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Creating a GTAP baseline for 2014 to 2050 using shock-intensive simulations

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Shock-intensive simulations can be used to: update computable general equilibrium (CGE) databases; estimate trends in industry technologies and the preferences of households, governments and importers; and generate baselines that incorporate forecasts from organizations specializing in different aspects of economies. We demonstrate the shock-intensive methodology by applying it to the Global Trade Analysis Project (GTAP) model. We update a 2014 GTAP database to 2019 with data-driven shocks to an array of macro and energy variables and describe the simulated shifts in technologies and preferences. Then, starting from the updated database, we conduct baseline simulations for 2019 to 2030, 2030 to 2040 and 2040 to 2050 in which macro and energy variables are driven by forecasts from the International Monetary Fund (IMF), International Institute for Applied Systems Analysis (IIASA) and International Energy Agency (IEA). The simulations connect disjoint years (e.g. 2019 and 2030) and use a smooth-growth assumption for savings in each region to jump over intermediate years. Investors are given forward-looking expectations so that their simulated decisions in 2030, for example, are realistic in light of prospects for 2030 to 2040. Considerable space in the paper is devoted to explaining closure swaps for facilitating shock-intensive simulations.

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1. Introduction

Shock-intensive simulations are those with shocks to many variables. These simulations arise when computable general equilibrium (CGE) models are used to track history. Assume that we have a CGE model set up with a database for year t, and that we have data on movements between t and t+ τ in a variety of variables such as: industry outputs and inputs; sales of domestic and imported commodities to households, government, capital creation and exports; and various prices. In a

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shock-intensive CGE simulation, we can introduce these data as shocks. We could do this for two reasons. First, if year t is the latest year for which we have a comprehensive database for our CGE model, then we might want to produce a database for year t+τ that is consistent with everything that we know happened to the economy between t and t+τ. Second, we might want to use the results from a shock-intensive simulation to analyze movements for the period in technology and preference variables. Shock-intensive simulations also arise in baselines incorporating forecasts prepared by organizations specializing in different aspects of economies.

In this paper, we start with a shock-intensive simulation for 2014 to 2019 with a 57-industry/13-region version of GTAP 10.1. Our primary purpose is updating, but we also use the results to quantify trends in technologies and preferences. We chose 2019 as the latest normal year prior to COVID-19. Then we undertake three shock-intensive baseline simulations for the periods 2019 to 2030, 2030 to 2040, and 2040 to 2050.

In 2020, the Journal of Global Economic Analysis (JGEA) devoted a special issue to papers on baselines in global CGE modelling arising from a conference organized by the Organisation for Economic Co-operation and Development (OECD) and Global Trade Analysis Project (GTAP). The papers provide comprehensive descriptions of the treatments in baselines of: capital, labor, land and natural resources; technology and structural change; composition of household and public consumption; use of results from other models; energy transition; and trade and current account. The main contributions of our paper are in database updating, and the treatments of investment, capital, wealth and current accounts.

On each topic, the papers in the JGEA special issue conclude with recommendations for future research. This paper is in the spirit of the recommendation in Bekkers et al. (2020, p. 311) "to implement proper back-casting exercises or historical simulations" as a way of identifying the determinants of trade growth, and we support their acknowledgement of "the very important decision by the Center for Global Trade Analysis to provide multiple base years in their recent releases of the GTAP Data bases, as this will help the community to run the required back-casting exercises."[1]

The paper is organized as follows. Section 2 contains background theory on simulations connecting disjoint years. We describe how explicit modelling of intervening years can be avoided by a smooth-growth assumption for saving in each region and how we model forward-looking expectations for investors. Then we set out the standard long-run closure from which we make swaps in preparation for shock-intensive simulations. Many of the shocks in these

[1] Historical simulations have been used for decomposing trade growth in single country models, see for example Dixon et al. (2000) and Dixon and Rimmer (2016; 2017).

simulations are applied to naturally endogenous variables. Swapping these variables from endogenous to exogenous so that they can receive shocks requires corresponding swaps of naturally exogenous variables to endogenous. Sections 3 and 4 explain the swaps we made from the standard long-run closure set out in section 2 to facilitate the 2014-19 historical simulation and the three baseline simulations. Sections 5 and 6 discuss the historical and baseline results. Concluding remarks are in section 7.

We hope the paper is accessible to general readers who would like to know about shock-intensive simulations and what they can deliver. For these readers, we have given intuitive explanations of our closure swaps and results. In the supplementary material we provide an algebraic specification of the smooth-growth assumption for saving, and for our procedure for computing solutions with forward-looking expectations for investors.

For readers who would like to conduct shock-intensive GTAP simulations, the supplementary material includes zip files for our simulations and details on the data and forecasts used to set the shocks. However, a note of caution. Shock-intensive simulations require an enormous amount of work before worthwhile insights can be obtained, and even then, success cannot be guaranteed.

2. Background theory

Models such as GTAP can usually be thought of as large systems of equations in which the variables are for a *single* year, year t. These equations impose familiar conditions such as: demand equals supply for commodities and factors in year t; prices equal costs in year t; and demands by households in year t reflect income and prices in year t. Perhaps less familiar is the treatment of stock variables. We assume that capital at the end of year t equals capital at the start of year t after depreciation *plus* investment during year t. All of these are year t variables. Similarly, we assume that net foreign assets at the end of year t equal net foreign assets at the start of year t possibly revalued via exchange-rate movements *plus* the current account surplus for year t. Again, these are all year t variables. Stylistically, we can represent the model as:

$$F(X) = 0 \tag{1}$$

where

X is the vector of variables for year t (prices, quantities, technology variables, preference variables, start-of-year stocks and end-of-year stocks, etc.) and

F is a vector of functions (demand minus supply, prices minus costs, end-of-year stocks minus revalued start-of-year stocks minus relevant flows, etc.).

The number of variables is always greater than the number of equations, that is $n > m$ where n is the dimension of X and m is the dimension of F. To obtain a solution of (1) we need to set values for n-m exogenous variables.

The GEMPACK and GAMS solution methods used in most applications of GTAP require an initial solution, a value for the vector X that satisfies (1).[2] Initial solutions can be obtained from GTAP databases. In these solutions we can assume that most prices are one. Then balance conditions in the databases ensure that quantities demanded for commodities and factors equal quantities supplied, and that prices equal costs. Stock equations can be satisfied by deducing end-of-year values from start-of-year values appropriately depreciated or revalued plus flow values explicitly given in the databases.

In year-on-year simulations, we start with a solution for year 0 given by a GTAP database. This solution becomes the *initial* solution for year 1. We compute the *required* solution for year 1 by shocking the exogenous variables with movements from their values in the initial solution (their year 0 values) to their required values for year 1. The exogenous variables include start-of-year stocks. The shock for start-of-year capital, for example, in the year-1 computation is the difference in year 0 between end-of-year capital and start-of-year capital. By applying this shock in the year-1 simulation, we impose the condition that start-of-year capital in year 1 equals end-of-year capital in year 0. The initial solution in the year-2 computation is the final (required) year-1 solution, and so on.

2.1 Disjoint-year simulations

Rather than conduct year-on-year simulations, in this paper we reduce the computational load by jumping forward in multi-year steps: 2014 to 2019 in a single 5-year jump; 2019 to 2030 in a single 11-year jump, etc. The initial solution for 2019 is the solution for 2014; the initial solution for 2030 is the final solution for 2019, etc.[3] But there is a problem: end-of-year stock variables in the solution for year t do not reveal values for start-of year stock variables in year $t+\tau$ where $\tau > 1$.

So how do we set start-of-year stocks in a sequence of simulations connecting disjoint years such as 2014, 2019, 2030, etc.? How do we avoid explicit modelling of the accumulation processes for the years between t and $t+\tau$?

Our approach is to use a smooth-growth assumption applied to saving. This can be understood by an example. Assume that saving in each region in any year is modeled as a function of variables (e.g. income) in that year. Assume that the simulated value for saving in region r is 50 per cent greater in year $t+\tau$ than in year

[2] See Horridge et al. (2013).

[3] Part 2 of the supplementary material explains that using the year-t solution as the initial solution for year $t+\tau$ requires the use of a homotopy variable, see Zangwill and Garcia (1981). The use of homotopy variables in dynamic simulations connecting disjoint years was worked out by our colleague Mark Horridge about 30 years ago.

t. Under the smooth growth assumption: saving in year t+1 is saving in year t *times* $(1.50)^{(1/\tau)}$, saving in year t+2 is saving in year t *times* $(1.50)^{(2/\tau)}$, etc. From here, we can write equations into the model that work out accumulated savings for each region across years t to t+τ-1 as functions only of the region's saving in years t and t+τ: no values are required for intermediate years (details are in part 2 of the supplementary material). Accumulated savings inform start-of-year levels for regional wealth in year t+τ and also the start-of-year value for *global* capital in year t+τ. Start-of-year global capital for year t+τ is distributed to the regions via equalization of rates of return. Changes in a region's net foreign assets between the start of year t and the start of year t+τ can then be deduced by comparing the change across this period in the region's start-of-year capital with its savings accumulated from year t to year t+τ-1.

2.2. Forward-looking expectations for investors

As described in the 2020 special issue of JGEA, most baseline simulations with large-scale global CGE models are recursive dynamic, see Dellink et al. (2020). An exception is McKibbin and Wilcoxen (1999) who assume that some households make forward-looking decisions. Recursive dynamics reduce computational burden by allowing multi-period solutions to be derived one period at a time. However, with disjoint years non-recursive dynamics become more feasible.

In our baseline simulations, we assume that investors are forward-looking. In year t (e.g. 2040) they determine their investment for that year taking account of growth prospects between years t and t+τ (e.g. 2040 and 2050). In section 6 we show that forward-looking expectations are important when there are foreseeable changes in economic growth. For example, it is reasonable to suppose investors in China in 2040 will understand that demographic slowdown means capital growth between 2040 and 2050 will be slower than in earlier periods. Failing to take a forward-looking perspective in year t for the period t to t+τ can lead to investment projections for year t which are out of line with capital growth for the period t to t+τ.

With only a few periods to deal with, a simple iterative approach to forward-looking expectations works well. We start by conducting a recursive dynamic simulation in which investors form their expectations based on past events. Then we modify the specification of expectations for year t taking account of simulated capital growth between years t and t+τ, and again solve recursively. We continue this process until the simulated capital growth rates in the q+1th recursive dynamic simulation match those in the qth recursive dynamic simulation. Details are in part 3 of the supplementary material.

2.3. The standard long-run closure for simulations connecting disjoint years

A major challenge for shock-intensive simulations is setting up suitable closures. Chateau et al. (2020, p. 113) describe the problem as:

"a complex procedure, which includes: (i) the choice of the main desired characteristics (i.e. targets) a baseline should reproduce, since not everything can be represented, (ii) the choice of the potential calibration variable for each target, and (iii) a check that the resulting baseline from the CGE model has not unpleasant characteristics. If the latest fails, then step (ii) should be done again."

The targets in a historical simulation are observed movements in an array of variables. In baseline simulations the targets are trends from historical simulations and expert forecasts. In both historical and baseline simulations, the target variables can be naturally endogenous or naturally exogenous variables. By naturally endogenous or naturally exogenous we are referring to status of variables in the starting closure.

When a target variable is naturally endogenous, then we must choose the 'calibration' variable from among the naturally exogenous variables, that is, we must make a closure swap by moving the target variable *onto* the exogenous list and the calibration variable *off* the exogenous list.

For us, avoiding 'unpleasant characteristics' requires a step-by-step approach. As explained in sections 3 and 4, in each step of shock-intensive historical and baseline simulations, we adjust the closure and introduce shocks for a small subset of our targets. Then we conduct a simulation and check that it is producing satisfactory interpretable results. When we are happy with the results, we make further closure adjustments and introduce shocks for another subset of targets.

The step-by-step approach is necessary so that we can locate and rectify problems. If step *x* produces a satisfactory solution but step *x*+1 fails, then we can confine the search for the problem to the limited changes that were made between steps *x* and *x*+1. While Chateau et al. (2020) warn us that 'not everything can be represented', we have found that with the step-by-step approach a great deal *can* be represented.

The rest of this subsection is devoted to the starting closure, which we refer to as the standard long-run closure. We used this closure as the starting point for developing the closures for the 2014-19 historical simulation and for the three baseline simulations.

Familiar features of the standard long-run closure are:

(a) All technology, preference and tax-rate variables are exogenous.
(b) Population, employment, availability of land and other natural resources in each region are exogenous.
(c) The average propensities to consume by households and government out of net national product (NNP) are exogenous. This is sufficient to tie

down global saving in a year which in turn gives us global investment in the year.

(d) Exchange rates are exogenous, implicitly set to one, and all values are in $US. We say implicitly because, in common with most versions of the GTAP model, the version we use does not include exchange rates explicitly.

(e) The nominal value of global GDP is exogenous, providing the numeraire.

Less familiar features arise in the treatments of capital and savings accumulation between disjoint years. This requires a distinction between what happens *in* a simulation year and what happens *between* simulation years. In simulations under the standard long-run closure:

(f) Global investment in t is allocated across regions so that capital growth *in* t (from the start-of-year to the end-of-year) in region r reflects the region's capital growth rate over the subsequent period, t to t+τ. Why "reflects", why not "equals"? This is because we need to introduce an endogenous scalar adjustment to investments at the regional level to reconcile their sum with global investment, which was tied down in point (c) by global saving. As explained already, we require an iterative method to set the t to t+τ capital growth rates in the year t solution (see part 3 of the supplementary material).

(g) Accumulated savings in each region is deduced from a smooth-growth path for real saving between years t and t+τ. In solving the model for year t+τ, saving in region r in year t is part of the initial solution and saving in year t+τ is determined according to point (c). Thus, in the solution for year t+τ we can determine the value of r's accumulated savings from the start of year t to the start of year t+τ as a function of saving in years t and t+τ.

(h) Capital stocks at the start of t+τ in each industry and region are endogenous, and *relative* actual rates of return across industries and regions are exogenous. Capital used in industry j in region r in year t+τ is the start-of-year quantity. It is not affected by investment *in* year t+τ.

(i) *Absolute* actual rates of return are endogenous so that global capital accumulation between start-of-t and start-of- t+τ equals global accumulated savings for the same period. If simulated accumulated savings happened to be low, then absolute actual rates of return would be high, reflecting scarcity of capital and vice versa.

The treatment in our standard closure of a region's saving and investment in year t conforms with option one in Bekkers et al. (2020, p. 290): "… domestic savings and domestic investment are independently determined, so that the trade balance … must then follow." Our treatment of accumulated savings and capital between years t and t+τ allows the t+τ solution of the model to reveal each region's wealth and net foreign assets at the start of year t+τ, and its current account balance in year t+τ. As we will see in sections 4 and 6, keeping track of wealth and net foreign assets enables the model in baselines to adjust propensities to consume (or save) to avoid what Fouré et al. (2020, p. 36) describe as "implausible accumulation of foreign assets in countries like Japan where savings exceeds investment."

3. Setting up the 2014-19 historical simulation: updating the GTAP database

The step-by-step development of the 2014-19 historical simulation is set out in Table 1. We apply shocks to represent observed movements between these two years in some variables and introduce assumptions for others. The shocked variables can be seen in columns 2 and 3 of Table 1 and data sources supplying the shocks are indicated in column 4. Part 1 of the supplementary material discusses the data in more detail and gives precise sources.

Some of the shocked variables are exogenous in the standard long-run closure and shocks can be applied without a closure change. Other shocked variables are endogenous in the standard long-run closure. Applying shocks to these variables requires closure changes, indicated in columns 5 and 6.

The final simulation (panel 19) encompasses all the closure swaps and shocks in Table 1. The order in which the shocks are brought in does not affect the final result: there is no problem of path dependence. The shocks could be introduced in a different order. Our strategy in Table 1, and in historical simulations more generally, is macro to micro. But there are no fixed rules. All that is necessary is to produce interpretable checkable results at each step.

Because of our macro-to-micro strategy, shocks introduced in early steps of Table 1 are sometimes modified or removed in later steps. For example, in an early step the nominal value of global GDP (the numeraire) is shocked with its observed movement. Later on, we introduce observed movements in the regional prices of GDP, which ties down global nominal GDP as the sum of regional values. Global nominal GDP, a scalar, must now be endogenous and its shock removed. But what is the corresponding scalar variable that must be swapped from endogenous to exogenous? This is a tricky question. As shown in the discussion of Table 1, the step-by-step approach helps us find an answer to this and similar questions.

By the time we had implemented all 19 steps in Table 1, the 2014-19 simulation produced a database for 2019 that was consistent with data for each region on real GDP, its income and expenditure components, global prices and quantities for fossil fuels, prices in each region for expenditure components of GDP, and net foreign liabilities for each region.

This list is limited only by the availability of data and the time that researchers can devote to the job. In a historical simulation for 2004 to 2014, we used GTAP databases for both years, enabling us to include final demands and intermediate use in each region disaggregated by commodity and domestic/imported (see Dixon and Rimmer (2023a)). We also used a preliminary version of the GTAP database for 2017 in a historical simulation from 2014 to 2017 but concluded that the 2017 database was not sufficiently comparable to the 2014 database to provide reliable movements between the two years in disaggregated variables (see Dixon and Rimmer (2023b)). Subsequently, the GTAP team revised the 2017 database. Revisiting the 2014-17 simulation would be worthwhile if the opportunity arose.

Table 1. Shocked variables and closure swaps for the 2014-19 simulation.

Panel no (1)	Exo variable (2)	Description (3)	Source for shock (4)	Swap *(goes endo)* (5)	Description (6)
1	*qgdp_obs(r)*	Real GDP	OECD data	*afereg(r)*	Primary factor tech change by region
	wgdpg	Global nominal GDP	OECD data	No swap	
2	*kb_obs(r)*	Observed capital in r	Penn data, real capital services	*f_rorc(r)*	Shift in rate of return in all industries in r
	ff_rorc	Shift in global rate of return	Zero shock	*shift_kb*	Uniform correction of regional capital growth to reconcile global capital growth and accumulated savings
3	*lsreg(r)*	Employment, same as labor supply	ILO data on working age population	No swap	
	pop(r)	Population	IMF data	No swap	
4	*qo(land,r)*	Supply of land	Zero shock	No swap	
5	*pm(natres,r)*	Price of natural resources	Assumed shock, -5.26%	*qo (natres,r)*	Use of natural resources
6	*twistKL(r)*	K/L technology twist	Extrapolate, 2004-14	No swap	
7	*cr(r)*	Real private consumption	OECD data	*apcnnp(r)*	Average Hhld propensity to consume out of net national product (NNP)
8	*gr(r)*	Real govt. consumption	OECD data	*dpgov(r)*	Average Govt propensity to consume

(Continued…)

Table 1. Shocked variables and closure swaps for the 2014-19 simulation. (…Continued)

Panel no (1)	Exo variable (2)	Description (3)	Source for shock (4)	Swap *(goes endo)* (5)	Description (6)
9	*qcgds(r)*	Real investment	OECD data	*f_ke(r)*	Disconnects investment by region from forward-looking capital growth
	ff_ke	Must now be exo to avoid indeterminacy with *f_ke(r)*	Zero shock	*f_qgdp_obs*	Scalar correction to observations for real GDP to reconcile global real expenditure (C+I+G) with global real GDP
10	*impvol(r)*	Real imports	OECD data	*twist_src_i(r)*	Domestic–import preference twist
11	*expvol_obs (r)*	Real exports	OECD data	*ff_qgdp_obs(r)*	Correction to regional GDP observations, reconciling to expenditure-side GDP
	f_qgdp_obs	Scalar GDP correction from panel 9 reset to zero	Zero shock	*f_expvol_obs*	Scalar correction to observations for real exports by region to reconcile global real exports with global real imports
12	*qworld(Foss)*	World output of coal, oil and gas	Our World in Data, energy	*wldout_sh(Foss)*	World-wide demand shifts in favour or against coal, oil and gas
	f_neut(j,r)	Neutralizes fossil fuel saving	Zero shock	*a_neut (j,r)*	Technical change to offset fossil-fuel saving tech change
13	*pworld(Foss)*	World prices of coal, oil and gas	World Bank and Saudi Arabia statistics	*ff_pworld(Foss)*	Turns off (13) to avoid over determination of *pworld(c)* for $c \in Foss$
	ff_pm (Foss,r)	Equates fossil fuel market prices across regions	Zero shock	*f_to (Foss,r)*	Phantom taxes to adjust fossil fuel costs

(Continued…)

Table 1. Shocked variables and closure swaps for the 2014-19 simulation. (…Continued)

Panel no (1)	Exo variable (2)	Description (3)	Source for shock (4)	Swap *(goes endo)* (5)	Description (6)
14	*f_pgdp_obs (r)*	Connects GDP price to observation	Zero shock	*f3_twistmd(r)*	World-wide preference shift towards/against exports from r
	pgdp_obs(r)	Price of GDP, observed	OECD data	No swap	
	f3twmd_ave	Ave pref shift across world	Zero shock	*wgdpg*	Value of global GDP
15	*f_p_i_obs(r)*, all r, except RoW	Connects investment price to observation	Zero shock	*a_cgds (r)*, all r, except RoW	Technical change in production of capital goods
	p_i_obs(r)	Price of investment, obs	OECD data	No swap	
16	*f_p_x_obs(r)*, all r, except RoW	Connects export price to observation	Zero shock	*phtx_i(r)*, all r, except RoW	Phantom tax on exports from r (excludes RoW)
	p_x_obs	Price of exports, obs	OECD data	No swap	
17	*f_p_m_obs (r)*, all r, except RoW	Connects import price to observation	Zero shock	*phtx_i2(r)*, all r, except RoW	Discriminatory tax on all exports sent to r, except RoW
	p_m_obs	Price of imports, obs	OECD data	No swap	
	d_rcolt_phtx_i2	Global real collection of revenue from discriminatory export taxes	Zero shock	*phtx_i2(RoW)*	Discriminatory tax on all exports sent to RoW

(Continued…)

Table 1. Shocked variables and closure swaps for the 2014-19 simulation. (…Continued)

Panel no (1)	Exo variable (2)	Description (3)	Source for shock (4)	Swap *(goes endo)* (5)	Description (6)
18	*d_tottaxf(r)*	Total collection of phantom export and production taxes	Zero shock	*f_tofr(r)*	Uniform shift in phantom rate of production tax across the industries in region r
19	*d_netflt(r),* for all r except RoW	Net foreign liabilities	IMF data	*d_swqh_b (r),* for all r except RoW	Disconnects growth in wealth from accumulated savings

3.1. Real GDP and supply-side determinants, panels 1-6 in Table 1

Panel 1: real GDP. In going from the standard long-run closure to the historical closure, we exogenized real GDP for each region. This enabled us to introduce OECD data on GDP movements between 2014 and 2019. The closure swap is to endogenize total primary-factor productivity in each region, *afereg(r)*.

How do we know that *afereg(r)* is the right variable to endogenize? As we move from step to step, there is no clear mathematically precise way of choosing the variables to be endogenized. In making choices, we are guided by back-of-the-envelope representations of relevant parts of the general equilibrium model. In the case of real GDP, our guiding back-of-the envelope framework is the aggregate production function:

$$RealGDP(r) = A(r) * F_r(L(r), K(r), Land(r), NatRes(r)) \qquad (2)$$

where

RealGDP(r) is real GDP in r;

A(r) is primary-factor-saving technology in region r; and

L(r), K(r), Land(r) and *NatRes(r)* are the inputs to production in region r of labor, capital, land, and natural resources.

At this stage in the transition from the standard long-run closure to the 2014-19 historical closure, employment and the use of land and natural resources are exogenous (see point (b) in section 2.3). Capital in each region is tied down by our assumptions for relative rates of return and accumulated global savings from start-of-2014 to start-of-2019 (points (g), (h) and (i)). Thus, with exogenization of *RealGDP(r)*, our model can generate a solution for primary-factor productivity growth in each region, *afereg(r)* (the percentage change in *A(r)* in (2)). This is not our final estimate of *afereg(r)*. As further information is introduced into the historical simulation, *afereg(r)* remains endogenous so that our estimate of it is continuously refined.

Together with the shocks to real GDP by region, OECD data also provided the shock for the numeraire - nominal global GDP. This was cosmetic. With this shock, the simulations at each step generated results with recognizable *values* for GDP and other macro variables.

Panel 2: regional capital stocks. Here we introduced Penn World data on movements between start-of-2014 and start-of-2019 in capital stocks by region (measured by real capital services). This required an endogenous scalar adjustment to the Penn regional data so that global growth in capital from start-of-2014 to start-of-2019 is compatible with simulated accumulated global savings over this period in accordance with points (g) and (i). To make the endogenous adjustment, we added the following equation to our GTAP model:

$$kb(r) = kb\_obs(r) + shift\_kb \; for \; r \in Reg \qquad (3)$$

where

kb(r) is simulated percentage growth in start-of-year capital stock for region r from 2014 to 2019;

kb_obs(r) is the observed percentage growth in capital stock for region r; and

shift_kb is a global shift variable that adjusts the simulated results for all regions by an equal percentage.

In the standard long-run closure, *kb(r)* and *kb_obs(r)* are endogenous and *shift_kb* is exogenous. With this setup, *kb(r)* is determined in the rest of the model and (3) merely determines *kb_obs(r)* as a repeat of *kb(r)*. To include the Penn data in the 2014-19 simulation, we endogenized *kb_obs(r)* and shocked it with the observed movements. Then to achieve the reconciliation between global growth in capital and accumulated savings, we endogenized the scalar adjustment, *shift_kb*. Fortunately, the adjustment was small, indicating a high degree of compatibility between simulated accumulated global savings and the Penn capital data.

With start-of-year capital stocks by region for 2019 in place, we must free up rates of return so that they can reflect the scarcity of capital in each region. We did this via:

$$rorc\_i(j,r) = f\_rorc(r) + ff\_rorc \qquad for\ all\ j \in Ind,\ r \in Reg \qquad (4)$$

where

rorc_i(j,r) is the simulated percentage change in the actual rate of return in industry j in region r between 2014 and 2019; and

f_rorc(r) and *ff_rorc* are shift variables.

In the standard long-run closure, *f_rorc(r)* is exogenous and *ff_rorc* is endogenous. In accordance with points (h) and (i), this means that rates of return move endogenously by the same percentage in all industries and regions. In the 2014-2019 historical closure, we endogenized *f_rorc(r)* and exogenized *ff_rorc*, allowing rates of return to vary across regions, but not across industries within a region.

Panel 3: employment and population. Employment and population are exogenous in the standard closure. Consequently, introduction of data on their growth between 2014 and 2019 does not require closure swaps. As indicated in Table 1 (column 4, panel 3), in the 2014-19 historical simulation we shocked these variables with percentage movements between 2014 and 2019 derived from International Labour Organization (ILO) and International Monetary Fund (IMF) data.

Panel 4: land. In the GTAP model, land is used as an input to agriculture. While the model allows for endogenous reallocation of land between agricultural industries, the economy-wide availability is normally exogenous. We adopt this treatment in the standard long-run closure and also in the 2014-19 historical closure. In the 2014-19 simulation, we assumed no change in land-availability by region between 2014 and 2019.

Panel 5: natural resources. GTAP data for 2014 shows that about 80 per cent of the returns to natural resources are in coal, oil and gas. In the standard long-run closure, the treatment of natural resources is similar to that of land. In the closure for the 2014-19 historical simulation, we treated natural resources as elastically supplied at exogenously given user prices. This required endogenization of supplies of natural resources, *qo(natres,r)*, and exogenization of rental or user prices, *pm(natres,r)*. With this treatment, we assume that the intensity with which natural resources are used in the production of coal, oil and gas adjusts to demand conditions. The shock that we applied to the rental price of natural resources in each region, -5.26 per cent, reflects the change between 2014 and 2019 in the average $US price of global GDP. However, this shock is of little importance. In panel 13, we will introduce data on movements in prices of coal, oil and gas. These overrule the -5.26 per cent assumption in the determination of the prices of these energy commodities, and endogenize profitability per unit of their production.

Our treatment of natural resources is not ideal for the other natural-resource-using industries: Mining, Fishing and Forestry. Better modelling will be required to produce reliable results for these industries.

Panel 6: Twists in capital-labor technology. The data introduced in panels 2 and 3 implies very large increases in capital/labor ratios (K/L) in all regions between 2014 and 2019. We also observed very large K/L increases in a historical simulation for 2004-14 (Dixon and Rimmer, 2023a). Large K/L increases suggest that technical change must be biased in favor of using capital. In our 2004-14 simulation, we estimated the bias for each region by introducing data on the earnings of capital and labor. For 2014-19, we did not have earnings data. In these circumstances, we introduced capital-using technology bias by extrapolating the bias for each region estimated for 2004-14. We did this by applying shocks, extrapolated from 2004-14, to the variable *twistKL(r)* for all r.

A movement in *twistKL(r)* of *x* per cent causes all industries in region r to increase their capital/labor ratio by *x* per cent beyond what can be explained by movements in the costs of using capital and labor. We made the technology changes imposed through *twistKL(r)* cost neutral for each industry j in region r: an increase in (j,r)'s use of K is offset by a compensating reduction in its use of L. By adopting cost-neutral technology changes, we avoided indeterminacy between the roles of the technology changes in this panel and the technology changes introduced to absorb real GDP data in panel 1.

3.2. Real GDP from the expenditure side (C, G, I, X and M), panels 7-11

Panels 7 and 8: real private and public consumption. In the standard long-run closure, these variables are linked to NNP (point (c) in section 2.3). We break these links in the 2014-19 simulations by endogenizing the private and public consumption propensities. This allows the movements in real private and government consumption to be set exogenously and shocked with their actual movements between 2014 and 2019.

Panel 9: real investment. The starting point for explaining the introduction of data on movements in real investment into the 2014-19 historical simulation is the equation:

$$ke(r) - kb(r) = g(r) + ff\_ke + f\_ke(r) \quad for\ all\ r \tag{5}$$

In this equation

ke(r) is the percentage growth in region r's end-of-year capital. In our 2014-19 simulation, this is growth from end-of-2014 to end-of-2019.

kb(r) is the percentage growth in region r's start-of-year capital, growth from start-of-2014 to start-of-2019.

g(r) is an exogenous variable introducing forward-looking expectations. Its value is set in an iterative process and represents average annual capital growth in region r in the next period. In the 2014-19 simulation, this is average annual capital growth from the start of 2019 to the start of 2030.

ff_ke and *f_ke(r)* are shift variables.

The LHS of (5) is the percentage change in the ratio of r's end-of-year capital to start-of-year capital. In the 2014-19 simulation, this ties down the percentage change in investment in r, the level in 2019 compared with the level in 2014. In the standard long-run closure, *f_ke(r)* is exogenous and unshocked, and the scalar variable *ff_ke* is endogenous. With this set up, growth in investment in region r is determined by future expectations of capital growth encapsulated in the shock to *g(r)*. The endogenous variable *ff_ke* moves in a way that reconciles global investment (in 2019) with global saving (in 2019).

In the 2014-19 historical simulation, we endogenized *f_ke(r)* and exogenized *ff_ke*. This left *f_ke(r)* free to adjust in a way that moved r's end-of-year/start-of-year capital ratio to the level compatible with the observed percentage change in investment (*qcgds(r)*) in r.

The variables *ff_ke* and *f_ke(r)* have no role in any equation apart from (5). By using endogenous movements in the *f_ke(r)*s to accommodate observed investment movements, we had no choice but to exogenize *ff_ke*. Otherwise there would be an indeterminacy in endogenously determining the values of *ff_ke* and the *f_ke(r)*s. However, exogenizing *ff_ke* left us with a puzzling problem. What is the corresponding endogenization?

The answer can be found in the identity:

$$\sum_r Z_{gdp}(r) * qgdp(r) = \sum_r Z_c(r) * cr(r) + \sum_r Z_g(r) * gr(r) + \sum_r Z_i(r) * qcgds(r) \tag{6}$$

In (6) the LHS is the percentage change in world real GDP calculated as a weighted average of the percentage changes in the real GDPs of the regions. The weights, $Z_{gdp}(r)$, are regional shares in world GDP. The RHS of (6) is the percentage change in world real GDP calculated as a weighted sum over all regions in the percentage changes in real private consumption, real government consumption and real investment. The weights, $Z_c(r)$, $Z_g(r)$, and $Z_i(r)$, are the shares in world GDP of private consumption, government consumption and investment in region r. In calculating world real GDP this way, we use the fact that world exports add up to world imports.

With the data introduced in panels 7 and 8 and in this panel, the RHS of (6) is known. With the introduction of the GDP data in panel 1, the LHS is known. Consequently, to avoid over-determination, we must backtrack and free up a scalar variable relevant to (6) to be determined endogenously. To do this we added the equation

$$qgdp\_obs(r) = qgdp(r) + f\_gdp\_obs + ff\_gdp\_obs(r) \tag{7}$$

We can think of the two shift variables on the RHS of (7) as being exogenous and unshocked through panels 1 to 8. The shocks to *qgdp_obs(r)* introduced in panel 1 simply set the movements in real GDP in each region. Now we endogenize the scalar shifter, *f_gdp_obs*. This introduces a uniform adjustment across the GDP observations, allowing (6) to be satisfied. In our simulation, the result for *f_gdp_obs* was small, indicating almost no tension between the OECD data on regional movements in GDP, C, I and G and the GTAP shares used to aggregate these movements to the world level in (6).

Panel 10: imports. To accommodate observations of percentage movements in aggregate imports for each region (*impvol(r)*), we added import-domestic twist variables to GTAP's Armington specification of choice between domestic and imported varieties. With this addition, we obtained equations of the form:

$$\begin{aligned} qm_a(j,r) &= q_a(j,r) + \{\text{price terms}\} \\ &\quad + SHRD_a(j,r) * twist\_src\_i(r) \\ qd_a(j,r) &= q_a(j,r) + \{\text{price terms}\} \\ &\quad - SHRM_a(j,r) * twist\_src\_i(r) \end{aligned} \tag{8}$$

where

qm$_a$*(j,r)* and *qd*$_a$*(j,r)* are the percentage changes in use by agent a (households, government and firms) of imported and domestic commodity j in region r;

q$_a$*(j,r)* is the percentage change in use of composite j in region r by agent a;

the terms in the brackets provide the usual GTAP specifications of price-induced import/domestic substitution;

twist_src_i(r) is a preference variable allowing shifts in import/domestic ratios beyond those that can be explained by price movements; and

SHRM$_a$*(j,r)* and *SHRD*$_a$*(j,r)* are shares of imported and domestic j in expenditure on composite j by agent a in region r.

In the standard long-run closure, *twist_src_i(r)* is exogenous. In the 2014-19 historical simulation, we accommodated observed movements in the quantities of imports by endogenous movements in *twist_src_i(r)*. The share coefficients attached to the twist terms in (8) and (9) preserve the condition that the share-weighted average of the percentage changes in the use of imported and domestic commodity j by agent a in region r equals the percentage change in the agent's use of composite j.

Panel 11: exports, making real GDP in each region the residual rather than exports. In panel 1, we used OECD income-side estimates of movements in real GDP. These were slightly modified in panel 9. With the completion of the first 10 panels, simulated exports in each region are determined as a residual: GDP *less* C, G, I *plus* M. This means that simulated exports, a relatively small component of GDP, reflect not only OECD observed exports, but also statistical discrepancies at the regional level between OECD income-side GDP movements and expenditure-side movements.

In this panel we overrule the residually determined export movements. We replace them with the observed movements (*expvol_obs(r)*) from the OECD. With C, I, G, X and M now given, we must endogenize GDP movements in each region. As can be seen in panel 11, we do this by endogenizing the vector shifter in (7) and exogenizing the scalar shifter. In effect, we switch to the expenditure-side OECD measure of GDP.

But when we exogenize the scalar shifter (*f_qgdp_obs*) what should we endogenize? The answer is that we must introduce a scalar adjustment of the export observations across all regions to allow world exports to equal world imports. This is the variable *f_expvol_obs* in the equation

$$expvol\_obs(r) = expvol(r) + \quad f\_expvol\_obs \qquad (9)$$

As shown in column 5 of panel 11, *f_expvol_obs* swaps with *f_gdp_obs*. Fortunately, our result for *f_expvol_obs* was small, indicating almost no tension between our data for aggregate world exports and imports.

3.3. World prices and quantities for fossil fuels, panels 12 and 13

Panel 12: world quantities of fossil fuels. In this panel we bring in data on percentage movements in world output of coal, oil and gas. These are the commodities in the set *Foss*.

Most of the demand for these commodities is intermediate, mainly in the petroleum and coal products and electricity industries. Consequently, we will explain how we modified the GTAP specification of intermediate demands to absorb data on world outputs of coal, oil and gas. We made similar modifications to the specifications of demands by households and governments.

The key equations in our explanation are:

$$q_f(c,j,r) = \{\textit{activity and price terms}\} + wldout\_sh(c) - FOSS(c) * a\_neut(j,r) \tag{10}$$

$$\left[\sum_{c \in NonFoss} SC(c,j,r)\right] * a\_neut(j,r) = \sum_{c \in Foss} SC(c,j,r) * wldout\_sh(c) + f\_neut(j,r) \ for\ j \in Ind, r \in Reg \tag{11}$$

Equation (10) is a stylized version of the GTAP equation for demand by industry j in region r for input c (includes both intermediate and primary factors), but with two additional technology terms. The first of these, *wldout_sh(c)*, can be used to introduce a uniform percentage change in demand for input c by all industries j in all regions r. In the second term, *FOSS(c)* is a parameter with value zero for $c \in Foss$ and one for $c \in NonFoss$. The variable *a_neut(j,r)* can be used to introduce a uniform percentage change across all inputs to industry j in region r excluding coal, oil and gas.

In (11), *SC(c,j,r)* is the share of costs in industry j in region r accounted for by inputs of c. Thus, the LHS of (11) is the percentage reduction in j,r's costs from the movement in *a_neut(j,r)*. The first term on the RHS is the effect on j,r's costs of movements in *wldout_sh(c)* for $c \in Foss$. The second term on the RHS is a shift variable.

In the standard closure, *wldout_sh(c)* and *a_neut(j,r)* are exogenous and unshocked. World outputs (*qworld(foss)*) of fossil fuels and *f_neut(j,t)* are endogenous. As indicated in panel 12 of Table 1, we made two closure changes to accommodate the introduction of data on world outputs of coal, oil and gas. First, we exogenized the percentage movements in the world outputs of these commodities and endogenized the technology variable *wldout_sh(Foss)*. This allowed worldwide demands to adjust to equal observed world outputs. Second, we exogenized *f_neut(j,r)* and endogenized the technology variable *a_neut(j,r)*. This had the effect of cost-neutralizing the fossil-fuel technology variables *wldout_sh(Foss)* for fossil-fuel-using industries. For example, if *wldout_sh(coal)* is negative, indicating a reduction in the use of coal per unit of output in coal-using industries, then we assume that the coal-related cost savings are offset by increases in the use of all non-fossil inputs.

Panel 13: world prices of fossil fuels. This panel allows us to move the price of each fossil fuel in each region in line with data on observed movements in its world price. The closure changes required to accommodate the data can be explained via:

$$pm(c,r) = pworld(c) + ff\_pm(c,r) \quad for\ c \in Com, r \in Reg \tag{12}$$

$$pworld(c) = \sum_{r \in REG} S_{wld}(c,r) * pm(c,r) + ff\_pworld(c) \quad for\ c \in Com \tag{13}$$

$$pm(c,r) = ps(c,r) - to(c,r) \quad for\ c \in Com, r \in Reg \tag{14}$$

$$to(c,r) = to\_wld(c) + f\_to(c,r) \quad for\ c \in Com, r \in Reg \tag{15}$$

In these equations,

pm(c,r) is the percentage change in the market price (factory-door price) of commodity c in region r.

pworld(c) can usually be interpreted as the world price of c. If the shifter *ff_pworld(c)* in (13) is on zero, then *pworld(c)* is a weighted average of movements in regional market prices with the weights (S_{wld}(c,r)) being the shares of each region in the market value of world output.

ff_pm(c,r) is the percentage change in the ratio of the market price of c in r to the world price of c.

ps(c,r) is the supply price of commodity c in region r. This is the percentage change in the cost of inputs per unit of output.

to(c,r) is the power of the subsidy applying to the production of c in r. Thus, (14) imposes the zero profits condition: the market price is costs less production subsidies.

to_wld(c) and *f_to(c,r)* are shifters that can be used to impose uniform changes across regions in the subsidies applying to the production of commodity c and changes specific to particular regions.

In the standard long-run closure, *ff_pworld(c), to_wld(c)* and *f_to(c,r)* are exogenous while the other variables in (12) - (15) are endogenous. In the 2014-19 historical simulation, we exogenised *pworld(c)* for c = coal, oil and gas and applied shocks representing observed movements in world prices. With *pworld(c)* exogenous, we needed to turn off its determination in (13) by endogenizing *ff_pworld(c)*. Next, we exogenized *ff_pm(c,r)* for c = coal, oil and gas and gave zero shocks. This equated regional movements in the market prices of coal, oil and gas to those in world prices. To reconcile market prices determined this way with supply prices and subsidies, we allowed subsidies to adjust via endogenous movements in *f_to(c,r)* for c = coal, oil and gas. These are phantom subsidies and can be interpreted as changes in the profitability of production.

3.4. Prices of GDP and selected expenditure components, panels 14-18

Panel 14: regional price indexes for GDP. OECD supplies movements in the price deflators for GDP in all regions. We bring these into the 2014-19 simulation via the equation

$$pgdp\_obs(r) = pgdp(r) + f\_pgdp\_obs(r) \quad for\ r \in Reg \qquad (16)$$

In the standard closure, *pgdp_obs(r)* is exogenous and *pgdp(r)* is determined elsewhere in the model. The equation is effectively turned off because *f_pgdp_obs(r)* is endogenous. In the 2014-19 simulation, we shock *pgdp_obs(r)* with observed movements and exogenize *f_pgdp_obs(r)*. This forces the simulated movements (*pgdp(r)*) to follow the OECD data.

In the GTAP model, the movement in the GDP price deflator for region r reflects the region's real exchange rate or international competitiveness. An increase in r's GDP price deflator relative to that of its trading partners is a real appreciation, corresponding to a loss of international competitiveness. In panel 11, we introduced data on movements in the volume of region r's exports. To allow the model to explain how region r can export the observed volume at the observed real exchange rate, we endogenized a preference variable, *f3_twistmd(r)*, by importing agents for commodities from r.

Observed rapid growth in exports from region r (a large value for *expvol_obs(r)*) relative to what would be expected on the basis of the real exchange rate movement, is accommodated by a positive value for *f3_twistmd(r)*. This causes importers in every region to buy more from r, and less from other regions.

We set the average (*f3twmd_ave*) of the preference twists (the average of *f3_twistmd(r)* over r with export weights) exogenously at zero. This is because preferences are relative: the twists recognize that if preferences worldwide by importers are moving in favor of some exporting regions, then they must be moving against other exporting regions.

With the prices of GDP by region now given and the quantities of GDP also given (via panels 1, 9 and 11), we have tied down nominal GDP in each region. Thus, nominal global GDP is tied down. Recall from point (e) in section 2.3 that in the standard long-run closure, nominal global GDP is exogenous, providing the numeraire. Now, nominal global GDP must be endogenous. This endogenization corresponds to the exogenization of *f3twmd_ave*.

Panel 15: regional price indexes for investment. In the GTAP model, investment in each region is the output of the capital-goods industry (the *cgds* industry). Like all other industries, the *cgds* industry operates under zero pure profits. That is, its market price reflects costs per unit of output and subsidies.

From OECD data, we observe percentage movements in investment price indexes between 2014 and 2019 in all regions except Rest of World (RoW). We interpret these as movements in the market price of regional *cgds* industries. In the 2014-19 simulation, we exogenized *f_p_i_obs(r)* on zero for all regions except RoW in the equation

$$p\_i\_obs(r) = pcgds(r) + f\_p\_i\_obs(r) \quad for\ r \in Reg \tag{17}$$

This allowed us to drive the simulated market price (*pcgds(r)*) for the *cgds* industry in region r by the observed movement (*p_i_obs(r)*). With *cgds* prices tied down, we endogenized productivity (*a_cgds(r)*) in *cgds* industries.

Panel 16: regional export-price indexes. In the standard closure, export prices are determined by costs. From OECD data, we observe movements in aggregate export prices for all regions except RoW. In the 2014-19 simulation, we use these data via the equation

$$p\_x\_obs(r) = psw(r) + f\_p\_x\_obs(r) \quad for\ r \in Reg \tag{18}$$

In this equation, we exogenize *f_p_x_obs(r)* on zero in all r except RoW and shock *p_x_obs(r)* with observed export price movements, forcing simulated export price movements (*psw(r)*) to reflect observed movements. Correspondingly, we endogenize a phantom export tax (*phtx_i(r)* for all r except RoW). This separates export prices from costs. Possible interpretations of these phantom taxes are discussed in section 5.4.

Panel 17: regional import-price indexes. To a large extent, a region's cif import prices are determined by the fob export prices of its trade partners. Consequently, having put in place export prices in panel 16, we expected import prices to be accurately tied down. However, our simulations to the end of panel 16 generated regional import price movements for 2014 to 2019 that were only broadly consistent with the movements in OECD data.

We imposed OECD import-price movements for all regions except RoW, for which there were no data, via the equation

$$p\_m\_obs(r) = piwreg(r) + f\_p\_m\_obs(r) \quad for\ r \in Reg \tag{19}$$

In this equation, we exogenized *f_p_m_obs(r)* on zero for all r except RoW and shocked *p_m_obs(r)*, forcing simulated import price movements (*piwreg(r)*) to reflect observed movements. Corresponding to the exogenization of the import-price index for region r, we endogenized a discriminatory phantom export tax, *phtx_i2(r)*, applied at the same rate by all regions on exports to r. Section 5.5 interprets the results for these discriminatory taxes.

Export prices were given for all regions in panel 16, exogenously via OECD data for all regions except RoW, and endogenously via costs for RoW. Movements in export prices averaged over regions must equal import prices averaged over regions. Consequently, when we put in place export prices for the 13 regions in our model and import prices for 12 regions, the import price for the 13th region is determined. Thus, as can be seen from panel 17, the phantom discriminatory taxes, *phtx_i2(r)*, are endogenized for all r including RoW even though we do not introduce import price data for RoW.

To avoid indeterminacy between the two sets of export taxes (those in panel 16 applying to exports *from* regions and those in this panel applying to exports *to* regions), we exogenized on zero the global collection of the phantom discriminatory taxes deflated by the price of global GDP, *d_rcolt_phtx_i2*. This exogenization balances the endogenization of *phtx_i2(RoW)*.

Panel 18: Return of phantom tax revenue as production subsidies. We were concerned that the build-up of phantom indirect taxes in panels 16 and 17 would distort the results for factor prices (wage rates and capital rentals). In regions where the phantom export taxes were high, we were worried that factor prices would be artificially low. To avoid this possibility, we endogenized a phantom production tax/subsidy in each region (*f_tofr(r)*) and determined its rate so that the regional collections (*d_tottaxf(r))* of phantom indirect taxes (including the phantom production tax) were zero.

3.5. Wealth and net foreign liabilities

Panel 19: Net foreign liabilities. We calculate the change in region r's real wealth from the start of 2014 to the start of 2019 according to

$$\Delta RW\text{14-19}(r) = \frac{VK(r,19)\ - NFL(r,19)}{PW(r,19)} - [VK(r,14)\ - NFL(r,14)] \quad for\ r \in Reg \tag{20}$$

where

VK(r,t) is the value of capital located in the region r at the start of year t;

NFL(r,t) is r's net foreign liabilities at the start of year t; and

PW(r,t) is the price of a unit of wealth in region r at the start of year t. This is a composite of the price of units of capital in region r and units of capital in other countries that make up r's foreign assets. We give this index a value of 1 in 2014.

The change in region r's real wealth is also given by accumulated real net saving for 2014 to 2018. In stylized form, we have

$$\Delta RW\text{14-19}(r) = ACC\_RSAV\text{14-18}(r) + SWQH\_B(r) \quad for\ r \in Reg \tag{21}$$

where

ACC_RSAV14-18(r) is real net savings for region r accumulated over the years 2014 to 2018, estimated via the smooth-growth assumption for saving; and

SWQH_B(r) is a shift variable.

In the standard long-run closure, the shift variable in (21) is exogenous. Accumulated real savings, capital and net foreign liabilities in the simulation year

(2019) are endogenous and the 2014 variables are data. In the 2014-19 simulation, we exogenized *NFL(r,19)* to accommodate its observed value and endogenized *SWQH_B(r)*. The endogenously determined value for *SWQH_B(r)* can be interpreted as the increase in the real value of r's wealth not derived from r's saving. As analyzed by Bruneau et al. (2017), this could arise from exchange rate revaluations of foreign assets and liabilities and from capital gains and losses experienced by the residents of region r in their foreign investments and borrowings.

4. Setting up the baseline simulations for 2019-30, 2030-40 and 2040-50

Because we do not know as much about the future as we do about the past, closures for baseline simulations are usually simpler than those for historical simulations. Relative to historical simulations, in baseline simulations we stay closer to the standard closure, relying more on normal CGE mechanisms to generate results for naturally endogenous variables than on imposed movements. Nevertheless, the difference is only a matter of degree. For simulating future periods, we need swaps so that we can impose results from expert groups specializing in forecasting naturally endogenous macro and energy variables. We also find that closure swaps and additional equations are required for endogenizing naturally exogenous consumption propensities. This is necessary to achieve plausible long-run projections for wealth and net foreign assets.

As with the 2014-19 historical simulation, the starting closure for the baseline simulations is the standard long-run closure. Again, we use a step-by-step macro-to-micro strategy. Thankfully, we reach the final baseline closure in only 7 steps, down from 19 in the 2014-19 simulation. This reflects the sketchiness of our knowledge of the future relative to the past.

Table 2 indicates shocked variables and closure changes. The final closure, reached with the implementation of panel 7, allows us to bring into the 3 baseline simulations projections for each region of:

- Real GDP, based on IMF forecasts and productivity trends;
- Population and working-age population from Shared Socioeconomic Pathway 2 (SSP2, middle of the road projections) published by the International Institute for Applied Systems Analysis (IIASA);
- Fossil-fuel use under Stated Policies Scenarios (STEPS) published by the International Energy Agency (IEA); and
- Capital/labor technology bias from a historical simulation for 2004-14 (see discussion of panel 6 in section 3).

4.1. Real GDP and supply-side determinants, panels 1-5

Panel 1: real GDP. This panel corresponds to panel 1 in Table 1: We exogenize real GDP in each region and endogenize primary-factor technical change. For 2019-30, we used GDP projections from the IMF. Beyond 2030, we used GDP projections based on IIASA's SSP2 projections for working-age population and on trends in GDP per worker derived from data and forecasts covering most of the past decade and going out to 2028 (see part 1 of the supplementary material).

Panel 2: employment and population. This panel corresponds to panel 3 in Table 1. No closure changes are required. For employment, we use projections of working-age population.

Panel 3: land and natural resources. As explained in connection with panels 4 and 5 in Table 1, land and natural resources can be reallocated among using industries. In the baseline simulations, we assume that the total availability of each of these factors in each region is fixed.

Panel 4: Twist in capital-labor technology. This panel corresponds to panel 6 in Table 1. As in the 2014-19 simulation, in the baseline simulations we introduce cost-neutral, capital-using technology bias by extrapolating the bias for each region estimated for 2004-14.

Panel 5: global price level. As mentioned in point (e) in section 2.3, the numeraire in the standard long-run closure is the nominal value of global GDP. We imposed the IMF forecast for this variable for 2019-30. In combination with the IMF forecasts for regional real GDPs imposed in panel 1, our 2019-30 simulation gave an increase in the world price of GDP in $US of 28.6 per cent. For 2030-40 and 2040-50, we set global growth in nominal GDP so that global inflation continues at the same rate as for 2019-30.

4.2. Real private and public consumption

Panel 6: adjustment of consumption propensities. We calculate average consumption propensities as ratios of private plus government consumption to NNP. As can be seen by glancing forward to the first column of Table 13, these propensities in 2019 varied from 0.645 for China to 1.003 for Mexico. The average across all regions was 0.857 implying that 14.3 per cent of world income was saved and devoted to investment.

In the baseline simulations, we assumed that regional average propensities will move towards the world average. High savers such as China will consume more of their income and low savers such as Mexico will tighten their belts. We also assumed that average propensities will rise in regions in which there is a tendency for wealth to grow relative to GDP. Without this wealth affect, our simulations gave unrealistic values in some regions for wealth and net foreign liabilities.

We implemented our consumption assumptions via the equations:

$$apcnnp(r) = 100 * ADJ1 * \left(\frac{APCW - APC(r)}{APC(r)}\right) + ADJ2 * \left(wqh(r) - wgdp(r)\right) + f\_apcnnp(r) \;\; for\ r \in Reg \quad (22)$$

$$cr(r) = gr(r) + f\_rcrgr(r) \;\; for\ r \in Reg \quad (23)$$

In these equations:

apcnnp(r) is the percentage change between t and t+τ in region r's private average propensity to consume (the ratio of private consumption to NNP);

APCW is the world average propensity to consume in t (0.857 in 2019);

APC(r) is the average propensity to consume in region r in t;

wqh(r) is the simulated percentage increase in nominal wealth in r between t and t+τ;

wgdp(r) is the simulated percentage increase in nominal GDP in r between t and t+τ;

f_apcnnp(r) is a shift variable;

cr(r) and *gr(r)* are the percentage changes between t and t+τ in real private and real government consumption;

f_rcrgr(r) is the percentage change in the ratio of real private to government consumption; and

ADJ1 and *ADJ2* are adjustment parameters set at 0.2 and 0.5. These values achieve a gradual closing of the gaps between regional average propensities to consume while leaving in place the original pattern of high savers and low savers. They also give plausible long-run movements in wealth to GDP ratios.

In the standard long-run closure, *apcnnp(r)* is exogenous and *f_apcnnp(r)* is endogenous, leaving equation (22) with no effect on simulation results. As can be seen in panel 6 of Table 2, in the baseline simulations we exogenized *f_apcnnp(r)* with a zero shock and endogenized *apcnnp(r)*. Thus, we assumed that the percentage movement in *apcnnp(r)* between t and t+τ will be 0.2 times the year-t percentage gap between *APCW* and *APC(r), plus* 0.5 times the simulated percentage growth between t and t+τ in r's wealth to GDP ratio.

A natural assumption was to give the average propensity to consume by government the same percentage change as for households. However, this led to unsatisfactory results in some regions for the ratio of real private to government consumption. Consequently, we assumed directly that real private and government consumption move together by exogenizing *f_rcrgr(r)* with zero shock, and endogenizing government average propensities to consume, *dpgov(r)*.

Table 2. Shocked variables and closure swaps for the 3 baseline simulations.

Panel no (1)	Exo variable (2)	Description (3)	Source for shock (4)	Swaps *(goes endo)* (5)	Description (6)
1	*qgdp(r)*	Real GDP	IMF & trend projections	*afereg(r)*	Primary factor tech change by region
2	*lsreg(r)*	Employment, same as labor supply	SSP2 projections for working age pop	No swap	
	pop(r)	Population	SSP2 projections	No swap	
3	*qo(land,r)*	Supply of land	Zero shock	No swap	
	qo(natres,r)	Supply of natural resources	Zero shock	No swap	
4	*twistKL(r)*	K/L tech twists	Extrapolate, 2004-14	No swap	
5	*wgdpg*	Nominal GDP for world	IMF projections	No swap	
6	*f_apcnnp(r)*	Activates apcnnp adjustment	Zero shock	*apcnnp(r)*	Average Hhld propensity to consume out of NNP
	f_rcrgr(r)	Ratio, real priv. to gov. consumption	Zero shock	*dpgov(r)*	Average Govt propensity to consume
7	*qabsorb2 (Foss, Reg2)*	Use of coal, oil and gas in 8 IEA regions (Reg2)	IEA STEPS projections	*a_int2 (Foss, Reg2)*	Demand shifts in favor or against coal, oil and gas in the eight Reg2 regions
	f_a_int(Foss,r)	Imparts demand shifts to industries in 13 regions	Zero shock	*a_int(Foss,r)*	Demand shifts in favor or against coal, oil and gas in inds in the 13 Reg regions
	f3_aint(Foss,r)	Imparts demand shifts to H'hlds in 13 regions	Zero shock	*a3com(Foss,r)*	Demand shifts in favor or against coal, oil and gas by H'hlds in the 13 Reg regions
	f5_aint(Foss,r)	Imparts demand shifts to Gov in 13 regions	Zero shock	*f_qg(Foss,r)*	Demand shifts in favor or against coal, oil and gas by Gov in the 13 Reg regions
	f_neut(j,r)	Neutralizes foss fuel saving by inds	Zero shock	*a_neut(j,r)*	Technical change to offset fossil-fuel saving.

4.3. Fossil fuels

***Panel 7: fossil-fuel use by region**.* IEA publishes several sets of forecasts for fossil-fuel use in 8 regions: USA, China, Japan, India, Rest of North America, European Union, Middle East and Rest of World. We use their STEPS to derive percentage changes in coal, oil and gas absorption by region for 2019 to 2050. In panel 7, we treat these forecasts as exogenous, which means that they are independent of other elements of our baseline, such as real GDP. Our interpretation is that the Stated Policies are commitments that are independent of other economic developments.

To take in the STEPS forecasts, we first added equations to our model that define percentage changes in coal, oil and gas use in these 8 regions. This required a mapping connecting our 13 regions with IEA's 8 regions. Then we shocked the use of coal, oil and gas in the 8 IEA regions with the percentage changes implied by the STEPS forecasts, and endogenized relevant technology and preference variables.

As shown in panel 7, we exogenized and shocked *qabsorb2(Foss,Reg2),* and endogenized *a_int2(Foss,Reg2)* where

qabsorb2(Foss,Reg2) refers to the percentage changes in the use of coal, oil and gas (the commodities in the set Foss) in the regions in Reg2 (the 8 IEA regions); and

a_int2(Foss,Reg2) refers to the percentage reduction in the use of coal, oil and gas per unit of activity by each agent in rr for rr in Reg2.

In spreading the *a_int2(c,rr)* movements for fossil commodity c to all agents in the regions at the 13 level we used the equations:

$$a\_int(Foss,r) = a\_int2\,(Foss, MAP(r)) + f\_a\_int(Foss,r)\ \ for\ r \in Reg \tag{24}$$

$$a3com(c,r) = -a\_int2\left(Foss, MAP(r)\right) + f3\_aint(c,r)\ \ for\ c \in Foss, r \in Reg \tag{25}$$

and

$$f\_qg(c,r) = -a\_int2\left(Foss, MAP(r)\right) + f5\_aint(c,r)\ \ for\ c \in Foss, r \in Reg \tag{26}$$

where

a_int(Foss,r) is a technology variable representing the percentage reduction in the use of coal, oil and gas per unit of activity in industries in the 13-order region r *(r ∈Reg);*

a3com(c,r) and *f_qg(c,r)* are preferences variables representing the percentage increases in private and government consumption of commodity c in region r beyond what can be explained by changes in incomes and prices;

MAP(r) is the 8-order region in Reg2 associated with r, e.g. *MAP(Mexico)* and *MAP(Canada)* both equal *Rest of North America*; and

f_a_int(Foss,r), f3_aint(c,r) and f5_aint(c,r) are shift variables.

In the standard long-run closure, the shift variables are endogenous and the technology and preference variables are exogenous. In the three baseline simulations, the shift variables become exogenous, and the technology and preference variables become endogenous and move in line with *a_int2.*

As in panel 12 of Table 1 for the 2014-19 simulation, we cost neutralized the savings made by industries in their use of fossil fuels. We do this via a variant of equation (11):

$$\left[\sum_{c \in NonFoss} SC(c,j,r)\right] * a\_neut(j,r) = -\sum_{c \in Foss} SC(c,j,r) * a\_int(c,r) + f\_neut(j,r) \; for \; j \in Ind, r \in Reg \quad (27)$$

5. Results from the 2014 to 2019 historical simulation

The 2014-19 historical simulation produces an updated GTAP database for 2019 that is consistent with regional data for macro variables and world data for energy variables. This gives us a database for starting the baseline simulations. The historical simulation also provides results for variables describing technologies, preferences, wealth and consumption propensities. These are of interest in their own right and can inform the baseline forecasts. Many of the results together with shocks to selected observed variables are set out in Tables 3 to 9 described in this section.

5.1. Real GDP and factor inputs and prices

Table 3 presents results for movements in real GDP, factor inputs, prices, and technology contributions to real GDP. The shaded columns refer to variables for which the percentage movements are based on data, although they may be slightly adjusted to satisfy various identities. The other columns show simulation results.

The standout growth regions in Table 3 are China and India, with real GDP growth over the 5 years of 37.96 per cent and 35.05 per cent. Both these economies achieved rapid capital growth and high rates of technical progress (technology contributions to GDP of 9.60 and 11.78 per cent). At the other end of the GDP growth spectrum is Japan. While Japan achieved moderate technical progress (2.94 per cent), its GDP growth was retarded by employment decline and weak capital growth. The worst performing region was Saudi Arabia. Despite rapid growth in factor inputs, growth in real GDP was only 8.04 per cent implying negative technical progress (-12.99 per cent).

Our simulation shows real wage growth for all regions, although it is very small for Saudi Arabia. With the exception of Saudi Arabia, the simulated increases in real wage rates reflect technology improvements and increases in capital/labor ratios. Simulated rates of return fell in most regions, despite the introduction to the simulation of historically determined technology twists favoring the use of capital (see the discussion of panel 6 in section 3).

Recall from the discussion of panel 5 in Table 1 that we assumed an elastic supply of natural resources. This produced volatile results - varying from a simulated 28.60 per cent reduction in natural resource use by the United Kingdom (UK) to a simulated 58.17 per cent increase in the USA. However, natural resources contribute a negligible fraction to GDP in all regions except Saudi Arabia, and even for Saudi Arabia, the contribution in the GTAP 2014 database is only 9 per cent.

Table 3. Percentage changes between 2014 and 2019 in real GDP, factor inputs and prices, together with contributions of technology to real GDP.

	Real GDP	Capital	Employ -ment	Natural resource use	Tech cont. to GDP	Real wage rate	Rate of return on capital
	qgdp	*kb*	*lsreg*	*qo(NatRes)*	*cont_tech*	*realwager*	*rorc*
USA	12.58	13.75	1.62	58.17	5.69	15.40	-2.43
Canada	9.78	14.14	2.97	-1.28	1.91	6.84	-7.08
Mexico	10.33	15.48	6.53	-18.29	-0.25	16.19	-22.75
China	37.96	58.20	-0.21	18.94	9.60	49.43	-32.07
Japan	4.37	7.28	-3.60	6.22	2.94	16.13	-10.00
SKorea	14.88	24.60	0.55	9.32	2.45	23.57	-16.47
India	35.05	42.96	4.33	36.61	11.78	37.50	0.51
France	8.32	12.92	-0.73	-6.31	2.65	15.36	-10.72
Germany	8.85	11.54	1.55	-7.78	2.06	16.66	-16.78
UK	10.62	14.25	1.56	-28.60	2.58	18.52	-22.04
RoEU	13.37	12.81	-3.15	-3.18	6.55	23.09	-2.30
Saudi Arabia	8.04	32.83	14.07	44.39	-12.99	0.30	-9.11
RoW	14.33	21.81	3.13	-9.90	3.13	19.17	-14.06

Source: Author calculations.

5.2. Real GDP and expenditure components

Given the data in the shaded columns of Table 4, our 2014-19 historical simulation implied that Canada, Mexico, China, India and Saudi Arabia increased their private and public consumption propensities (ratios of private and public consumption to NNP). By contrast, UK and Rest of EU (RoEU) reduced their consumption propensities. For the remaining regions, one propensity increased, and one fell. At the global level, consumption propensities decreased. Global savings increased, relative to global GDP generating continuing downward pressure on returns to capital.

In Table 4, we refer to a region's investment in 2019 relative to capital growth anticipated out to 2030, as the region's investment propensity. This is the variable *f_ke(r)* in equation (5). The movements in investment propensities in 2019 necessary to accommodate observed investment levels, are positive for two regions and negative for the others. Investment is a volatile variable. In 2019 investment in the USA happened to be strong relative to its anticipatable future prospects ((*f_ke(USA)* was 0.65) whereas investment in Saudi Arabia happened to be weak ((*f_ke(Saudi Arabia)* was -4.38).

The final column of Table 4 shows a mixture of positives (preference twists towards imports) and negatives (preference twists against imports). The twists were positive for the European regions (France, Germany, UK and RoEU) consistent with open-trade policies and lengthening supply chains. Similarly, Canada and Mexico showed preference twists towards imports. By contrast, the twist for the USA was negative, consistent with moves away from free-trade policies. Both India and China had twists against imports, perhaps explained by the increasing ability to produce commodities that compete successfully in their domestic markets with imports.

Table 4. Percentage changes between 2014 and 2019 in real GDP and its expenditure components, related consumption propensities, investment propensities and preference twists.

	Real GDP	Real private consumption	Real gov consumption	Real investment	Export volumes	Import volumes	Private cons. propensity	Public cons. propensity	Investment propensity	Pref twist towards imports
	qgdp	*cr*	*gr*	*qcgds*	*expvol*	*impvol*	*apcnnp*	*dpgov*	*f_ke*	*twist_src_i*
USA	12.58	13.70	8.20	17.60	8.74	17.50	0.21	-0.55	0.65	-25.37
Canada	9.78	12.90	9.80	-2.70	13.86	9.40	2.92	1.54	-0.45	14.21
Mexico	10.33	13.10	6.30	-1.30	26.19	22.40	0.88	0.28	-2.70	73.62
China	37.96	48.50	45.30	30.20	11.45	15.20	7.09	12.89	-0.75	-9.22
Japan	4.37	0.00	6.70	7.60	14.66	7.50	-5.22	6.30	-0.86	-18.97
SKorea	14.88	13.50	26.30	21.50	9.94	16.60	-4.97	15.70	-1.03	-21.74
India	35.05	39.70	40.80	30.60	12.35	24.50	3.36	13.00	-2.68	-3.03
France	8.32	7.70	5.70	16.20	18.47	20.10	-2.21	0.12	0.25	14.68
Germany	8.85	9.20	12.60	13.50	17.67	24.40	-3.96	3.48	-0.74	10.13
UK	10.62	12.80	7.00	7.30	20.68	19.60	-0.83	-2.11	-1.55	21.82
RoEU	13.37	11.60	6.60	32.80	29.30	33.10	-4.40	-4.38	-2.12	29.69
Saudi Arabia	8.04	19.00	-13.00	-3.30	7.64	-8.80	30.42	3.70	-4.38	-58.72
RoW	14.33	8.15	20.97	14.91	19.45	11.49	-4.31	13.95	-2.68	4.06

Source: Author calculations.

5.3. World fossil-fuel variables

The last column of Table 5 shows sharp shifts against the use of fossil fuels, especially coal. The result for coal means that worldwide use of coal in 2019 was 21.47 per cent lower than can be explained by changes in activity by electricity industries and other coal users, and by changes in the price of coal relative to the prices of other energy carriers.

Table 5. Percentage changes between 2014 and 2019 in world energy variables.

	Quantity of world output	Average world price[a]	Shifts in world demand
	qworld	*pworld*	*wldout_sh*
coal	0.63	11.06	-21.47
oil	6.02	-29.86	-15.86
gas	15.57	-43.87	-4.13

Notes: [a] $US price relative to $US price of global GDP.

Source: Author calculations.

5.4. Exports and related variables

The phantom export tax movements in Table 6 are percentage changes in the power of taxes where the 2014 level of these powers is one (zero rate). The role of these phantom taxes is to reconcile data on movements in export price indexes, with export costs. To a large extent, export costs are reflected in movements in the price deflator for GDP. In the cases of the USA, Canada, Japan, South Korea, and Germany, the required phantom taxes are in fact subsidies. The prices of exports from these countries are lower than would be anticipated on the basis of movements in their general cost levels. This is consistent with modern trade theory (e.g. Melitz (2003)) which suggests that exporting firms in a region are more productive and have lower costs than non-exporting firms in the region.

However, the phantom tax movements are positive for the other seven regions for which we have export price data. For China, France and RoEU, the discrepancies between observed export prices and the price indexes for GDP are resolved by only small positive phantom export taxes. This is also true for Saudi Arabia: the large gap between the movements in the GDP and export price indexes for Saudi Arabia is explained by the reduction in the price of their principal export, oil.

India also exports energy products, particularly petroleum, coal products and chemicals. With the reductions in the prices of oil and gas, we would expect the price index for Indian exports to fall relative to the price index for GDP. This is what we observe (a 1.40 per cent increase compared with 3.57 per cent increase). However, given the composition of Indian exports, the reduction in the ratio of export prices to the price of GDP is less than would be expected on the basis of energy prices and other costs. Consequently, our simulation shows a relatively large positive phantom export tax for India (4.54 per cent). For an emerging economy such as India, higher than expected export prices may reflect improved quality in their exports relative to that of domestic products sold on their domestic market. A similar explanation might be valid for Mexico for which the phantom export tax is 7.71 per cent.

The quality argument seems an unlikely explanation of the strongly positive phantom tax for the UK (5.62 per cent). A more likely explanation is the mismeasurement of relative costs across UK exports. For the UK, services are a substantial component of exports. If we have overestimated productivity growth in the UK service sector relative to that of other sectors, then this would provide an explanation of the positive export tax required to reconcile simulated export prices for the UK with observed export prices.

The final column of Table 6 shows preference shifts by importers towards or against different sources. The largest positive preference twist was towards Indian products. The twist result for India means that the shares of Indian products in the imports of other countries increased by 101.81 per cent relative to what could be explained on the basis of relative prices: the volume of Indian exports increased by 12.35 per cent despite its export price increasing relative to all other regions. There were also strong twists towards USA exports (80.66 per cent). At the other extreme, South Korea suffered a large adverse twist (-55.37 per cent). South Korea had relatively low export growth (9.94 per cent) despite a relatively large decline in its export price (-16.70 per cent).

Table 6. Percentage changes between 2014 and 2019 in export prices and volumes, and related variables.

	Price index for GDP	Price index for exports	Export volumes	Phantom tax on exports from regions	Preference shift towards a region's exports
	pgdp_obs	*p_x_obs*	*expvol*	*phtx_i*	*f3_twistmd*
USA	8.42	-1.50	8.74	-4.35	80.66
Canada	-11.81	-13.20	13.86	-2.40	-21.30
Mexico	-13.68	-6.60	26.19	7.71	27.18
China	-1.61	-5.80	11.45	1.92	37.56
Japan	-0.03	-8.40	14.66	-10.03	1.96
SKorea	-3.22	-16.70	9.94	-13.26	-55.37
India	3.57	1.40	12.35	4.54	101.81
France	-11.89	-13.80	18.47	1.50	-12.62
Germany	-8.09	-12.80	17.67	-0.51	-10.83
UK	-15.94	-14.70	20.68	5.62	-13.06
RoEU	-10.24	-13.30	29.30	0.32	2.24
Saudi Arabia	-3.03	-24.90	7.64	0.31	4.33
RoW	-15.12	0.00	19.45	0.00	-21.05

Source: Author calculations.

5.5. Import prices

With movements in export prices given from OECD data, we expected simulated movements in import prices to be closely consistent with OECD data. However, as shown in Table 7, reconciling simulated and observed import price movements required significant phantom discriminatory export taxes. The largest such tax was for China. Explaining the observed movement in China's import prices of -5.00 per cent required a 11.35 per cent discriminatory phantom tax applied by all exporters to China. For India, the discriminatory phantom export tax was 10.17 per cent.

Table 7. Percentage changes between 2014 and 2019 in import prices and explanatory phantom-tax movements.

	Price index for imports	Discriminatory phantom tax on exports to regions
	p_m_obs	*phtx_i2*
USA	-8.20	6.06
Canada	-8.50	-2.33
Mexico	-6.80	-0.45
China	-5.00	11.35
Japan	-13.80	0.39
SKorea	-18.70	-6.69
India	-8.20	10.17
France	-16.00	-4.12
Germany	-15.50	-3.58
UK	-15.90	-4.61
RoEU	-14.90	-3.47
Saudi Arabia	-6.00	4.14
RoW	10.00	-4.03

Source: Author calculations.

It is possible that with increasing wealth, consumers in both these countries became more discriminating, demanding higher quality imports. Improved quality might be reflected in higher prices, without adequate adjustment of quantities. For example, if quantities of wine imports are measured by volume, and Chinese consumers moved to high quality wine, then import prices for China could increase relative to the prices paid by the importers of wine in other countries. In our simulation, this would show up as a positive tax on exports to China and a negative tax on exports to other countries (recall that the sum over countries of the discriminatory phantom taxes is zero).

5.6. Investment prices

Creation of units of capital (investment) in each region is undertaken in the GTAP model by the region's capital goods (*cgds*) industry. This industry creates capital by mixing intermediate inputs, mainly construction, machinery and finance.

The price index for GDP is an indicator of average prices of goods and services including the mix of goods and services used by the *cgds* industry. Thus, we expected movements in investment price indexes to be broadly in line with those in GDP price indexes. However, as can be seen from Table 8, there were significant differences. For example, the investment price index for the U.K. moved by -9.80 per cent, whereas the movement in the price index for GDP was -15.94 per cent.

The 2014-19 historical simulation reconciled simulated movements in investment price indexes with observed movements by allowing endogenous changes in output per unit of input (productivity) in *cgds* industries. For the UK, for example, in which the investment price index increased relative to the GDP price index, the reconciliation generated a cost-increasing productivity deterioration (-7.90 per cent) in the UK *cgds* industry.

The biggest disconnect in Table 8 between the observed movements in the price indexes for GDP and investment is for Saudi Arabia (-3.03 per cent compared with 11.40 per cent). Nevertheless, the implied productivity change for the Saudi Arabian *cgds* industry is positive (1.01 per cent). For Saudi Arabia, the movement in the price index for GDP is dominated by movements in energy prices, particularly oil. This makes movements in the Saudi Arabian price index for GDP an unreliable indicator of movements in the prices of individual industries such as the *cgds* industry in which energy inputs are relatively minor.

Table 8. Percentage changes between 2014 and 2019 in investment prices and explanatory variables.

	Price index for GDP	Price index for investment	Productivity in capital goods
	pgdp_obs	*p_i_obs*	*a_cgds*
USA	8.42	6.30	1.39
Canada	-11.81	-8.10	-2.07
Mexico	-13.68	-5.50	-7.44
China	-1.61	-1.20	-3.23
Japan	-0.03	0.10	0.75
SKorea	-3.22	-3.20	-1.41
India	3.57	-5.70	7.95
France	-11.89	-11.80	-0.48
Germany	-8.09	-4.40	-6.42
UK	-15.94	-9.80	-7.90
RoEU	-10.24	-9.90	-1.44
SaudiArabia	-3.03	11.40	1.01
RoW	-15.12	NA	0.00

Source: Author calculations.

5.7. Real wealth

The first column in Table 9 shows changes in real wealth (defined in the discussion of panel 19 in section 3) from the start of 2014 to the start of 2019 expressed as percentages of GDP in 2014.

At first glance, some of the wealth increases seem surprisingly large. For example, real wealth in China as a per cent of 2014 GDP is 220.25 per cent higher at the start of 2019 than it was at the start of 2014. However, when we recall that China saved about 40 per cent of its GDP in each year of the 5-year period, and that its GDP was growing rapidly, China's huge increase in real wealth becomes understandable. The second column of Table 9 shows that 192.65 percentage points of the 220.25 is contributed by accumulated real saving.

For some regions, the other-factor effects shown in the third column of Table 9 are large. These other factors were calculated in the 2014-19 simulation from shift variables in (21). Their values reflect increases in wealth not derived from the region's saving. Mexico, for example, benefitted from a considerable increase in its real wealth (64.51 per cent of its 2014 GDP) but did almost no saving (contribution to real wealth of 0.56). For a heavily indebted country such as Mexico, a wealth increase without saving can be generated by devaluation. Between 2014 and 2019, Mexico's currency devalued by about 45 per cent relative to $US without a commensurate increase in Mexico's price level. In these circumstances, the devaluation reduced the $US value of foreign-owned assets in Mexico denominated in Mexican currency. Mexico's gain is a loss for the foreign holders of Mexican assets. It is noticeable in Table 9 that the other-effects contribution for the U.S. is strongly negative (-3.51 per cent of 2014 GDP).

Table 9. Changes in real wealth between 2014 and 2019 as percentages of GDP in 2014, and contributions from real saving and other factors.

		Change in real wealth between 2014 and 2019	Real accumulated saving: 2014, 2015, 2016, 2017 and 2018	Contributions of other effects on wealth between 2014 and 2019
		Per cent of 2014 GDP		
1	USA	14.49	18.00	-3.51
2	Canada	64.48	62.06	2.42
3	Mexico	64.51	0.56	63.95
4	China	220.25	192.65	27.60
5	Japan	33.19	69.17	-35.99
6	SKorea	125.80	95.82	29.98
7	India	140.61	75.09	65.52
8	France	29.78	34.15	-4.37
9	Germany	71.13	71.94	-0.81
10	UK	52.20	2.37	49.83
11	RoEU	58.36	34.01	24.35
12	SaudiArabia	115.51	163.51	-47.99
13	RoW	64.51	64.51	0.00

Source: Author calculations.

6. Results: baseline projections for 2019-30, 2030-40 and 2040-50

Tables 10 - 14 contain results for the baseline simulations. For comparison, we also include results from the 2014-19 simulation. In the tables, the shaded columns are for variables that were exogenous in the simulations or only slightly adjusted to fulfil consistency conditions such as global exports summing to global imports. To aid comparability across periods of different lengths, all results are expressed as average annual percentage changes.

6.1. Real GDP, factor inputs and prices, and technology (Table 10)

In terms of GDP, China and India were the fastest growing economies in 2014-19. They remain in the first two positions in our baseline out to 2050. However, growth in both economies slows. For China, average annual percentage growth in real GDP in the four periods in Table 10 goes from 6.65 to 4.16 to 3.05 to 3.25. The slowdown is explained by demographic factors, generating negative growth in employment (annual percentage growth rates of -0.04, -0.32, -1.18 and -0.99) and associated reductions in capital growth (annual percentage growth rates of 9.61, 5.36, 4.09 and 3.94). Annual percentage contributions to Chinese GDP growth from total factor productivity growth also flatten out (technology contributions of 1.85, 1.57, 1.33 and 1.27 per cent).

Relative to China, the slowdown in real GDP growth for India is less pronounced (6.19 per cent in 2014-19 down to 5.10 per cent in 2040-50). For India, workforce growth remains positive and total factor productivity continues to contribute strongly.

Japan is the slowest growing economy, going from annual GDP growth of 0.86 per cent in 2014-19 to 0.23 per cent in 2040-50. Throughout the four periods, Japan's workforce declines rapidly.

Global saving is sufficient through the simulation periods to support capital growth in excess of employment growth in all regions (increases in K/L ratios). In the majority of cases, capital growth also exceeds GDP growth.

Growth in K/L ratios leads, in nearly all cases, to growth in real wage rates relative to rates of return on capital. This is despite the inclusion in our simulations of strong trends from 2004-14 in technology bias favoring the use of capital relative to labor.

The simulated percentage changes in rates of return for 2014-19 are mainly negative but vary across regions. The variation reflects the use of Penn data on capital growth in each region. In the other simulation periods, capital is allocated across regions in a way that equalizes percentage movements in rates of return. The simulated worldwide changes in rates of return for 2019 to 2050 are small. They imply that a rate of return of 10 per cent in 2019 would fall to about 9.57 per cent in 2050.

Table 10. Average annual % changes in real GDP, factor inputs and prices, and technology.

	Real GDP	Capital	Employment	Population	Tech cont	Real wage	RoR on cap
	qgdp	*kb*	*lsreg*	*pop*	*cont_tech*	*realwager*	*rorc*
Period 1: 2014-19							
USA	2.40	2.61	0.32	0.62	1.11	2.91	-0.49
Canada	1.88	2.68	0.59	1.19	0.38	1.33	-1.46
Mexico	1.99	2.92	1.27	1.08	-0.05	3.05	-5.03
China	6.65	9.61	-0.04	0.48	1.85	8.36	-7.44
Japan	0.86	1.42	-0.73	-0.14	0.58	3.04	-2.09
SKorea	2.81	4.50	0.11	0.40	0.49	4.32	-3.54
India	6.19	7.41	0.85	1.13	2.25	6.58	0.10
France	1.61	2.46	-0.15	0.33	0.52	2.90	-2.24
Germany	1.71	2.21	0.31	0.52	0.41	3.13	-3.61
UK	2.04	2.70	0.31	0.67	0.51	3.46	-4.86
RoEU	2.54	2.44	-0.64	0.09	1.28	4.24	-0.46
SaudiArabia	1.56	5.84	2.67	2.67	-2.74	0.06	-1.89
RoW	2.71	4.02	0.62	1.85	0.62	3.57	-2.98
Period 2: 2019-30							
USA	1.78	1.98	0.23	0.74	0.95	1.61	-0.84
Canada	1.53	2.30	0.30	0.94	0.34	1.48	-0.84
Mexico	1.19	1.01	0.75	0.82	0.32	0.72	-0.84
China	4.16	5.36	-0.32	0.02	1.57	3.48	-0.84
Japan	0.41	1.37	-0.59	-0.35	0.12	1.12	-0.84
SKorea	2.05	2.61	-0.99	0.06	1.21	3.39	-0.84
India	5.24	5.48	1.17	0.97	2.05	3.31	-0.84
France	1.09	1.64	0.13	0.52	0.32	1.07	-0.84
Germany	0.81	0.79	-0.90	-0.05	0.80	2.69	-0.84
UK	0.96	0.95	0.17	0.55	0.39	1.03	-0.84
RoEU	2.53	2.65	-0.31	0.09	1.21	3.32	-0.84
SaudiArabia	2.78	4.30	2.13	1.92	-0.12	0.69	-0.84
RoW	2.71	3.51	1.49	1.36	0.32	1.08	-0.84

(Continued…)

Table 10. Average annual % changes in real GDP, factor inputs and prices, and technology. (…Continued)

	Real GDP	Capital	Employment	Population	Tech cont	Real wage	RoR on cap
	qgdp	*kb*	*lsreg*	*pop*	*cont_tech*	*realwager*	*rorc*
Period 3: 2030-40							
USA	2.17	1.87	0.48	0.60	1.17	1.81	0.08
Canada	2.09	2.39	0.63	0.74	0.68	1.23	0.08
Mexico	1.22	0.89	0.28	0.54	0.59	1.99	0.08
China	3.05	4.09	-1.18	-0.30	1.33	3.25	0.08
Japan	0.16	0.24	-1.24	-0.48	0.66	1.61	0.08
SKorea	1.69	1.86	-1.30	-0.21	1.32	3.39	0.08
India	5.57	5.62	0.77	0.74	2.59	4.12	0.08
France	1.30	1.41	0.16	0.47	0.55	1.15	0.08
Germany	1.00	0.57	-0.70	-0.12	1.01	2.36	0.08
UK	1.53	1.22	0.21	0.47	0.73	1.74	0.08
RoEU	2.65	2.31	-0.41	0.00	1.51	3.52	0.08
SaudiArabia	1.54	2.74	1.15	1.51	-0.37	-1.95	0.08
RoW	3.05	3.33	1.20	1.09	0.82	1.34	0.08
Period 4: 2040-50							
USA	2.05	1.70	0.35	0.49	1.17	1.77	0.41
Canada	1.81	1.97	0.36	0.66	0.65	1.23	0.41
Mexico	1.06	0.54	0.12	0.30	0.66	1.73	0.41
China	3.25	3.94	-0.99	-0.59	1.27	2.25	0.41
Japan	0.23	0.17	-1.16	-0.55	0.73	1.51	0.41
SKorea	1.78	1.88	-1.22	-0.51	1.37	3.06	0.41
India	5.10	4.79	0.32	0.52	2.71	3.93	0.41
France	1.38	1.37	0.23	0.37	0.58	1.05	0.41
Germany	1.24	0.61	-0.46	-0.18	1.12	2.17	0.41
UK	1.55	1.07	0.22	0.43	0.80	1.61	0.41
RoEU	2.37	1.89	-0.68	-0.04	1.58	3.48	0.41
SaudiArabia	1.06	1.89	0.68	1.13	-0.31	-2.15	0.41
RoW	2.64	2.79	0.81	0.85	0.82	1.40	0.41

Source: Author calculations.

6.2. Consumption

Our assumptions in equations (22) and (23) give China, the region with the lowest consumption propensity in 2019, a rapidly increasing propensity over the entire period from 2019 to 2050 (Table 13). With an increasing consumption propensity, real consumption in China grows relative to real GDP in 2019-30 and 2030-40 (Table 11). But what happens in 2040-50? Why does China's consumption growth drop below GDP growth (2.93 compared with 3.25) despite continuing increases in the consumption propensity?

As we reach 2040, the average propensity to consume in China moves up towards the world average, and growth in China's wealth/GDP ratio slows. These factors reduce the rate of growth of China's consumption propensity. Nevertheless, in the 2040-50 simulation, it is still growing. Consequently, we must look for other factors to explain the reduction in China's consumption/GDP ratio. There are two factors underlying this result.

First, as we go from the 2030-40 simulation to the 2040-50 simulation, there is a reduction in China's NNP/GDP ratio. With NNP driving consumption (point (c) in section 2.3) this reduces the consumption/GDP ratio. The NNP/GDP ratio falls because China's increased consumption relative to GDP in earlier periods reduces the rate of growth of its net foreign assets (and foreign earnings) relative to GDP.

Table 11. Average annual % changes in real GDP and its expenditure components.

	Real GDP	Real priv cons	Real gov cons	Real investment	Export volume	Import volume
	qgdp	*cr*	*gr*	*qcgds*	*expvol*	*impvol*
			Period 1: 2014-19			
USA	2.40	2.60	1.59	3.30	1.69	3.28
Canada	1.88	2.46	1.89	-0.55	2.63	1.81
Mexico	1.99	2.49	1.23	-0.26	4.76	4.13
China	6.65	8.23	7.76	5.42	2.19	2.87
Japan	0.86	0.00	1.31	1.48	2.77	1.46
SKorea	2.81	2.56	4.78	3.97	1.91	3.12
India	6.19	6.92	7.08	5.48	2.36	4.48
France	1.61	1.49	1.11	3.05	3.45	3.73
Germany	1.71	1.78	2.40	2.56	3.31	4.46
UK	2.04	2.44	1.36	1.42	3.83	3.64
RoEU	2.54	2.22	1.29	5.84	5.27	5.89
SaudiArabia	1.56	3.54	-2.75	-0.67	1.48	-1.83
RoW	2.71	1.58	3.88	2.82	3.62	2.20
			Period 2: 2019-30			
USA	1.78	1.70	1.70	-1.16	5.12	0.18
Canada	1.53	2.13	2.13	0.76	0.90	1.87
Mexico	1.19	-0.22	-0.22	2.77	3.37	1.86
China	4.16	5.10	5.10	3.09	2.55	3.20
Japan	0.41	1.83	1.83	-1.92	-2.93	1.24
SKorea	2.05	2.82	2.82	0.67	1.52	2.00
India	5.24	3.91	3.91	6.68	7.20	4.33
France	1.09	1.51	1.51	-1.37	1.76	1.12
Germany	0.81	2.30	2.30	-1.23	-0.82	1.16
UK	0.96	0.01	0.01	1.13	3.27	0.62
RoEU	2.53	2.13	2.13	2.78	2.86	2.36
SaudiArabia	2.78	3.50	3.50	6.15	-0.41	4.20
RoW	2.71	2.65	2.65	4.60	1.76	3.28

(Continued…)

Table 11. Average annual % changes in real GDP and its expenditure components. (…Continued)

	Real GDP	Real priv cons	Real gov cons	Real investment	Export volume	Import volume
	qgdp	*cr*	*gr*	*qcgds*	*expvol*	*impvol*
Period 3: 2030-40						
USA	2.17	2.08	2.08	1.42	3.11	1.76
Canada	2.09	1.84	1.84	1.59	3.02	2.06
Mexico	1.22	1.86	1.86	0.03	0.96	1.31
China	3.05	3.50	3.50	3.76	0.06	4.04
Japan	0.16	0.51	0.51	-0.11	-1.00	0.88
SKorea	1.69	2.33	2.33	1.73	0.43	1.90
India	5.57	5.55	5.55	4.65	6.23	4.54
France	1.30	1.24	1.24	1.17	1.74	1.49
Germany	1.00	1.58	1.58	0.48	0.23	1.43
UK	1.53	2.02	2.02	0.79	1.01	1.83
RoEU	2.65	2.90	2.90	1.53	2.62	2.46
SaudiArabia	1.54	1.49	1.49	1.33	0.75	0.48
RoW	3.05	2.77	2.77	2.48	3.92	2.68
Period 4: 2040-50						
USA	2.05	2.22	2.22	1.31	1.90	2.22
Canada	1.81	1.84	1.84	1.59	1.89	1.85
Mexico	1.06	1.60	1.60	0.07	0.55	0.95
China	3.25	2.93	2.93	3.65	3.48	3.10
Japan	0.23	0.47	0.47	-0.34	0.09	0.84
SKorea	1.78	1.91	1.91	1.50	1.90	2.02
India	5.10	5.20	5.20	4.51	5.20	4.61
France	1.38	1.42	1.42	0.96	1.56	1.45
Germany	1.24	1.56	1.56	0.14	1.01	1.38
UK	1.55	1.82	1.82	0.64	1.42	1.66
RoEU	2.37	2.69	2.69	1.51	2.08	2.21
SaudiArabia	1.06	0.90	0.90	1.51	0.62	0.85
RoW	2.64	2.65	2.65	2.45	2.79	2.63

Source: Author calculations.

The second factor is the terms of trade. Between 2040 and 2050, China's terms of trade declines by 0.35 per cent a year (Table 12). This reduces China's real consumption relative to real GDP by increasing the price of consumption relative to that of GDP. Why does China's terms of trade fall? By 2040-50, the growth rate for China's investment has fallen back towards that of GDP. This, combined with the reduction in the growth of consumption relative to that of GDP, causes real exchange rate devaluation. Consequently, there is an increase in the growth rate of Chinese exports (3.48 per cent in 2040-50 compared with 0.06 per cent in 2030-40, Table 11). Without preference twists, the Armington assumption built into the GTAP model generally implies terms-of-trade deterioration for regions like China and India where export growth is rapid relative to world GDP growth.

Table 12. Average annual percentage change in the terms of trade

	2014-19	2019-30	2030-40	2040-50
USA	1.42	-0.43	-0.03	0.22
Canada	-1.05	0.40	-0.11	0.14
Mexico	0.04	-0.19	0.20	0.20
China	-0.17	-0.28	0.41	-0.35
Japan	1.22	0.96	0.69	0.50
SKorea	0.48	0.19	0.38	0.11
India	2.00	-0.85	-0.40	-0.48
France	0.52	0.13	0.18	0.15
Germany	0.63	0.58	0.42	0.19
UK	0.28	-0.20	0.27	0.14
RoEU	0.37	-0.12	-0.02	0.03
SaudiArabia	-4.38	0.18	-0.74	-0.23
RoW	-0.81	0.15	-0.28	-0.02

Source: Author calculations.

Saudi Arabia is another region with an increasing consumption propensity through to 2050 (Table 13) but a declining consumption to GDP ratio in the later simulation periods (Table 11). As is the case for China, the decline in Saudi Arabia's consumption/GDP ratio in these periods is mainly attributable to negative terms-of-trade movements (Table 12). For Saudi Arabia, it is the price of oil rather than the volume of exports that is the main determinant of the terms of trade. As can be seen in Table 14, we project weak world growth in the demand for oil leading to relatively low oil prices.

At the other extreme are Mexico and UK, both of which had high consumption propensities in 2019. Movements in their consumption propensities down towards the global average give them sharp declines in their propensities in the 2019-30 simulation, leaving their consumption growth rates close to zero (-0.22 and 0.01, Table 11). After the downward adjustments of 2019-30, consumption propensities for Mexico and UK are relatively stable. In 2030-40 and 2040-50, consumption in both regions rises relative to GDP.

Table 13. Consumption propensities and movements in the ratios of wealth to GDP.

		Average propensity to consume				Ratio of wealth to GDP *per cent change between:*		
		2019	2030	2040	2050	2019-30	2030-40	2040-50
1	USA	0.962	0.961	0.946	0.948	3.468	-0.088	2.539
2	Canada	0.876	0.925	0.919	0.919	9.456	0.126	1.017
3	Mexico	1.003	0.901	0.922	0.931	-13.908	2.999	1.256
4	China	0.645	0.738	0.791	0.803	12.970	5.157	0.058
5	Japan	0.840	0.945	0.957	0.959	21.647	3.539	1.843
6	SKorea	0.789	0.855	0.892	0.903	8.166	2.981	-0.884
7	India	0.872	0.808	0.819	0.829	-13.405	-0.233	0.484
8	France	0.915	0.953	0.943	0.938	9.907	0.383	1.263
9	Germany	0.830	0.910	0.924	0.923	14.261	1.999	-0.174
10	UK	0.988	0.916	0.933	0.934	-9.993	4.411	1.714
11	RoEU	0.899	0.884	0.894	0.904	-4.836	-0.425	-0.485
12	SaudiArabia	0.712	0.796	0.842	0.861	15.267	13.092	7.339
13	RoW	0.855	0.869	0.868	0.874	2.241	-0.546	0.489
	World average	0.857	0.873	0.880	0.883			

Source: Author calculations.

6.3. *Investment*

To explain the results in Table 11 for average annual growth in investment between 2019 and 2030, we start with the equation:

$$\frac{I(r,30)}{I(r,19)} = \frac{KB(r,30) * \left[\frac{k(r,30)}{100} + D\right]}{KB(r,19) * \left[\frac{k(r,19)}{100} + D\right]} \quad for\ r \in Reg \tag{28}$$

In (28), *I(r,30)* and *I(r,19)* are the quantities of investment in region r in 2030 and 2019. In the numerator on the RHS of (28), investment in region r in 2030 is calculated as the growth in capital in 2030 plus depreciation. Growth in capital in 2030 is r's capital at the start of 2030 ($KB(r,30)$) multiplied by the fractional growth rate in capital *in* 2030 (the percentage growth rate, *k(r,30)*, divided by 100). Investment required to cover depreciation in 2030 is start-of-year capital times the depreciation rate D. The denominator applies a similar calculation to obtain investment in 2019.

From (28) we obtain

$$i(r,19,30) = \tag{29}$$

$$100*\left\{\left[\left(1+\frac{kb(r,19{,}30)}{100}\right)^{11}*\left(\frac{\frac{k(r,30)}{100}+D}{\frac{k(r,19)}{100}+D}\right)\right]^{\frac{1}{11}}-1\right\}for\ r\in Reg$$

where

i(r,19,30) is the average annual percentage growth rate for investment in region r between 2019 and 2030, that is the investment results in Table 11; and

kb(r,19,30) is the average annual percentage growth rate for capital in region r between the start of 2019 and the start of 2030, that is, the capital results in Table 10.

Equation (29) shows that the simulated average annual percentage growth in investment in region r between 2019 and 2030 depends on r's average annual percentage growth in capital between these two years, and r's growth in capital *in* 2030 compared with that *in* 2019. If r's capital grows rapidly between 2019 and 2030, then on this account r's investment will grow rapidly between 2019 and 2030. However, r's investment growth for 2019 to 2030 will be reduced below its capital growth if r's capital growth *in* 2030 slows relative to that *in* 2019. Under our assumption of forward-looking expectations, capital growth rates *in* 2030 depend mainly on capital growth between 2030 and 2040 (see point (f) in section 2.3). Capital growth rates *in* 2019 are given by data. Thus, for example, average annual investment growth in China for 2019 to 2030 is low (3.09 per cent, Table 11) relative to capital growth for the same period (5.36 per cent, Table 10). This is because Chinese capital growth *in* 2019 (calculated from data) was high relative to Chinese capital growth *in* 2030 (projected to reflect slowing capital growth from 2030-40, 4.09, Table 10).

Equations similar to (29) can be derived for average annual investment growth by region for 2030-40 and 2040-50. Part 3 of the supplementary material provides further analysis of the investment results in Table 11 generated under forward-looking expectations and compares them with results under static expectations.

6.4. Exports and imports

Export growth relative to import growth for a region is determined in a mechanical way from the GDP identity, which can be written in growth form as:

$$qgdp(r) = S_c(r) * cr(r) + S_g(r) * gr(r) + S_i(r) * qcgds(r) + S_x(r) * exp\,v\,ol(r) - S_m(r) * impvol(r) \quad (30)$$

where

qgdp(r) is the percentage change in real GDP in region r;

cr(r), gr(r), qcgds(r), expvol(r) and *impvol(r)* are percentage changes in real private consumption, real government consumption, real investment, export volumes and import volumes; and

$S_c(r)$, $S_g(r)$, $S_i(r)$, $S_x(r)$ and $S_m(r)$ are the shares of expenditure aggregates in GDP.

For most regions, $S_x(r)$ is approximately equal to $S_m(r)$. In 2019, the absolute value of $S_x(r)$ - $S_m(r)$ was less than 0.05 for all regions except Saudi Arabia which had a trade surplus of about 13 per cent of GDP. With trade close to balanced, whether exports grow relative to imports or vice versa depends on whether GDP grows relative to absorption (consumption plus investment).

For all regions, consumption (private plus public) is large relative to investment. Thus, in most cases we would expect exports to grow relative to imports if GDP grows relative to consumption and vice versa. In the 2019-30 simulation, this holds for 11 regions out of 13. The two exceptions are France and RoW. For France, growth in exports exceeds growth in imports (1.76 per cent compared with 1.12 per cent, Table 11) but GDP growth is less than consumption growth (1.09 compared with 1.51). The explanation is France's very weak growth in investment (-1.37 per cent). For RoW, strong investment growth (4.60 per cent) explains the increase in imports relative to exports despite faster growth in GDP than in consumption.

In the 2030-40 and 2040-50 simulations, the movements in the consumption/GDP and exports/import ratios have opposite signs in 20 out of 26 cases. In the 6 exceptional cases the movements in both ratios are small.

While the GDP identity (30) helps us to understand export growth relative to import growth, it does not tell us whether to expect trade to grow fast or slow relative to GDP. As a starting point, we might assume that a region's exports and imports grow broadly in line with its GDP. If the movements in GDP and absorption (already explained) dictate that exports must increase relative to imports, then we would expect real devaluation, stimulating export growth above GDP growth and retarding import growth below GDP growth. Similarly, if imports must increase relative to exports, then we would expect real appreciation, retarding export growth below GDP growth and stimulating import growth above GDP growth. On this basis, we would expect GDP growth to lie between export and import growth. With reference to Table 11, we see that in the three forecast periods GDP growth *does* lie between export and import growth in 26 of the 39 possibilities (13 regions by 3 periods).

In 6 cases, export and import growth exceed GDP growth and in 7 cases GDP growth exceeds export and import growth. We suspect that in these 13 cases export-oriented industries rely heavily on imported intermediate inputs. Thus, elevation of export growth above GDP growth can elevate import growth above GDP growth, despite devaluation. Similarly, retardation of export growth below GDP growth can retard import growth below GDP growth, despite appreciation. Ten out of the 13 cases fit this pattern with import growth lying between GDP growth and export growth.

6.5. Fossil fuel variables

The upper part of Table 14 shows shifts in fossil fuel use per unit of activity in each region in the three forecast periods. The 2019-30 coal result for the USA, for example, means that through this period, under Stated Policies, the use of coal per unit of output by industries such as electricity generation is projected to decline at an average annual rate of 13.69 per cent. Over 11 years this is an 80 per cent reduction. Almost all the entries in the upper part of Table 14 are negative. The only exceptions are gas use by India and coal use by Saudi Arabia in 2019-30.

Recall from the discussion of panel 7 in Table 2 that we treated the Stated Policies for fossil-fuel use in each region as commitments, independent of other economic variables such as GDP. If we adopted a slower GDP growth rate for a region, then the projected rates of decline in fossil-fuel use per unit of activity in the region would be less than those shown in Table 14 and vice versa. In calculations not reported here, we found that varying the GDP forecasts over plausible ranges does not affect the conclusions that can be drawn from the upper part of Table 14.

Despite the general declines in fossil-fuel use per unit of activity, worldwide use of fossil fuels under Stated Policies is stubbornly persistent. As shown in the lower part of Table 14, worldwide use (equals output) of coal declines by only 1 to 2 per cent a year across the forecast periods. Use of oil and gas actually increases between 2019 and 2030. The use of oil then declines slowly while the use of gas stays close to constant.

In the baseline simulations we assumed no change in the availability of natural resources, which are used principally by the fossil-fuel industries. This did not generate scarcity of natural resources. With weak demand for fossil fuels, the last row of Table 14 projects little change in their real prices.

Table 14. Projections for fossil-fuel variables under Stated Policies (STEPS)

Average annual % shifts in fossil-fuel inputs per unit of activity by using agents									
	Coal			Oil			Gas		
	2019-30	2030-40	2040-50	2019-30	2030-40	2040-50	2019-30	2030-40	2040-50
USA	-13.69	-9.11	-9.48	-2.57	-4.49	-3.81	-2.64	-4.64	-4.20
Canada	-5.78	-1.78	-1.44	-1.40	-2.68	-2.07	-0.66	-2.05	-1.65
Mexico	-5.78	-1.78	-1.44	-1.40	-2.68	-2.07	-0.66	-2.05	-1.65
China	-3.84	-4.83	-5.47	-2.17	-3.57	-4.35	-0.64	-2.30	-3.28
Japan	-3.96	-2.85	-2.83	-2.28	-2.80	-2.73	-5.28	-2.26	-2.27
SKorea	-3.96	-2.85	-2.83	-2.28	-2.80	-2.73	-5.28	-2.26	-2.27
India	-2.18	-6.49	-5.92	-1.20	-4.58	-3.88	0.51	-3.99	-3.24
France	-6.46	-5.81	-5.72	-2.41	-3.88	-3.91	-3.34	-3.91	-3.76
Germany	-6.46	-5.81	-5.72	-2.41	-3.88	-3.91	-3.34	-3.91	-3.76
UK	-6.46	-5.81	-5.72	-2.41	-3.88	-3.91	-3.34	-3.91	-3.76
RoEU	-6.46	-5.81	-5.72	-2.41	-3.88	-3.91	-3.34	-3.91	-3.76
Saudi Arabia	2.91	-1.22	-0.23	-1.33	-2.00	-1.10	-0.27	-2.23	-1.16
RoW	-2.76	-3.07	-2.45	-0.58	-2.48	-1.90	-1.68	-2.59	-1.98
World average	-4.35	-4.84	-4.77	-1.69	-3.42	-2.95	-2.18	-2.98	-2.42
Average annual % changes in world outputs and prices									
Output	-1.09	-1.70	-1.51	1.13	-0.33	-0.14	0.13	-0.06	0.09
Real price: price relative to global GDP price	-0.10	-0.78	-0.68	-0.14	-1.20	-0.71	0.01	-1.10	-0.61

Source: Author calculations

7. Concluding remarks

Over the last 25 years, researchers at the Centre of Policy Studies have completed several studies involving shock-intensive historical and baseline simulations using single-country models, see for example Dixon and Rimmer (2002; 2004; 2017) and Giesecke (2002). This paper forms part of our first project on applying the shock-intensive methodology in a multi-country framework. In addition to the work reported here, the broader project includes a detailed historical simulation connecting the GTAP databases for 2004 and 2014, and a validation exercise, see Dixon and Rimmer (2023a; 2023b). We hoped to build technology trends by industry and region from the 2004 to 2014 historical simulation into our update simulation for 2014-19 and our baseline simulations. In this way, we hoped to go beyond the 4-sector technology disaggregation (agriculture, mining, manufacturing and services) in Britz and Roson (2019). However, we were discouraged by our 2014-17 validation exercise which gave no support for trending forward our technology results at an industry/region level. With revisions to the 2017 GTAP database, we hope in future research to revisit the validation work.

Confronting models with time-series data, either past or forecast, has sharpened our understanding of the limitations and strengths of the CGE framework. The major lesson on limitations comes from seeing how little of the past can be explained by a CGE model without help from large movements in unexplained preference and technology shifts and phantom taxes. For example, in the 2014-19 simulation, we found that a massive preference shift by importing agents in favor of Indian products was required to explain the observed growth in Indian exports that took place despite substantial cost increases. Similarly with the future. For example, taking IEA fossil-fuel forecasts into our baselines required large technology shifts not explained in our model, against the use of fossil fuels.

On the other hand, a strength of CGE modelling is that it quantifies the shift variables. This can lead to hypotheses on why particular events took place. For example, was there a sharp improvement in the quality and marketing of Indian exports between 2014 and 2019? In light of the implied technology shifts, are the IEA fossil-fuel forecasts plausible?

Other practical strengths of shock-intensive CGE studies are updating and data checking. For example, starting from a comprehensive GTAP database for 2014, our 2014-19 simulation produced an updated GTAP database for 2019 that was consistent with a large body of macro and energy data. This process also revealed problems requiring rectification in the 2014 database (see Dixon and Rimmer (2024) and Wittwer and Waschik (2024)).

While we are convinced that shock-intensive historical and baseline simulations are a potentially fruitful direction for the development of CGE modelling, our experience suggests that work along these lines cannot be undertaken lightly. Worthwhile results require theoretical insights especially with respect to closures and enormous efforts in data handling and reconciliation between sources.

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