAP. In *Global Trade Analysis: Modeling and Applications*, pages 9–71.
- Ianchovichina, E. and Walmsley, T. L. (2012). *Dynamic modeling and applications for global economic analysis*. Cambridge University Press.
- ICP (2015). *Purchasing Power Parities and Real Expenditures of World Economics: A Comprehensive Report of the 2011 International Comparison Program*. World Bank, Washington, D.C.
- Israilevich, P. R., Hewings, G. J., Sonis, M., and Schindler, G. R. (1997). Forecasting structural change with a regional econometric input-output model. *Journal of Regional science*, 37(4):565–590.

- Itakura, K. and Hertel, T. (2001). A note on changes since gtap book model (version 2.2 a/gtap94). *Center for Global Trade Analysis, Purdue University, USA: Indiana*.
- Kirsanova, T. and Sefton, J. (2007). A comparison of national saving rates in the uk, us and italy. *European Economic Review*, 51(8):1998–2028.
- Lee, H.-L., Hertel, T. W., and Rose, S. (2009). An integrated global land use database for cge analysis of climate policy options. In *Economic analysis of land use in global climate change policy*, pages 92–108. Routledge.
- Loayza, N., Schmidt-Hebbel, K., and Servén, L. (2000). What drives private saving across the world? *Review of Economics and Statistics*, 82(2):165–181.
- Lutz, W., Butz, W. P., and Samir, K. e. (2017). *World Population & Human Capital in the Twenty-First Century: An Overview*. Oxford University Press.
- Masson, P. R., Bayoumi, T., and Samiei, H. (1998). International evidence on the determinants of private saving. *The World Bank Economic Review*, 12(3):483–501.
- Matsuyama, K. (2002). The Rise of Mass Consumption Societies. *Journal of Political Economy*, 110(5):1035–1070.
- Matsuyama, K. (2016). The Generalized Engel’s Law : In Search for A New Framework. Public lecture, Canon Institute for Global Studies.
- Matsuyama, K. (2017). Engel’s law in the global economy: Demand-induced patterns of structural change and trade across countries.
- McGilvray, J. and Simpson, D. (1969). Some tests of stability in interindustry coefficients. *Econometrica: Journal of Econometric Society*, pages 204–221.
- McMillan, M. and Rodrik, D. (2011). Globalization, Structural Change and Productivity Growth. *NBER Working Paper*, w17143.
- Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., Clarke, L., Dahe, Q., Dasgupta, P., et al. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change*. IPCC.
- Padilla-Pérez, R., Villarreal, F. G., et al. (2017). Structural change and productivity growth in mexico, 1990–2014. *Structural Change and Economic Dynamics*, 41:53–63.
- Peterson, E. (2006). Gtap-m: a gtap model and data base that incorporates domestic margins.
- Powell, A. A., McLaren, K. R., Pearson, K. R., and Rimmer, M. T. (2002). Cobb-Douglas Utility - Eventually! *CoPS Working Paper No. IP80*.

- Riahi, K., Grübler, A., and Nakicenovic, N. (2007). Scenarios of long-term socio-economic and environmental development under climate stabilization. *Technological Forecasting and Social Change*, 74(7):887–935.
- Riahi, K., Van Vuuren, D. P., Kriegler, E., Edmonds, J., O’Neill, B. C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., et al. (2017). The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview. *Global Environmental Change*, 42:153–168.
- Rimmer, M. T. and Powell, A. A. (1992). Demand Patterns across the Development Spectrum: Estimates for the AIDADS System. *CoPS Working Paper No. OP75*.
- Rodrik, D. (2016). Premature deindustrialization. *Journal of Economic Growth*, 21:1–33.
- Rose, A. (1995). Input-output economics and computable general equilibrium models. *Structural Change and Economic Dynamics*, 6:295–304.
- Roson, R. (2006). Introducing imperfect competition in cge models: technical aspects and implications. *Computational Economics*, 28(1):29–49.
- Roson, R. (2018). Understanding the global dynamics of sectoral labor productivity. *International Economics Letters*.
- Roson, R. and Damania, R. (2017). The macroeconomic impact of future water scarcity: An assessment of alternative scenarios. *Journal of Policy Modeling*, 39(6):1141–1162.
- Roson, R. and van der Mensbrugghe, D. (2018). Demand-driven structural change in general equilibrium models. In Perali, F. and Scandizzo, P. L., editors, *The New Generation of Computable General Equilibrium Models*. Springer.
- Sawyer, J. A. (1992). Forecasting with input–output matrices: are the coefficients stationary? *Economic Systems Research*, 4(4):325–348.
- Skolka, J. (1989). Input-output structural decomposition analysis for Austria. *Journal of Policy Modeling*, 11(1):45–66.
- Sorensen, B. A. (2001). Comparing Apples to Oranges : Productivity Convergence and Measurement across Industries and Countries: Comment. *The American Economic Review*, 91(4):1160–1167.
- Swaminathan, P. and Hertel, T. W. (1996). Introducing monopolistic competition into the gtap model. *GTAP Technical Paper*, 6.
- Swiecki, T. (2017). Determinants of structural change. *Review of Economic Dynamics*, 24:95–131.

- Teixeira, A. A. and Queirós, A. S. (2016). Economic growth, human capital and structural change: A dynamic panel data analysis. *Research Policy*, 45(8):1636–1648.
- Triplett, J. E. and Bosworth, B. P. (2003). Productivity Measurement Issues in Services Industries: Baumol’s Disease Has Been Cured. *Economic Policy*, (September):23–33.
- Triplett, J. E. and Bosworth, B. P. (2006). Productivity Measurement Issues in Services Industries: Baumol’s Disease Has Been Cured. *The new economy and beyond: Past, present, and future*, pages 34–71.
- Üngör, M. (2013). De-agriculturalization as a result of productivity growth in agriculture. *Economics Letters*, 119:141–145.
- van der Mensbrugghe, D. (2008). The environmental impact and sustainability applied general equilibrium (envisage) model. *The World Bank, January*.
- van der Mensbrugghe, D. (2017). The Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model: Version 10.01. Technical report, The Center for Global Trade Analysis, Purdue University.
- Van Vuuren, D. P., Kriegler, E., O’Neill, B. C., Ebi, K. L., Riahi, K., Carter, T. R., Edmonds, J., Hallegatte, S., Kram, T., Mathur, R., et al. (2014). A new scenario framework for climate change research: scenario matrix architecture. *Climatic Change*, 122(3):373–386.
- Vu, K. (2017). Structural change and economic growth: Empirical evidence and policy insights from asian economies. *Structural Change and Economic Dynamics*, 41:64–77.
- Young, A. (2014). Structural transformation, the mismeasurement of productivity growth, and the cost disease of services. *American Economic Review*, 104(11):3635–3667.