Creating a GTAP Baseline for 2014 to 2050 With Special Reference to Canada

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Creating a GTAP baseline for 2014 to 2050 with special reference to Canada

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Abstract: By 2020, the GTAP team had created 4 comparable GTAP databases, referring to the years 2004, 2007, 2011 and 2014. They had also produced a preliminary 2017 database. The aim of the project reported in this paper was to use this time series of databases to derive and apply methods for:

1. **estimating trends** at a disaggregated level in industry technologies and consumer preferences;
2. **creating baseline forecasts** incorporating a wide range of macro, demographic and energy forecasts from specialist organizations together with disaggregated technology and preference trends; and
3. **updating and checking GTAP databases, and establishing validation methods** for assessing the performance of baseline forecasts.

Towards these objectives, we produced several interim reports and 3 final reports. This paper explains our methods and reviews the project findings.

JEL codes: C68, E17, D57 and D58

Key words: GTAP data; Estimating technology trends; Baseline forecasting; Updating and validation

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Summary

(1) This paper describes the construction of a *baseline* for a 57-commodity, 13-region version of the GTAP model covering the period 2014 to 2050. It completes the third part of a project undertaken with financial support from the USITC, the WTO and Global Affairs Canada. In the first part, we deduced changes in industry technologies and consumer preferences by conducting an *historical* simulation from 2004 to 2014. In the second part, we undertook a *validation* exercise for 2014 to 2017.

(2) The baseline consists of four linked simulations starting from the GTAP database for 2014. The first simulation moves from 2014 to 2019 in a single 5-year jump. The second starts from the 2019 database formed in the first simulation and moves out 11 years to 2030, again in a single jump. The third and fourth simulations each jump out 10 years starting from the database created in the previous simulation. The shocks in the first simulation were derived from data on actual movements in a considerable number of variables. In the other simulations, we built in forecasts from the IMF, the ILO, IEA and IIASA.

(3) Conducting the simulations required three methodological innovations:
- (i) the use of a smooth-growth assumption for saving in each region to handle the accumulation of capital, wealth and net foreign assets in simulations which jump across years without explicit modelling of intervening years;
- (ii) the introduction of forward-looking expectations so that capital creation in a region in year t is informed by demographic and other foreseeable developments in the upcoming period; and
- (iii) the specification of closures that enable incorporation of observed and forecasted movements in a wide range of naturally endogenous variables.

(4) At the national macro level, the baseline shows:
- A slowdown in the Chinese economy with weak investment growth to 2030 and a turnaround in its trade accounts after 2030 with import growth exceeding export growth;
- Extremely strong growth in trade for India with annual export growth sustained out to 2050 at between 6 and 8 per cent and import growth between 4 and 5 per cent;
- Strong wage growth in most regions out to 2050 and reductions in rates of return on capital reflecting continuing high rates of global saving supporting fast growth in capital relative to labour;
- Sluggish growth and a poor wage outcome for Saudi Arabia reflecting declining markets for oil and gas;
- Weak GDP growth for Japan reflecting declining employment but, at the same time, moderate improvement in wages;
- Rapid reductions in coal per unit of output in using industries in most regions but relatively slow decline in global use of coal because of strong growth in GDP and electricity production in major using economies such as India;
- Reductions in use of oil and gas per unit of output in using industries in most regions but almost no decline in global use.

(5) In addition to macro results, GTAP produces a huge volume of industry results. To guide analysis of these results, we develop a framework that decomposes the gap between an industry's growth rate and that of GDP into the part attributable to the allocation of the industry's sales across markets and the part attributable to its performance in those markets. We apply the framework to the industry results for Canada.

(6) With different strengths for different industries, we find that all of the following play a role in determining the output growth rate for a Canadian industry relative to GDP:

- the distribution of the industry's sales to different sales categories and the growth rates of the categories;
- the capital-labour ratio in the industry's production function and the economy-wide movements in capital rental rates relative to wage rates;
- the expenditure elasticity of demand by households for the industry's product;
- the distribution of the industry's exports across trading partners (the proportions of its exports that go to the U.S., China, etc) and the changes in the prices of competitors in Canada's export markets relative to changes in the price of the Canadian product;
- the sources (U.S., China, etc) of imports that compete with the industry's product in Canadian markets and changes in the prices of these imported products relative to that of the Canadian product;
- technological/environmental changes affecting the use of fossil-fuel products; and
- assumptions about the availability of agricultural land and the share of the industry's costs accounted for by land.

(7) We conclude the paper with what we hope is an impartial assessment of the success/shortcomings of the overall project. The project has not yet fulfilled our initial hopes. We have not satisfactorily integrated the historical and validation components into the baseline. In the baseline we did not obtain realistic results for accumulation in each region of foreign assets and liabilities. Nevertheless, our conclusions are optimistic. We have solved a lot of theoretical and data problems. We have obtained results that are interpretable and point the way for future improvements. We remain convinced that historical, validation and baseline exercises are an important vehicle for improving the quality and policy relevance of global economic modelling with GTAP.

Creating a GTAP baseline for 2014 to 2050 with special reference to Canada

1. Introduction

This paper describes the construction of a baseline for a 57-commodity, 13-region version of the GTAP model. The baseline covers the period 2014 to 2050. It was created by four linked simulations for the periods 2014-2019, 2019-2030, 2030-2040 and 2040-2050.

The starting point for the first simulation is the GTAP database for 2014. We simulate from 2014 to 2019 in a single 5-year jump. The main purpose of the 2014-19 simulation is to create a relatively up-to-date launching point for the subsequent simulations. We chose 2014 because this is the year of the latest "mature" GTAP database[1]. We chose 2019 because it is the latest year for comprehensive data uncontaminated by Covid. The second simulation starts from the 2019 database formed in the first simulation and moves out 11 years to 2030, again in a single jump. The third and fourth simulations each jump out 10 years starting from the database created in the previous simulation.

The 2014-19 simulation is historical. In setting the shocks that morphed the 2014 world economy into the 2019 world economy we drew on data showing actual movements in a considerable number of variables. In the other simulations, we built in forecasts from the International Monetary Fund (IMF), the International Labor Organization (ILO), the International Energy Agency (IEA) and the International Institute for Applied Systems Analysis (IIASA).

The paper is set out as follows. Sections 2 and 3 are short, theoretical and we hope readable. Section 2 gives an interpretation of a CGE model, even a dynamic one, as a system of equations in variables that refer to a single year. This is important for understanding how long-run simulations that jump over a number of years can be computed in GEMPACK software. Section 3 describes what we refer to as the standard long-run closure. The principal innovations in this closure are: (a) the use of the smooth-growth assumption for saving in each region to bridge the gap between disjoint years, 2014 to 2019, 2019 to 2030, etc; and (b) the imposition of forward-looking expectations for the determination of investment. Understanding the standard long-run closure is helpful for understanding the development of the baseline closures. Forming these closures requires swapping some variables (e.g. real GDP) that are endogenous in the standard long-run closure to the exogenous category so that they can receive shocks in our baseline simulations either from data (in the 2014-19 simulation) or from extraneous forecasts (in simulations for later periods).

[1] As explained in Dixon and Rimmer (2023b), we did a lot of work on the GTAP database for 2017 but decided that it wasn't ready for use in the construction of a baseline. We understand that the 2017 database has subsequently been revised. The 2014 database we used as the starting point for our simulations is close to but not exactly the database supplied by GTAP. Our 2014 database reflects the update simulation described in Dixon and Rimmer (2023a). We have also made some revisions based on macro data. For example, the data supplied by GTAP shows a substantial trade deficit in 2014 for Canada. We revised and rebalanced so that in our database for 2014, Canada has a small trade deficit in line with OECD data in Table A1.2a (see Appendix 1).

The details of the closure modifications for the 2014-19 simulation are in section 4. The closure was developed in 19 steps. At each step, we introduced additional shocks and monitored progress by running a checking simulation. The process is documented in Table 4.1 which shows swaps of variables between endogenous and exogenous categories and the data sources for the shocks. We conclude section 4 with a summary of the changes in technology and preference variables revealed by the 2014-19 simulation.

Section 5 displays the modifications to the standard long-run closure required to bring IMF, ILO, IIASA and IEA forecasts into the simulations for 2019-30, 2030-40 and 2040-50. These modifications are not as complex as those required for the data-driven 2014-19 simulation. They were implemented in a 7-step procedure documented in Table 5.1.

Section 6 sets out results for macro and energy variables for all four simulations together with intuitive and back-of-the-envelope explanations.

GTAP produces a huge volume of industry results. In section 7, we develop a framework for analysing industry results. The framework decomposes the gap between an industry's growth rate and that of GDP into the part attributable to the allocation of the industry's sales across markets and the part attributable to its performance in those markets. We apply the framework to the industry results for Canada.

Concluding remarks are in section 8. We explain that the current paper addresses the third part, baseline creation, of a larger project. In the first two parts, we undertook an historical simulation for 2004 to 2014 and a validation simulation for 2014 to 2017. We try to make an impartial assessment of the success of the project. The project has not yet fulfilled our initial hopes. We have not satisfactorily integrated the three parts. In particular, we have not taken much from the historical and validation simulations into the baseline simulation.

Nevertheless, our conclusions in section 8 are optimistic. We have solved a lot of theoretical and data problems. We have obtained results that are interpretable and point the way for future improvements. We remain convinced that historical, validation and baseline exercises are an important vehicle for improving the quality and policy relevance of global economic modelling with GTAP.

The paper has four appendices. Appendix 1 provides details of the data and forecasts used to set the shocks in the four simulations. Appendix 2 gives the mathematical details of the smooth-growth assumption for saving and its use in long-run simulations. Appendix 3 describes our iterative procedure for computing with forward-looking expectations for investors and compares solutions under for forward-looking and static expectations. Appendix 4 defines the GTAP industries.

2. Simulations connecting disjoint years

A system of equations in variables for a single year

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 depreciated *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

$$F(X) = 0 \tag{2.1}$$

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 (2.1) we need to set values for n-m exogenous variables.

The GEMPACK solution method[2] used in most application of GTAP requires an initial solution, a value for the vector X that satisfies (2.1). 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.

Year-on-year simulations

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. In the year-2 computation, we compute the required solution for year 2 by shocking the exogenous variables with movements from their values in the initial solution for year 2 (the final values for year 1) to their required values for year 2. Using differences in the final year-1 solution in the values for end-of-year and start-of-year stock variables, we can impose shocks to start-of-year stock variables in the year-2 computation that equate start-of-year stocks in year 2 to end-of-year stocks in year 1.

Disjoint-year simulations

Rather than conduct year-on-year simulations, we jump forward in multi-year steps. The problem is that 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 $t+\tau$?

[2] See Horridge *et al.* (2018).

Our approach is to use a smooth growth assumption applied to saving. This can be understood by an example. Assume that the simulated value for saving in region r is 50 per cent greater in year t+τ than in year t. Under the smooth growth assumption, we assume that: 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 the 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 (see Appendix 2). 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. Net foreign assets for each region at the start of year t+τ can then be deduced by comparing the region's start-of-year capital with its savings accumulated from year t to year t+τ-1.

Essentially, in our GEMPACK computations, the initial solution for year t+τ is provided by the solution for year t. However, there are complications. Under the smooth-growth assumption, the determination of accumulated savings and therefore start-of-year stock variables for year t+τ depend on saving *in* year t+τ. Consequently, we can't simply treat start-of-year stock variables as exogenous and give them shocks derived from a database or from a solution for a previous year. Start-of-year stock variables for year t+τ depend endogenously on saving in year t+τ. This means that the smooth-growth assumption invalidates the simple representation of the model in (2.1). It also means that the year t solution does not immediately reveal an initial solution for year t+τ. Fortunately, as explained in Appendix 2, these difficulties were overcome a couple of decades ago exploiting an insight provided by our colleague Mark Horridge.

3. The standard long-run closure

In setting up the simulations for 2014-19, 2019-30, 2030-40 and 2040-50, our starting point in each case is what we will refer to as the standard long-run closure[3]. In this closure:

(a) all technology, consumer preference and tax-rate variables are exogenous.
(b) population, employment, and availability of land and other natural resources in each region are exogenous.
(c) saving in each region in year t+τ is determined as a function of the region's net national product. This is sufficient to tie down global saving in t+τ which in turn gives us global investment in t+τ.
(d) global investment in t+τ is allocated across regions so that capital growth *in* t+τ in region r reflects the region's capital growth over the subsequent period. For example, global investment in the 2030 solution is allocated across regions to reflect average annual capital growth rates for 2030 to 2040. This gives our regional investors forward-looking expectations. Because a region's capital growth over the subsequent period is not known when we are solving the model for year t+τ, we set regional capital growth rates in the year-t+τ computation via an iterative approach (see Appendix 3).

[3] This is standard only in the context of this paper. Variants of this closure have been used at the Centre of Policy Studies (CoPS) for many years in simulations that connect disjoint years but nevertheless account for accumulation processes, see for example Dixon and Rimmer (2002). Our method dates back to Evans (1972).

(e) 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.
(f) 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.
(g) accumulated savings in each region is deduced from a smooth-growth path for real saving between year t and year t+τ-1.
(h) exchange rates are implicitly set on one, and all values are in $US.
(i) the nominal value of global GDP is effectively exogenous, providing the numeraire.

4. The 2014-19 historical simulation: updating the GTAP database[4]

4.1. Bringing in data for 2014-2019: explanation of the 19 steps (panels) in Table 4.1

In the 2014-19 historical simulation, we apply shocks to represent observed movements between these two years in some variables and introduce assumptions for other variables. Appendix 1 contains details on the formulation of the shocks.

The shocked variables can be seen in columns 2 and 3 of Table 4.1. Some of these variables are exogenous in the standard long-run closure. For these variables, shocks can be applied without a closure change. An example of such a variable is regional population growth [pop(r), panel 3, Table 4.1]. Other shocked variables are endogenous in the standard long-run closure. Applying shocks to these variables requires a closure change. An example is real GDP in each region [qgdp_obs(r), panel 1]. Movements in this variable from 2014 to 2019 can be observed from OECD data [column 4, panel 1]. For real GDP to become exogenous, we must endogenize a naturally exogenous variable (a variable that is exogenous in the standard long-run closure). As can be seen from columns 5 and 6, the variable that we chose for endogenization was primary-factor-saving technical change [afereg(r)].

In creating the 2014-19 historical closure, we used a step-by-step approach. Each step added to the previous step by introducing a movement in an additional variable and computing a new solution. As we moved through the steps, the closure became increasingly complex. The step-by-step approach was necessary so that we could locate and rectify problems. If step *x* produced a satisfactory solution but step *x*+1 failed, then to a large extent we could confine our search for the problem to the limited changes that were made between steps *x* and *x*+1. As can be seen from Table 4.1, we conducted the 2014-19 simulation in 19 steps.

The broad outline of our 19-step strategy can be seen in the five-part organization of Table 4.1. The first part introduces real GDP for each region, explained by factor inputs and macro technology (total factor productivity). The second part introduces expenditure components of real GDP for each region. The third part puts in place energy variables at the global level. The fourth part introduces macro price variables for each region and the fifth part is concerned with net foreign liabilities and wealth.

By the time we had implemented all 19 steps in Table 4.1, the 2014-19 simulation produced a database for 2019 that was consistent with data for each region on real GDP and its income

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[4] We record storage details for project simulations in Appendix 5.

Table 4.1. Shocked variables and closure swaps for the 2014-19 simulation

Panel no	Exo variable	Description	Source for shock	Swap variable *(goes endogenous)*	Description
(1)	(2)	(3)	(4)	(5)	(6)
Part 1:	***Real GDP and supply-side determinants***				
1	qgdp_obs(r)	Real GDP	OECD data	afereg(r)	Primary factor tech change by region
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
3	lsreg(r)	Employment, same as labour supply	Penn data on total hours of employment	No swap	
	pop(r)	Population	OECD 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 from 2004-14	No swap	
Part 2a:	***Real GDP from the expenditure side (C, G, I and M, with X as a residual)***				
7	cr(r)	Real private consumption	OECD data	apcnnp(r)	Average Hhld propensity to consume out of net national product
8	gr(r)	Real govt. consumption	OECD data	dpgov(r)	Average Govt propensity to consume out of net national product
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

Table 4.1 continues …

… Table 4.1 continued

Panel no	Exo variable	Description	Source for shock	Swap variable *(goes endogenous)*	Description
(1)	(2)	(3)	(4)	(5)	(6)
Part 2b: Introducing shocks for exports, making real GDP in each region the residual rather than exports					
11	expvol_obs(r)	Real exports	OECD data	ff_qgdp_obs(r)	Correction to regional GDP observations to reconcile them with expenditure determination of GDP
	f_qgdp_obs	Scalar real GDP correction from panel 9 must now be eliminated by setting it exogenously on zero	Zero shock	f_expvol_obs	Scalar correction to observations for real exports by region to reconcile global real exports with global real imports
Part 3: World prices and quantities for fossil fuels					
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 & Saudi Arabia statistics	ff_pworld(Foss)	Facilitates assumption that import price for fossil fuel f is same worldwide
	ff_pm(Foss,r)	Equates fossil fuel import price across regions	Zero shock	f_to(Foss,r)	Phantom taxes to adjust fossil fuel costs

Table 4.1 continues …

… Table 4.1 continued

Panel no	Exo variable	Description	Source for shock	Swap variable *(goes endogenous)*	Description
Part 4: Prices of GDP and selected expenditure components					
14	f_pgdp_obs(r)	GDP price index	OECD data	f3_twistmd(r)	World-wide preference shift towards/against exports from r
	f3twmd_ave	Ave pref shift across world	Zero shock	f_wgdpg	Turns off earlier determination of wld price level
15	f_p_i_obs(r), all r, except RoW	Investment price index	OECD data	a_cgds (r), all r, except RoW	Technical change in production of capital goods
16	f_p_x_obs(r), all r, except RoW	Export price index	OECD data	phtx_i(r), all r, except RoW	Phantom export tax
17	f_p_m_obs(r), all r, except RoW	Import price index	OECD data	phtx_i2(r), all r, except RoW	Discriminatory tax on all exports sent to r, except RoW
	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
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
	ff_tofr(i,r)	Vector shift in phantom production taxes across the industries in region r	Zero shock	tof(i,r)	Phantom subsidy component of production taxes (to)
Part 5: Wealth and net foreign liabilities					
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 growth in saving

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.

Part 1 of Table 4.1: Real GDP and supply-side determinants

Panel 1: real GDP. As mentioned earlier, 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. These movements are given in Table 4.2. 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

Table 4.2. Percentage growth between 2014 and 2019

	Population (pop), data	Real GDP (qgdp_obs), data	Capital stock (kb_obs), data	Employment (lsreg), data	K/L tech twist (twistKL), extrap from 2004-14
1 USA	3.12	12.43	11.11	1.62	3.73
2 Canada	6.07	9.70	11.49	2.97	7.17
3 Mexico	5.54	10.41	12.81	6.53	-1.63
4 China	2.44	38.55	54.57	-0.21	24.37
5 Japan	-0.71	4.29	4.79	-3.60	4.19
6 SKorea	2.01	14.88	21.72	0.55	11.2
7 India	5.80	37.88	39.67	4.33	15.94
8 France	1.67	8.48	10.30	-0.73	4.23
9 Germany	2.61	8.72	8.95	1.55	0.76
10 UK	3.41	10.74	11.60	1.56	0.97
11 RoEU	0.47	13.61	10.19	-3.15	6.45
12 SaudiArabia	14.07	8.06	29.77	14.07	13.42
13 RoW	9.60	14.16	18.99	3.13	7.84

relevant parts of the general equilibrium model. In the particular case of real GDP, our guiding back-of-the envelope framework is the aggregate production function:

$$\mathrm{RealGDP}(r) = A(r) * F_r\left(L(r), K(r), \mathrm{Land}(r), \mathrm{NatRes}(r)\right) \tag{4.1}$$

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 labour, 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 3]. Capital in each region is tied down by our assumptions for relative actual rates of return and accumulated global savings from start-of-2014 to start-of-2019 [points (e) - (g)]. 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) from equation (4.1)]. 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.

Panel 2: regional capital stocks. Now we introduce data from the Penn World Tables on movements between start-of-2014 and start-of-2019 in capital stocks by region (measured by real capital services). These data are shown in Table 4.2. We make an endogenous scalar adjustment 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 (f) and (g). The scalar adjustment is achieved by endogenizing the variable shift_kb which occurs in the model equation:

$$\mathrm{kb}(r) = \mathrm{kb\_obs}(r) + \mathrm{shift\_kb} \quad \text{for all } r \in \mathrm{Reg} \tag{4.2}$$

where

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

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

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

Fortunately, the scalar 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 now in place, we must free up rates of return so that they can reflect the scarcity of capital in each region. We do this via the equation:

$$\text{rorc\_i}(j,r) = \text{f\_rorc}(r) + \text{ff\_rorc} \qquad \text{for all } j \in \text{Ind},\ r \in \text{Reg} \tag{4.3}$$

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 (e) and (f), this treatment of the shift variables means that rates of return move endogenously by the same percentage in all industries in all regions. In the 2014-2019 historical closure, we endogenize f_rorc(r) and exogenize ff_rorc. This allows rates of return to vary across regions, but not across industries within a region.

Panel 3: employment and population. Employment and population in each region are exogenous in the standard closure. Consequently, introduction of data on growth in these variables between 2014 and 2019 does not require closure swaps. As indicated in Table 4.1 [column 4, panel 3], in the 2014-19 historical simulation we shock these variables with percentage movements between 2014 and 2019 derived from Penn World Tables and OECD data. The shocks are in Table 4.2.

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 assume no change in land-availability by region between 2014 and 2019.

Panel 5: natural resources. The GTAP database for 2014 shows that about 80 per cent of the returns to natural resources are in the coal, oil and gas industries. In the standard long-run closure, the treatment of natural resources is similar to that of land. In the closure for our 2014-19 historical simulation, we treated natural resources as elastically supplied at exogenously given user prices. This required endogenization of the supply of natural resources, qo(natres,r), in each region and exogenization of the rental or user price, 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 apply 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. As will be apparent in later steps in the development of the 2014-19 historical closure, we introduce data on movements in prices of coal, oil and gas.

These over-rule the -5.26 per cent assumption in the determination of the prices of these energy commodities and endogenize profitability per unit of their production.

Panel 6: Twist in capital-labour technology. Table 4.2 shows very large increases in capital/labour ratios in all regions between 2014 and 2019. For example, the K/L ratio for China increased by 54.90 per cent [= 100*((1.5457)/(1-0.0021)-1)]. We also observed very large K/L increases in our historical simulation for 2004-14 (Dixon and Rimmer, 2023a). Large K/L increases suggest that technical change must be biased in favour of using capital. In our 2004-14 simulation, we estimated the bias for each region by introducing data on the earnings of capital and labour. For 2014-19, we do not have earnings data. In these circumstances, we introduce 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/labour ratio by *x* per cent beyond what can be explained by movements in the costs of using capital and labour. 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 avoid indeterminacy between the roles of the technology changes in this panel and the technology changes introduced to absorb real GDP data in panel 1.

In the absence of the twistKL shocks, our 2014-19 simulation would have implied unrealistic movements in factor prices. As we found in our 2004-14 simulation, twists towards capital (positive movements in twistKL) were required in the 2014-19 simulation for most regions to prevent collapse in the rental price of capital and correspondingly unrealistically large increases in real wage rates.

Overview of Part 1

The data inputs and closure swaps to the end of panel 6 complete, to a large extent, the estimation of the contribution to GDP of technical change. This is indicated by the similarity of the first two columns of Table 4.3. These show the technology contributions after implementation of panel 6, and the final estimated contributions at the end of panel 19. As we move from panel 6 to panel 19, real GDP and the major factor inputs don't change leaving the technology contribution approximately unchanged. An exception is Saudi Arabia. As explained in the discussion of panel 5, natural resource inputs are endogenous. They change when we introduce data in Part 3 on output of oil and other fossil fuels. This is important for Saudi Arabia for which there is a large contribution to GDP from the input of natural resources.

The 3rd and 4th columns in Table 4.3 show percentage changes in wage rates deflated by consumer prices. With factor inputs and technologies including K/L biases largely fixed by the end of panel 6, we expected to see little movement in these real wage rates beyond panel 6. This expectation was fulfilled only approximately. Simulated real wage movements are affected by the introduction in later parts of Table 4.1 of data on movements in energy variables and in the prices of consumer goods (the deflator used for real wages) relative to the prices of other components of GDP. Similarly, introduction of these data affect simulated movements in rates of return on capital. This is shown by the comparison of the 5th and 6th columns of Table 4.3.

Table 4.3. Percentage growth between 2014 and 2019: simulation results after Part 1 (panels 1-6) compared with final results

	Contributions of tech change to GDP (cont_tech)		Real wage rate (realwager)		Actual rate of return (rorc)	
	Panels 1- 6	Final	Panels 1- 6	Final	Panels 1- 6	Final
1 USA	6.50	5.69	12.29	15.40	-3.97	-2.43
2 Canada	2.66	1.91	7.48	6.84	-0.65	-7.08
3 Mexico	0.05	-0.25	8.57	16.19	-11.26	-22.75
4 China	11.16	9.60	47.05	49.43	-25.98	-32.07
5 Japan	3.49	2.94	10.24	16.13	-1.80	-10.00
6 SKorea	3.39	2.45	17.54	23.57	-10.21	-16.47
7 India	13.95	11.78	35.67	37.50	-11.62	0.51
8 France	3.52	2.65	12.30	15.36	-6.22	-10.72
9 Germany	2.75	2.06	11.62	16.66	-5.20	-16.78
10 UK	3.32	2.58	13.94	18.52	-10.10	-22.04
11 RoEU	8.05	6.55	19.73	23.09	1.90	-2.30
12 SaudiArabia	-5.02	-12.99	-3.23	0.30	-18.29	-9.11
13 RoW	2.50	3.13	12.32	19.17	-8.51	-14.06

Part 2a of Table 4.1: Real GDP from the expenditure side (C, G, I and M, with X as a residual)

Panels 7 and 8: real private and public consumption. In the standard long-run closure, these variables are linked to net national income [point (c) in section 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 public consumption to be set exogenously and shocked with their actual movements between 2014 and 2019.

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

$$\mathrm{ke(r) - kb(r) = g(r) + ff\_ke + f\_ke(r)} \qquad \text{for all r} \tag{4.4}$$

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 year capital, growth from start of 2014 to start of 2019.

g(r) is an exogenous variable introducing forward-looking expectations. As explained in Appendix 3, g(r) is determined in an iterative process. It 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 (4.4) 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 change in investment expenditure for r.

The variables ff_ke and f_ke(r) have no role in any equation apart from (4.4). Consequently, 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. For whatever solution we found for the model, another solution could be found by adding *x* to ff_ke and subtracting *x* from each of the f_ke(r)s. However, exogenizing ff_ke left us with a puzzling problem.

When we exogenize ff_ke, what is the corresponding endogenization?

The answer can be found in the identity:

$$\sum_r S_{gdp}(r) * qgdp(r) = \sum_r S_c(r) * cr(r) + \sum_r S_g(r) * gr(r) + \sum_r S_i(r) * qcgds(r) \qquad (4.5)$$

In (4.5) 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, $S_{gdp}(r)$, are regional shares in world GDP.

The RHS of (4.5) 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, $S_c(r)$, $S_g(r)$, and $S_i(r)$, 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 that fact that world exports must add up to world imports.

With the data introduced in panels 7 and 8 and in this panel, the RHS of (4.5) 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 (4.5) to be determined endogenously. To do this we added the equation

$$qgdp\_obs(r) = qgdp(r) + f\_gdp\_obs + ff\_gdp\_obs(r) \qquad (4.6)$$

We can think of the two shift variables on the RHS of (4.6) as being exogenous and unshocked through panels 1 to 8 in Table 4.1. Thus, 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 equation (4.5) to be satisfied. In our simulation, the result for f_gdp_obs was very small. This indicates that there was almost no tension between the OECD data on movements in regional GDP, C, I and G and the GTAP shares used to aggregate these movements to the world level in equation (4.5).

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:

$$qm_a(j,r) = q_a(j,r) + \{\text{price terms}\} \; + SHRD_a(j,r) * twist\_src\_i(r) \tag{4.7}$$

$$qd_a(j,r) = q_a(j,r) + \{\text{price terms}\} \; - SHRM_a(j,r) * twist\_src\_i(r) \tag{4.8}$$

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 by agent a of composite j in region r;

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 the shares of imported and domestic j in expenditure by agent a on composite j in r.

In the standard long-run closure, twist_src_i(r) is exogenous. In our 2014-19 historical simulation, we accommodate observed movements in the quantities of imports by allowing adjustments in the simulated quantities through endogenous movements in twist_src_i(r).

The share coefficients attached to the twist terms in (4.7) and (4.8) preserve the condition that the share-weighted average of the percentage changes in the use of imported and domestic commodity j in region r by agent a equals the percentage change in the use of composite j in region r by agent a.

Part 2b of Table 4.1: Introducing shocks for exports, making real GDP in each region the residual rather than exports

Panel 11: 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 over-rule 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 (4.6) 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 shown in column 5 of panel 11. Fortunately, our result for this variable was small.

Part 3 of Table 4.1: World prices and quantities for fossil fuels

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. In the notation used in Table 4.1, these are the commodities in the set Foss.

Most of the demand for these commodities is intermediate, mainly in the Petroleum & 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:

$$q_f(c,j,r) = \{\text{activity and price terms}\} + wldout\_sh(c) - FOSS(c) * a\_neut(j,r) \qquad (4.9)$$

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

$$\text{for } j \in Ind,\ r \in Reg \qquad (4.10)$$

Equation (4.9) 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 additional terms, 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. A positive value for wldout_sh(c) means that industries use more of commodity c per unit of output (corresponds to a technological deterioration). 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. A positive value for a_neut(j,r) means that industry j uses less inputs per unit of output (corresponds to a technological improvement).

In equation (4.10), SC(c,j,r) is the share of costs in industry j in region r accounted for by inputs of c (includes intermediates and primary factors). Thus the LHS of (4.10) 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. f_neut(j,t) is endogenously determined at zero. As indicated in panel 12 of Table 4.1, 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 outputs of these commodities [qworld(foss)] and endogenized the technology variable wldout_sh(Foss). Thus, we accommodate the observations on world outputs by allowing world-wide shifts in the demands for coal, oil and gas.

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. Thus, 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. In this panel, we perform closure changes that allow us to move the price of each fossil fuel in each region in line with the movement in the world price. These closure changes can be explained via the model equations:

$$pm(c,r) = pworld(c) + ff\_pm(c,r) \quad \text{for } c \in Com,\ r \in Reg \qquad (4.11)$$

$$pworld(c) = \sum_{r \in REG} S_{wld}(c,r) * pm(c,r) + ff\_pworld(c) \quad \text{for } c \in Com \qquad (4.12)$$

$$pm(c,r) = ps(c,r) - to(c,r) \quad \text{for } c \in Com,\ r \in Reg \qquad (4.13)$$

$$to(c,r) = to\_wld(c) + f\_to(c,r) \quad \text{for } c \in Com,\ r \in Reg \qquad (4.14)$$

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 (4.12) 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 a shifter that can usually be interpreted as the percentage change in the ratio of the market price of c in r to the world price of c.

ps(c,r) is, in GTAP jargon, 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, (4.13) 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. The other variables in (4.11) - (4.14) are endogenous. ps(c,r) is determined by input prices and technology. pm(c,r) is determined in (4.13) by the supply price and subsidy. The subsidy is determined in (4.14) by shift variables. pworld(c,r) is determined in (4.12) as an average across regions of market prices. ff_pm(c,r) is determined in (4.11) as the movement in the ratio of the market price of c in r to the average price of c across regions.

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 (4.12) by endogenizing ff_pworld(c).

exogenized ff_pm(c,r) for c = coal, oil and gas and gave zero shocks. This equated movements in the market prices of coal, oil and gas across regions to movements 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.

Part 4 of Table 4.1: Prices of GDP and selected expenditure components

Panel 14: regional price indexes for GDP. OECD data show movements in the price deflator for GDP in all regions. We bring these movements into the 2014-19 simulation by exogenizing the variable f_pgdp_obs(r) for all r. This variable connects the simulated movements in GDP deflators with observed movements.

In the GTAP model, the movement in the GDP price deflator for region r reflects its real exchange rate or international competitiveness. An increase in r's GDP price deflator relative to that of its trade 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 than can be explained by changes in relative prices.

We set the average [f3twmd_ave] over the exporting countries 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 favour 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 (i) in section 3 that in the standard long-run closure, nominal global GDP is exogenous, providing the numeraire. Now, nominal global GDP must be endogenous. This is achieved in our version of the GTAP code by endogenizing the variable f_wgdpg. 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 RoW. We interpret these movements as referring to the market price of the cgds industry in each region. In the 2014-19 simulation, we exogenized f_p_i_obs(r) for all regions except RoW. This allowed us to shock the market prices of the cgds industries with the observed percentage movements in the investment price indexes. With cgds prices tied down, we endogenized productivity [a_cgds(r)] in the 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. So that we could take these observations into the 2014-19 simulation, we endogenized an export-tax variable for each region, separating export prices from costs. These are phantom taxes. Possible interpretations of these phantom taxes are discussed in section 4.2 under the heading "Exports and related variables".

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 simulation to the end of panel 16 generated regional import price movements for 2014 to 2019 that were only broadly consistent with the movements shown in OECD data.

We imposed import-price movements from OECD data for all regions except RoW, for which there were no data. 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 their exports to r. In section 4.2 (see the discussion of "Import prices") we interpret 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 all regions must equal import prices averaged over all 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 was 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* all regions and those in this panel applying to exports *to* all regions), we exogenized the global collection of the phantom discriminatory taxes deflated by the price of global GDP, d_colt_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). For example, in regions in which the phantom export taxes are 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 and determined its rate so that the regional collections of phantom indirect taxes (including the phantom production tax) were zero.

Part 5 of Table 4.1: Wealth and net foreign liabilities

Panel 19. We calculate region r's wealth at the start of year t, W(r,t), as the value of capital located in the region, VK(r,t) *less* the region's net foreign liabilities, NFL(r,t):

$$\mathrm{W(r,t) = VK(r,t)\ \text{-}NFL(r,t)} \quad \mathrm{r{\in}Reg} \tag{4.15}$$

Real wealth, RW(r,t), is given by

$$\mathrm{RW(r,t)} = \frac{\mathrm{W(r,t)}}{\mathrm{PW(r,t)}} \quad \mathrm{r{\in}Reg} \tag{4.16}$$

where PW(r,t) is the price of a unit of wealth in region r at the start of year t relative to the price at the start of a base period. In our 2014-19 simulation PW(r,t) is the price of a unit of wealth at the start of 2019 (year t) relative to the price at the start of 2014 (base period). By the price of a unit of wealth, we mean 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.

With the base year being 2014, the change in r's real wealth, RW14-19(r), between the start of 2014 and the start of 2019 is given by

$$\Delta\mathrm{RW14\text{-}19(r)} = \frac{\mathrm{VK(r,19)\ \text{-}NFL(r,19)}}{\mathrm{PW(r,19)}} - \left[\mathrm{VK(r,14)\ \text{-}NFL(r,14)}\right] \quad \mathrm{r{\in}Reg} \tag{4.17}$$

As explained in Appendix 2, we also determine the change in region r's real wealth via accumulated real net saving for 2014 to 2018. In stylized form, we have

$$\Delta RW14\text{-}19(r) = ACC\_RSAV14\text{-}18(r) + SWQH\_B(r) \quad r \in Reg \qquad (4.18)$$

where

ACC_RSAV14-18(r) is real net saving for region r accumulated over years 2014, 2015, 2016, 2017 and 2018; and

SWQH_B(r) is a shift variable.

In the standard long-run closure, the shift variable in (4.18) is exogenous. Net foreign liabilities in the simulation year is endogenous and net foreign liabilities in the base year is data. In the 2014-19 simulation, we exogenize NFL(r,19) to accommodate its observed value and we endogenize the shift variable SWQH_B(r).

To see how this works, it is useful to eliminate changes in real wealth from equations (4.17) and (4.18):

$$SWQH\_B(r) = \left[\frac{VK(r,19)}{PW(r,19)} - VK(r,14)\right] - ACC\_RSAV14\text{-}18(r) - \left[\frac{NFL(r,19)}{PW(r,19)} - NFL(r,14)\right] \quad r \in Reg \qquad (4.19)$$

With reference to (4.19), we see that the endogenously determined value for SWQH_B(r) can be interpreted as the increase in the real value of r's capital which is finance neither by r's saving, nor by an increase in r's real net foreign liabilities. In terms of (4.18), it is as though region r has received a gift of wealth. As analyzed by Bruneau *et al.* (2017), the gift 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.

4.2. Results from the 2014 to 2019 historical simulation

The main purpose of the 2014-19 historical simulation is to update the 2014 GTAP database to 2019, giving us a more current starting year for baseline simulations. In performing the update, we have taken account of movements between 2014 and 2019 in regional macro and world energy variables. While updating is the main purpose, the results for technology and preference variables generated in the update process are of interest. Many of these results together with shocks to selected observed variables are set out in Tables 4.4 to 4.10.

Real GDP and factor inputs and prices

Table 4.4 presents final results for movements in real GDP, factor inputs and 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 4.4 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 relative to other regions.

Table 4.4. Percentage changes between 2014 and 2019 in real GDP, factor inputs and prices, together with contributions of technology to real GDP*

	Real GDP qgdp	Capital kb	Employ-ment lsreg	Natural resource use qo(NatRes)	Tech cont. to GDP cont_tech	Real wage rate realwager	Rate of return on capital 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
SaudiArabia	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

* The capital and GDP numbers in this table differ from the data in Table 4.2 because of endogenous adjustments introduced in equations (4.2) and (4.6).

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 very small for Saudi Arabia. With the exception of Saudi Arabia, the simulated increases in real wage rates reflect technology improvements and reductions in rates of return on capital in all regions except India. Simulated rates of return fell in most regions despite the introduction to the simulation of historically determined technology twists favouring the use of capital (see the discussion of panel 6 in Table 4.1). Between 2014 and 2019 world saving increased relative to world GDP, leading to large increases in capital/labour ratios.

Recall from the discussion of panel 5 that we assumed elastic supply of natural resources. This produced quite volatile results varying from a simulated 28.60 per cent reduction in natural resource use by the 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 was only about 9 per cent.

Real GDP and expenditure components

Given the data in the shaded columns of Table 4.5, our 2014-19 historical simulation implied that Canada, Mexico, China, India and Saudi Arabia increased both their private and public consumption more rapidly than can be explained by the increases in their net national products: they experienced increases in their private and public average propensities to consume. By contrast, UK and RoEU reduced their average propensities to consume. For the remaining regions, one propensity increased and one fell. As mentioned earlier, at a global level consumption propensities decreased. Global saving increased relative to global GDP generating continuing downward pressure on returns to capital.

Table 4.5. Percentage changes between 2014 and 2019 in real GDP and its expenditure components, and 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
SaudiArabia	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

In Table 4.5, 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 (4.4). 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 4.5 shows a mixture of positives (preference twists towards imports) and negatives (preference twists against imports). The twists were positive for the European regions (France, German, 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 increasing ability to produce commodities that compete successfully in their domestic markets with imports.

World fossil-fuel variables

The last column of Table 4.6 shows sharp shifts against the use of fossil fuels, especially for 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 4.6. Percentage changes between 2014 and 2019 in world energy variables

	Quantity of world output	Average world price in $US	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

Exports and related variables

The phantom export tax movements in Table 4.7 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 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.

Table 4.7. Percentage changes between 2014 and 2019 in export prices and volumes, and related variables

	Price index for GDP pgdp_obs	Price index for exports p_x_obs	Export volumes expvol	Phantom tax on exports from regions phtx_i	Preference shift towards a region's exports 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
SaudiArabia	-3.03	-24.90	-7.64	0.31	4.33
RoW	-15.12	0.00	-19.45	0.00	-21.05

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 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 4.7 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 4.8. 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
SaudiArabia	-6.00	4.14
Row	10.00	-4.03

Table 4.9. 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

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 4.8, 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 an 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.

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).

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.

For most regions, the price index for GDP is a reasonable 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 4.9, 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.

In the 2014-19 historical simulation, we reconciled simulated movements in investment price indexes with observed movements by allowing endogenous changes in inputs per unit of output (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 4.9 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 moderate (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.

Real wealth

The first column in Table 4.10 shows changes in real wealth from the start of 2014 to the start of 2019 expressed as percentages of GDP in 2014. As previously mentioned, we calculate wealth in a region as the value of capital in the region *less* net foreign liabilities. To convert from nominal wealth to real wealth, we use price indexes that combine the price of a region's capital goods with the price of the region's foreign assets represented by prices of capital goods in other regions.

At first glance, some of the wealth increases seem surprisingly large, for example, 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 4.10 shows that 192.65 percentage points of the 220.25 is contributed by accumulated real saving.

Table 4.10. 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 & 2019	Real accumulated saving: 2014, 2015, 2016, 2017 & 2018	Contributions of other effects on wealth between 2014 & 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

For some regions, the other-factor factor effects shown in the third column of Table 4.10 are large. These other factors were calculated in the 2014-19 simulation as the shift variables in (4.18). 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 (63.95 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.

Thus, Mexico's net foreign liabilities could fall and wealth increase without any saving contribution by Mexican residents. Mexico's gain is a loss for the foreign holders of Mexican assets. It is noticeable in Table 4.10 that the other-effects contribution for the U.S. is strongly negative (-3.51 per cent of 2014 GDP).

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

5.1. The 2019-30 simulation: explanation of the 7 steps (panels) in Table 5.1

In the simulation for 2019-30, we bring in for each region:

- IMF projections for real GDP;
- populations and working-age population projections from Shared Socioeconomic Pathway 2 (SSP2, middle of the road projections) published by the *International Institute for Applied System Analysis* (IIASA);
- projections of fossil-fuel use under Stated Policies Scenarios (STEPS) published by the *International Energy Agency* (IEA); and
- projections of capital/labour technology bias from our historical simulation for 2004-14.

Details of these projections are in Appendix 1.

As with the 2014-19 historical simulation, our starting point for the baseline 2019-30 simulation is the standard long-run closure. Table 5.1 indicates shocked variables and closure changes in the 2019-30 simulation. [5]

Part 1 of Table 5.1: Real GDP and supply-side determinants

Panel 1: real GDP. This panel corresponds to panel 1 in Table 4.1: we exogenize real GDP in each region and endogenize primary-factor technical change. This enabled us to introduce IMF projections for real GDP movements. These movements can be seen in the Period 2 section of Table 6.1.

Panel 2: employment and population. This panel corresponds to panel 3 in Table 4.1: we introduce shocks to employment and population. No closure changes are required.

Both sets of shocks were taken from SSP2, described by IIASA as the "medium" scenario. The shocks for employment are in fact IIASA projections for working-age population. We assume that employment in each region will move in the same way as working-age population. The population and working-age population (employment) growth rates can be seen in the Period 2 section of Table 6.1.

Panel 3: land and natural resources. As explained in connection with panels 4 and 5 in Table 4.1, land and natural resources can be reallocated among using industries, but consistent with normal GTAP practice, we assume that the total availability of each of these factors in each region is fixed.

Panel 4: Twist in capital-labour technology. This panel corresponds to panel 6 in Table 4.1. As in the 2014-19 simulation, in the 2019-30 simulation we introduce capital-using technology bias by extrapolating the bias for each region estimated for 2004-14. Again, we make the twist-related technological changes in each industry j and region r cost neutral.

Panel 5: global price level. As mentioned in point (i) in section 3, the numeraire in the standard long-run closure is the nominal value of global GDP. We imposed the IMF forecast for this variable. 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.

Part 2 of Table 5.1: Real private and public consumption

Panel 6: adjustment of consumption propensities. Table 5.2 shows average propensities to consume in 2019. These are calculated as the ratio of private plus public consumption to net national income. In 2019, the consumption propensities varied from lows of 0.712 and 0.645 for Saudi Arabia and China to a high of 1.003 for Mexico. The average across all regions was 0.857 implying that 14.3 per cent of world income is saved and devoted to investment.

In the 2019-30 simulation, we assumed that regional average propensities to consume will move towards the world average. High savers such as Saudi Arabia and China will consume

[5] The database for 2019 created in the 2014-19 simulation includes non-zero values for the shift variables, SWQH_B(r), in (4.18). These non-zero values indicate contributions to wealth from factors other than saving. In the 2019-30 simulation, we assume that these other factors will contribute zero. Consequently, in the 2019-30 simulation, it is necessary to shock SWQH_B(r) back to zero. This technicality is not included in Table 5.1.

Table 5.1. Shocked variables and closure swaps for the 2019-30 simulation

Panel no	Exo variable	Description	Source for shock	Swap variable *(goes endo)*	Description
(1)	(2)	(3)	(4)	(5)	(6)
Part 1:	***Real GDP and supply-side determinants***				
1	qgdp(r)	Real GDP	IMF projections	afereg(r)	Primary factor tech change by region
2	lsreg(r)	Employment, same as labour 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 technology twist	Extrapolate from 2004-14	No swap	
5	wgdpg	Nominal GDP for world	IMF projections	No swap	
Part 2: Real private and public consumption					
6	f_apcnnp(r)	Activates adjustment of apcnnp's towards world mean	Zero shock	apcnnp(r)	Average Hhld propensity to consume out of net national income
	f_rcrgr(r)	Ratio, real priv. to gov. consumption	Zero shock	dpgov(r)	Average Govt propensity to consume out of net national product
Part 3: Fossil fuels					
7	qabsorb2(Foss, Reg2)	Use of coal, oil and gas in 8 aggregated regions (Reg2)	IEA projections	a_int2(Foss, Reg2)	Demand shifts in favour 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 favour 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 favour 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 favour or against coal, oil and gas by Gov in the 13 Reg regions
	f_neut(j,r)	Neutralizes fossil fuel saving by inds	Zero shock	a_neut(j,r)	Technical change to offset fossil-fuel saving tech change

more of their income and low savers such as Mexico will tighten their belts. We also assumed that average propensities to consume will rise in regions in which there is a tendency for wealth to grow relative to GDP, where wealth is the value of capital in the region less the region's net foreign liabilities. Without this wealth affect, our simulations gave unrealistic values for some regions for wealth and net foreign liabilities.

We implemented our consumption assumptions via the equations:

$$\text{apcnnp}(r) = 100 * \text{ADJ1} * \left(\frac{\text{APCW} - \text{APC}(r)}{\text{APC}(r)} \right) + \text{ADJ2} * \left(\text{wqh}(r) - \text{wgdp}(r) \right) + \text{f\_apcnnp}(r) \qquad r \in \text{Reg} \qquad (5.1)$$

$$\text{cr}(r) = \text{gr}(r) + \text{f\_rcrgr}(r) \qquad r \in \text{Reg} \qquad (5.2)$$

In these equations:

apcnnp(r) is the percentage change between 2019 and 2030 in the private average propensity to consume (the ratio of private consumption to net national income);
APCW is the world average propensity to consume in 2019 (0.857, see Table 5.2);
APC(r) is the average propensity to consume in region r in 2019 (see Table 5.2);
wqh(r) is the simulated percentage increase in nominal wealth in region r between 2019 and 2030;
wgdp(r) is the simulated percentage increase in nominal GDP in region r between 2019 and 2030;
ADJ1 and ADJ2 are adjustment parameters set at 0.2 and 0.5;
f_apcnnp(r) is a shift variable;
cr(r) and gr(r) are the percentage changes between 2019 and 2030 in real private and real government consumption; and
f_rcrgr(r) is the percentage change in the ratio of real private consumption to real public consumption.

In the standard long-run closure, apcnnp(r) is exogenous and f_apcnnp(r) is endogenous. With this setup, equation (5.1) has no effect on simulation results. As can be seen in panel 6 of Table 5.1, in the 2019-30 simulation we exogenized f_apcnnp(r) with a zero shock and endogenized apcnnp(r). Thus, we assumed that the percentage movement in apcnnp(r) will be determined as 0.2 times the 2019 percentage gap between the world APC and r's APC *plus* 0.5 times the simulated percentage growth between 2019 and 2030 in r's wealth to GDP ratio.

A natural assumption at this stage was to give the average propensity to consume for government the same percentage change as for households. However, this led to unsatisfactory results in some regions for the movement in the ratio of real private consumption to real government consumption. Consequently, we decided to assume directly that real private and public consumption move together. As shown in panel 6 we did this by exogenizing f_rcrgr(r), with zero shock, and endogenizing government average propensities to consume, dpgov(r).

Table 5.2. Consumption propensities

	Ratio, Private plus public consumption to NNP in 2019 RAT_CYB
USA	0.962
Canada	0.876
Mexico	1.003
China	0.645
Japan	0.840
SKorea	0.789
India	0.872
France	0.915
Germany	0.830
UK	0.988
RoEU	0.899
SaudiArabia	0.712
RoW	0.855
World average	0.857

Part 3 of Table 5.1: Fossil fuels

Panel 7: fossil-fuel use by region. IEA publishes forecasts of energy demands by region. We use their Stated Policies Scenarios (STEPS) for percentage changes in coal, oil and gas absorption by region for 2019 to 2030. The relevant regions in the IEA forecasts available to us are USA, China, Japan, India, Rest of North America (Canada plus Mexico), EU, Middle East and Rest of World.

To absorb the STEPS forecasts we first added equations to our model that define percentage changes in coal, oil and gas use in these 8 regions. For USA, China, Japan, India and Rest of World, there was no problem. Our model already identified percentage changes in demands in these regions. For IEA region Rest of North America, we defined the percentage changes in use as the percentage changes in the sums of demands in Mexico and Canada. For IEA region EU, we defined the percentage changes in use as the sums of the percentage changes in demands in France, Germany, UK and RoEU. For IEA region Middle East, we defined the percentage changes in use as the percentage changes in demands in Saudi Arabia.

Next, we shocked the use of coal, oil and gas in the 8 IEA regions with the percentage changes implied by the STEPS forecasts. To absorb these shocks, we endogenized relevant technology and preference variables applying to all agents in each of the 8 regions.

As shown in panel 7, we exogenized and shocked absorb2(Foss,Reg2) and endogenized a_int2(Foss,Reg2) where

absorb2(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 a_int2(c,rr) movements for fossil commodity c to all agents in the regions at the 13 level we defined a_int(Foss, r) by the equation:

$$a\_int(Foss,r) = a\_int2(Foss,MAP(r)) + f\_a\_int(Foss,r) \quad r \in Reg \tag{5.3}$$

where

a_int(Foss,r) is 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);

MAP(r) is the 8-order region in Reg2 associated with r as indicated in Table 5.3; and

f_a_int(Foss,r) is a shift variable.

In the standard long-run closure f_a_int(Foss,r) is endogenous and a_int(Foss,r) is exogenous. As indicated in panel 7 of Table 5.1, in the 2019-30 simulation, f_a_int(Foss,r) is exogenous, with zero shock, and a_int(Foss,r) is endogenous. With this setup, a_int(Foss,r) receives the appropriate shock from a_int2.

We let a_int(Foss,r) drive the preferences of households and governments via the equations

$$\mathrm{a3com(c,r)} = -\mathrm{a\_int(c,r)} + \mathrm{f3\_aint(c,r)} \quad \text{for } c \in \text{Foss},\ r \in \text{Reg} \tag{5.4}$$

and

$$\mathrm{f\_qg(c,r)} = -\mathrm{a\_int(c,r)} + \mathrm{f5\_aint(c,r)} \quad \text{for } c \in \text{Foss},\ r \in \text{Reg} \tag{5.5}$$

In these equations, a3com(c,r) is a percentage change in private consumption of commodity c in region r beyond what can be explained by changes in incomes and prices. A similar definition applies to f_qg(c,r) for government consumption. As we move from the standard long-run closure to the 2019-30 baseline closure, the shift variables f3_aint(c,r) and f5_aint(c,r) are exogenized on zero shock and a3com(c,r) and f_qg(c,r) are endogenized.

As in panel 12 of Table 4.1 for the 2014-19 simulation, we cost neutralize the savings made by industries in their use of fossil fuels. We do this via a variant of equation (4.10):

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

$$\text{for } j \in \text{Ind},\ r \in \text{Reg} \tag{5.6}$$

5.2. The 2030-40 and 2040-50 simulations

The closures for the 2030-40 and 2040-50 baseline simulations are the same as that for the 2019-30 baseline simulation (see Table 5.1).

In the 2030-40 and 2040-50 simulations, we bring in IIASA's SSP2 projections for employment (working-age population), population and IEA's STEPS projections fossil fuel use in each region. The IMF does not publish GDP projections for these later periods. In setting the percentage movements in real GDP for each region in the 2030-40 and 2040-50 simulations, we projected forward growth in GDP per worker combined with the SSP2 forecasts for working-age population. As explained in Appendix 1, the trends in GDP per worker were derived from data and forecasts covering most of the past decade and going out to 2028.

The employment, population and GDP forecasts used in our 2030-40 and 2040-50 simulations are in the Period 3 and 4 sections of Table 6.1. We continue to assume that regional consumption propensities move in accordance with equations (5.1) and (5.2) with the adjustment parameters set on 0.2 and 0.5 and we continue to adopt the capital-labour technology twists from the 2004-14 historical simulation. In setting the numeraire, we assumed that global nominal GDP will grow between 2030 and 2050 at rates that maintain the global rate of inflation projected for 2019-30.

Table 5.3. Map from 13-order regions to Reg2

r	Map(r)
USA	USA
Canada	Rest of North America
Mexico	Rest of North America
China	China
Japan	Japan
SKorea	Japan
India	India
France	EU
Germany	EU
UK	EU
RoEU	EU
SaudiArabia	Middle East
RoW	RoW

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

Tables 6.1 – 6.6 contain results from the update simulation for 2014-19 and the baseline simulations for 2019-30, 2030-40 and 2040-50. Results from the update simulation were discussed in section 4, particularly section 4.2. In this section, we focus mainly on the three simulations for future periods.

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 6.1)

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 identified in Table 6.1 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 in our baseline, 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 in Table 6.1, Japan's workforce declines quite rapidly with annual growth rates between -0.59 and -1.24 per cent. Capital growth is sluggish (annual growth of 1.37 per cent in 2019-30 falling to 0.17 per cent in 2040-50. The contributions to growth from total factor productivity are weak (0.66 per cent or less in all periods).

Table 6.1. Ave. annual % changes in real GDP, factor inputs & 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
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

Global saving is sufficient through the simulation periods to support strong growth in capital. In the majority of cases, the capital growth rates in Table 6.1 exceed the corresponding GDP growth rates. In all cases, capital growth rates exceed employment growth rates, implying strong growth in K/L ratios.

In our simulations, growth in K/L ratios leads, in nearly all cases, to growth in real wage rates relative to rates of return on capital (capital rental rates divided by the cost of a unit of capital *minus* the rate of depreciation). Real wage rates rise relative to rates of return on capital despite the inclusion in our simulations of strong trends from 2004-14 in technology bias favouring the use of capital relative to labour.

In Table 6.1, 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 simulations 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 shown in Table 6.1 for 2019 to 2050 imply that a rate of return of 10 per cent in 2019 would fall to about 9.57 per cent in 2050.

6.2. Real GDP and expenditure components (Table 6.2) and the terms of trade (Table 6.3)

Consumption

Recall from the discussion of Table 5.2 and equation (5.1) that we assume that consumption propensities in each region will move towards the global average but will also adjust to counter movements in wealth relative to GDP. Saudi Arabia and China are the two regions with the lowest average propensity to consume in 2019 (see Table 6.4). Low propensities also give these regions rapid growth in wealth relative to GDP. As can be seen from Table 6.4, the average propensities to consume for these two regions are projected to increase rapidly over the entire period from 2019 to 2050.

With increasing consumption propensities, real consumption in Saudi Arabia and China grows relative to real GDP in both the 2019-30 and the 2030-40 simulations (3.50 & 1.49 compared with 2.78 & 1.54 for Saudi Arabia, and 5.10 & 3.50 compared with 4.16 & 3.05 for China, see Table 6.2). But what happens in 2040-50? Why do the consumption growth rates in the two regions drop below the GDP growth rates (0.90 compared with 1.06 for Saudi Arabia, and 2.93 compared with 3.25 for China, see Table 6.2). This is despite continuing increases in the consumption propensities. There are three factors underlying these results.

First, as we reach 2040, the average propensities to consume in Saudi Arabia and China move up towards the world average. At the same time, the growth rates in the regions' wealth/GDP ratios are considerably lower in 2040-50 than in 2030-40. These developments reduce the rates of growth of the consumption propensity in both regions (Table 6.4). But in the 2040-50 simulation the propensities are still growing.

Second, as we go from the 2030-40 simulation to the 2040-50 simulation, there is a slowing in the contribution to net national product in Saudi Arabia and China from earnings on net foreign assets. Net national product drives consumption [point (c) in section 3]. Thus, the slowing in the earnings contributions from net foreign assets reduces the rates of growth of consumption in both regions. The earnings contributions from net foreign assets slow because Saudi Arabia and China's increased consumption relative to GDP in earlier periods reduces the rate of growth of their net foreign assets relative to GDP (right panel, Table 6.4).

Table 6.2. Ave. 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
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

Table 6.3. 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

Table 6.4. 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			

The third factor is the terms of trade (the price of exports relative to the price of imports), see Table 6.3. In our simulations from 2019 to 2050, we assume no preference twists in favour or against the products of particular regions. Without preference twists, the Armington assumption built into the GTAP model generally implies terms-of-trade improvement for regions such as Japan in which export growth is slow relative to world GDP growth and terms-of-trade deterioration in regions such as India in which export growth is rapid.

As can be seen in Table 6.3, China's terms of trade decline between 2040 and 2050 (-0.35 per cent a year). Falling terms of trade reduce 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).

Faster export growth reduces prices (movement down demand curves), explaining China's terms-of-trade decline.

In the case of Saudi Arabia, it is the price of oil rather than the volume of exports that is the main ingredient in the determination of the terms of trade. As can be seen in Table 6.6, we project weak growth in the demand for oil leading to relatively low prices. This gives Saudi Arabia declining terms of trade in 2030-40 and 2040-50. The negative term-of-trade effect on Saudi Arabia's consumption/GDP ratio is overwhelmed by positive factors in earlier periods. However, it emerges in 2040-50 to become part of the explanation for the decline in this period in Saudi Arabia's consumption relative to GDP.

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 and negative growth in their wealth to GDP ratios give both regions sharp declines in their consumption propensities in the 2019-30 simulation (1.003 to 0.901 for Mexico and 0.988 to 0.916 for UK). For both regions, the declines in the propensities leave consumption growth close to zero (-0.22 and 0.01). After the adjustments in the 2019-30 period, consumption propensities for Mexico and UK are relatively stable. In the 2030-40 and 2040-50 simulations consumption in both regions rises relative to GDP.

Investment

To explain the results in Table 6.2 for average annual growth in investment between 2019 and 2030, we start with the equation:

$$\frac{I(r,30)}{I(r,19)} = \frac{KB(r,30) * \left[\frac{k(r,30)}{100} + D\right]}{KB(r,19) * \left[\frac{k(r,19)}{100} + D\right]} \qquad \text{for } r \in Reg \qquad (6.1)$$

In (6.1), 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 (6.1), 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 (6.1) we obtain

$$i(r,19,30) = 100 * \left\{ \left[\left(1 + \frac{kb(r,19,30)}{100}\right)^{11} * \left(\frac{\frac{k(r,30)}{100} + D}{\frac{k(r,19)}{100} + D} \right) \right]^{\frac{1}{11}} - 1 \right\} \qquad \text{for } r \in Reg \qquad (6.2)$$

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 6.2; and kb(r,19,30) is the average annual percentage growth rate for capital in region r between 2019 and 2030, that is the capital results in Table 6.1.

Equation (6.2) 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 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 (d) in section 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 6.2) relative to capital growth for the same period (5.36 per cent, Table 6.1). This is because Chinese capital growth *in* 2019 was high relative to Chinese capital growth *in* 2030 (6.73 compared with 4.44, see right panel in Table A3.2 in Appendix 3). Chinese capital growth *in* 2030 reflects capital growth projected for 2030-40 (4.09, Table 6.1).

Equations similar to (6.2) can be derived for average annual investment growth by region for 2030-40 and 2040-50.

Appendix 3 provides further analysis of the investment results in Table 6.2 generated under forward-looking expectations, and compares them with results under static expectations.

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:

$$\begin{aligned} \mathrm{qgdp}(r) = {} & S_c(r) * \mathrm{cr}(r) + S_g(r) * \mathrm{gr}(r) + S_i(r) * \mathrm{qcgds}(r) \\ & + S_x(r) * \exp\mathrm{vol}(r) - S_m(r) * \mathrm{impvol}(r) \end{aligned} \tag{6.3}$$

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 public 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 private consumption, public consumption, investment, exports and imports 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 6.2) 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 (6.3) helps us to understand export growth relative to import growth, it doesn't 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. Then 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 6.2, 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.

6.3. Fossil fuel variables (Tables 6.5 and 6.6)

Table 6.5 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 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 Table 6.5 are negative. The only exceptions are gas use by India and coal use by Saudi Arabia in 2019-30.

Despite the general declines in fossil-fuel use per unit of activity, worldwide use of fossil fuels is stubbornly persistent. As shown in Table 6.6, 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.

7. Output by industry: illustrative results for Canada

In addition to macro results of the type analysed in the previous sections, models such as GTAP produce a huge volume of industry results. In this section we analyze output results for Canadian industries. These are set out in Table 7.1.

Table 6.5. Average annual % shifts in regional demand for fossil fuels: inputs per unit of activity by using agents

	Coal	Oil	Gas
	-a_int		
Period 2: 2019-30			
USA	-13.69	-2.57	-2.64
Canada	-5.78	-1.40	-0.66
Mexico	-5.78	-1.40	-0.66
China	-3.84	-2.17	-0.64
Japan	-3.96	-2.28	-5.28
SKorea	-3.96	-2.28	-5.28
India	-2.18	-1.20	0.51
France	-6.46	-2.41	-3.34
Germany	-6.46	-2.41	-3.34
UK	-6.46	-2.41	-3.34
RoEU	-6.46	-2.41	-3.34
SaudiArabia	2.91	-1.33	-0.27
RoW	-2.76	-0.58	-1.68
World average	***-4.35***	***-1.69***	***-2.18***
Period 3: 2030-40			
USA	-9.11	-4.49	-4.64
Canada	-1.78	-2.68	-2.05
Mexico	-1.78	-2.68	-2.05
China	-4.83	-3.57	-2.30
Japan	-2.85	-2.80	-2.26
SKorea	-2.85	-2.80	-2.26
India	-6.49	-4.58	-3.99
France	-5.81	-3.88	-3.91
Germany	-5.81	-3.88	-3.91
UK	-5.81	-3.88	-3.91
RoEU	-5.81	-3.88	-3.91
SaudiArabia	-1.22	-2.00	-2.23
RoW	-3.07	-2.48	-2.59
World average	***-4.84***	***-3.42***	***-2.98***
Period 4: 2040-50			
USA	-9.48	-3.81	-4.20
Canada	-1.44	-2.07	-1.65
Mexico	-1.44	-2.07	-1.65
China	-5.47	-4.35	-3.28
Japan	-2.83	-2.73	-2.27
SKorea	-2.83	-2.73	-2.27
India	-5.92	-3.88	-3.24
France	-5.72	-3.91	-3.76
Germany	-5.72	-3.91	-3.76
UK	-5.72	-3.91	-3.76
RoEU	-5.72	-3.91	-3.76
SaudiArabia	-0.23	-1.10	-1.16
RoW	-2.45	-1.90	-1.98
World average	***-4.77***	***-2.95***	***-2.42***

Table 6.6. Average annual % changes in world fossil energy variables

	Quantity of world output	Average real world price in $US	Shifts in input per unit of output in using industries
	qworld	pworld/pgdpg	wldout_sh, wldout_sh2
Period 1: 2014-19			
coal	0.13	3.23	-4.70
oil	1.18	-5.83	-3.39
gas	2.94	-9.94	-0.83
Period 2: 2019-30			
coal	-1.12	-0.11	-4.37
oil	1.15	-0.15	-1.68
gas	0.13	0.01	-2.17
Period 3: 2030-40			
coal	-1.72	-0.77	-4.88
oil	-0.34	-1.20	-3.40
gas	-0.06	-1.11	-2.95
Period4: 2040-50			
coal	-1.53	-0.68	-4.82
oil	-0.14	-0.72	-2.95
gas	0.09	-0.61	-2.39

The table shows wide variations in average annual growth rates between time periods and within time periods. For example, the simulated average annual growth rate for wheat output (wht, ind 2) varies between time periods from 6.15 per cent in 2014-19 to 1.06 per cent in 2040-50, while within the 2014-19 time period industry growth rates vary from 7.33 per cent for leather products (lea, ind 29) to -2.44 per cent for coal (coa, ind 15).

At the sectoral level the variations are damped, but still considerable. For example, the simulated average annual growth rate for manufacturing (MANU) varies between time periods from 3.05 per cent in 2030-40 to 0.78 per cent in 2019-30. Within the 2014-19 time period, sectoral growth rates vary from 3.21 per cent for agriculture, forestry and fishing (AFF) to 0.17 per cent for construction (CONST).

To help in the explanation of the industry and sectoral variations, we have extracted the macro results for Canada from Table 6.2 and displayed them in Table 7.2. Using the macro results in Table 7.2 we can go some of the way to explaining the industry and sectoral results. For example, weak investment growth in 2014-19 (-0.55 per cent), recovering to moderate growth in 2030-40 and 2040-50 (1.59 per cent in both periods) underpins the simulated growth trajectory for construction (0.17 per in 2014-19 rising to 1.68 and 1.64 per cent in the last two simulation periods). Relatively fast growth in real private consumption in 2014-19 of 2.46 per cent slowing to 1.84 per cent in 2030-40 and 2040-50 explains the slowdown in housing services[6] (dwe, ind 57) from 3.00 per cent in 2014-19 to 2.16 per cent in 2040-50. A relatively flat performance for real government consumption (growth rates between 1.84 and 2.13 per cent) explains the relatively flat performance of government services (osg, ind 56, growth rates between 1.82 and 1.95 per cent). Weak export growth in 2019-30 relative to the other periods explains the dip in the growth rate for this period in the manufacturing sector and many of its constituent industries.

[6] This is an artificial industry supplying the services of the housing stock almost entirely to private consumption.

Table 7.1. Industry and sectoral outputs for Canada: average annual growth, 2014-19, 2019-30, 2030-40 and 2040-50

No	IND*	14-19	19-30	30-40	40-50
1	pdr	1.29	1.24	1.88	1.67
2	wht	6.15	2.07	2.11	1.06
3	gro	2.42	2.38	2.66	2.15
4	v_f	2.26	2.03	2.67	2.55
5	osd	4.37	2.96	2.99	2.47
6	c_b	1.08	1.24	1.80	1.60
7	pfb	1.90	1.53	1.90	1.79
8	ocr	3.79	2.32	1.96	1.23
9	ctl	1.73	1.17	1.88	1.49
10	oap	2.45	1.62	2.67	2.14
11	rmk	1.95	1.50	1.51	1.30
12	wol	5.23	3.90	2.08	0.94
13	frs	3.07	0.40	2.64	1.81
14	fsh	0.02	1.89	2.67	2.32
	AFF	***3.21***	***2.00***	***2.54***	***2.03***
15	coa	-2.44	-2.25	-0.17	-1.18
16	oil	0.90	0.49	-1.79	-1.66
17	gas	0.29	-0.06	-1.10	-1.13
18	omn	2.27	1.57	2.54	1.84
	MINE	***0.83***	***0.47***	***-0.08***	***0.02***
19	cmt	2.82	1.38	2.14	1.81
20	omt	5.40	1.31	3.65	2.97
21	vol	3.90	2.13	2.99	1.71
22	mil	1.95	1.52	1.50	1.30
23	pcr	1.28	0.96	1.38	1.14
24	sgr	1.64	1.54	2.06	1.89
25	ofd	1.82	1.67	2.80	2.41
26	b_t	1.21	1.94	2.22	2.02
27	tex	3.69	0.55	3.97	2.64
28	wap	3.18	1.14	3.97	2.42
29	lea	7.33	1.70	4.49	2.59
30	lum	3.47	-0.19	2.80	1.75
31	ppp	3.22	0.85	3.01	2.04
32	p_c	3.28	2.14	2.99	2.22
33	crp	3.29	0.93	3.34	2.08
34	nmm	0.82	0.53	2.44	1.71
35	i_s	1.48	-0.24	2.92	1.28
36	nfm	2.61	1.46	3.23	1.26
37	fmp	1.96	-0.02	2.87	1.51
38	mvh	0.00	0.57	3.10	2.23
39	otn	4.32	0.66	3.63	1.80
40	ele	1.28	-0.58	2.86	0.62
41	ome	2.97	-0.42	3.48	1.38
42	omf	2.08	0.10	3.24	1.66
	MANU	***2.41***	***0.78***	***3.05***	***1.91***

No	IND*	14-19	19-30	30-40	40-50
43	ely	2.77	1.67	2.45	1.83
44	gdt	2.41	1.83	2.35	1.93
45	wtr	1.98	1.56	1.98	1.78
	UTIL	***2.72***	***1.69***	***2.44***	***1.84***
46	***CONST***	***0.17***	***0.92***	***1.68***	***1.64***
47	***TRADE***	***2.06***	***1.60***	***1.99***	***1.78***
48	otp	2.44	1.51	2.29	1.87
49	wtp	2.90	1.52	2.36	1.97
50	atp	2.06	1.40	2.09	1.68
	TRANSP	***2.43***	***1.50***	***2.28***	***1.86***
51	cmn	1.95	1.61	2.01	1.76
52	ofi	2.07	1.57	2.11	1.83
53	isr	1.98	1.50	2.28	1.88
54	obs	1.66	1.29	2.09	1.74
55	ros	1.93	1.52	2.01	1.78
56	osg	1.92	1.95	1.86	1.82
57	dwe	3.00	2.65	2.30	2.16
	SERVIC	***2.04***	***1.82***	***2.03***	***1.85***
	GDP	***1.88***	***1.53***	***2.09***	***1.81***

* Full industry names and definitions are in Appendix 4.

Table 7.2. Macro results for Canada: average-annual per cent growth

	2014-19	2019-30	2030-40	2040-50
Real GDP	1.88	1.53	2.09	1.81
Real private consumption	2.46	2.13	1.84	1.84
Real government consumption	1.89	2.13	1.84	1.84
Real investment	-0.55	0.76	1.59	1.59
Export volume	2.63	0.90	3.02	1.89
Import volume	1.81	1.87	2.06	1.85

However, movements in macro variables alone can give us only a partial explanation of the industry and sectoral results. For example, why does the consumption-oriented housing services industry (ind 57) grow quicker in every period than aggregate real private consumption? Why does the investment-oriented construction sector outperform aggregate real investment in every period? What determines the very strong growth rate (7.33 per cent) for leather products (lea, ind 29) in 2014-19?

To answer quantitative questions like these and to explore the industry results systematically, we need a framework. In the next subsection, we develop such a framework. Then in subsection 7.2 we apply the framework to the Canadian results.

7.1. A decomposition framework for interpreting industry results

The principal question addressed by our framework is: why is the simulated growth in output of industry j fast or slow relative to growth in GDP? We break the answer into two parts: the *sales-mix* effect (SME) and the *industry-performance* effect (IPE). These two effects are computed for industry j in region r as follows:

$$\mathrm{SME}(j,r) = \sum_{f}\left(S_f(j,r) - T_f(r)\right) * gt_f(r) \tag{7.1}$$

and

$$\mathrm{IPE}(j,r) = \sum_{f}\left(g_f(j,r) - gt_f(r)\right) * S_f(j,r) \tag{7.2}$$

In these equations:

f denotes sales categories. These are intermediate sales to industry 1, industry 2, …, industry 57, and sales to households, government, investment and export.

$S_f(j,r)$ is the share of the sales of industry j in region r accounted for by category f.

$T_f(r)$ is the share of category f in total sales of all commodities produced in region r. In calculating these shares, we use the sum of the values of industry outputs as the denominator. For the industry categories (f= 1, …, 57) the numerator is the value of domestic intermediates sold to a particular industry. For the final demand categories (f= C, G , I, X) , the numerator is the value of domestic commodities sold to the particular final demand category.

$g_f(j,r)$ is the growth rate for the quantity of sales from industry j in region r to category f.

$gt_f(r)$ is the growth rate we adopt for category f in region r. Where f is an industry, $gt_f(r)$ is the the growth rate for output of industry f in region r. Where f is a final demand category, $gt_f(r)$ is the growth rate in region r for real private consumption, real government consumption, real investment and real exports.

From (7.1) and (7.2) we obtain

$$SME(j,r) + IPE(j,r) = g_{ind}(j,r) - gdp\_approx(r) \tag{7.3}$$

where

$g_{ind}(j,r)$ is the growth rate in the output of industry j in region r given by:

$$g_{ind}(j,r) = \sum_f S_f(j,r) * g_f(j,r) \tag{7.4}$$

and

gdp_approx(r) is an approximation to the growth rate in GDP in region r given by:

$$gdp\_approx(r) = \sum_f T_f(r) * gt_f(r) \tag{7.5}$$

As can be seen from (7.5), gdp_approx(r) is a weighted average of growth rates in industry outputs and final demand categories. This is not the same as the growth in GDP. But in our simulations it is a close approximation and we will interpret it as growth in GDP in region r. With this interpretation, (7.3) confirms that SME(j,r) and IPE(j,r) are a complete decomposition of the gap between industry j's growth rate in region r and the growth rate of GDP in region r.

SME(j,r), is the part of the gap for industry j in region r associated with sales-mix. To see how this works, it is convenient to rewrite (7.1) as:

$$SME(j,r) = \sum_f \left(S_f(j,r) - T_f(r)\right) * \left(gt_f(r) - gdp\_approx(r)\right) \tag{7.6}$$

The inclusion of gdp_approx(r) makes no difference to the value of the RHS of (7.6) because

$$\sum_f S_f(j,r) = \sum_f T_f(r) = 1 \tag{7.7}$$

However, with the inclusion we see that SME(j,r) will be positive if industry (j,r) has a relatively high share of its sales [$S_f(j,r) > T_f(r)$] to categories f with relatively high growth rates [$gt_f(r) >$ gdp_approx]. Similarly, SME(j,r) will be positive if industry (j,r) has a relatively low share of its sales [$S_f(j,r) < T_f(r)$] to categories f with relatively low growth rates [$gt_f(r) <$ gdp_approx]. SME(j,r) will be negative if (j,r)'s sales are concentrated on low growth categories or if (j,r) has low sales to high growth categories.

IPE(j,r) is the part of the gap between industry (j,r)'s growth and GDP growth accounted for by (j,r)'s performance in each of its sales categories. Industry (j,r)'s performance in sales category f is measured by the growth [$g_f(j,r)$] in its sales to f compared with the growth [$gt_f(r)$] in all sales to f. IPE(j,r) will be positive if (j,r) has strong performance [$g_f(j,r) - gt_f(r) > 0$] in markets that are important for the industry [$S_f(j,r)$ is large]. IPE(j,r) will be negative if (j,r) has weak performance [$g_f(j,r) - gt_f(r) < 0$] in its important markets.

7.2. Simulated growth rates in Canadian industries

Table 7.3 has 4 panels corresponding to our 4 linked simulations. The first column in each panel shows average annual growth rates for industry outputs in Canada, reproduced from

Table 7.3. Average annual growth rates for Canadian industries and decomposition into sales-mix and industry-performance effects

	2014-2019				2019-2030				2030-2040				2040-2050			
Industry	Output	Gap	SME	IPE	Output	Gap	SME	IPE	Output	Gap	SME	IPE	Output	Gap	SME	IPE
1 pdr	1.29	-0.63	-0.64	0.01	1.24	-0.26	-0.27	0.00	1.88	-0.27	-0.29	0.00	1.67	-0.14	-0.14	0.00
2 wht	6.15	4.23	0.69	3.45	2.07	0.57	-0.61	1.17	2.11	-0.05	0.84	-0.90	1.06	-0.74	0.08	-0.82
3 gro	2.42	0.51	0.54	-0.06	2.38	0.88	-0.12	0.98	2.66	0.51	0.56	-0.08	2.15	0.34	0.14	0.19
4 v_f	2.26	0.34	0.59	-0.27	2.03	0.53	-0.36	0.88	2.67	0.52	0.66	-0.16	2.55	0.74	0.10	0.63
5 osd	4.37	2.45	1.07	1.31	2.96	1.45	-0.19	1.62	2.99	0.84	0.82	-0.01	2.47	0.66	0.07	0.58
6 c_b	1.08	-0.84	-0.57	-0.28	1.24	-0.26	-0.08	-0.19	1.80	-0.35	-0.20	-0.17	1.60	-0.20	-0.01	-0.19
7 pfb	1.90	-0.02	-0.08	0.05	1.53	0.03	0.13	-0.11	1.90	-0.25	-0.15	-0.12	1.79	-0.01	0.03	-0.05
8 ocr	3.79	1.88	0.34	1.49	2.32	0.82	-0.37	1.17	1.96	-0.19	0.49	-0.69	1.23	-0.58	0.03	-0.61
9 ctl	1.73	-0.18	0.72	-0.91	1.17	-0.33	-0.27	-0.07	1.88	-0.28	0.30	-0.59	1.49	-0.32	0.02	-0.34
10 oap	2.45	0.53	1.47	-0.95	1.62	0.12	-0.21	0.31	2.67	0.52	0.71	-0.22	2.14	0.33	0.43	-0.12
11 rmk	1.95	0.03	0.08	-0.07	1.50	0.00	0.06	-0.07	1.51	-0.64	-0.58	-0.07	1.30	-0.50	-0.44	-0.07
12 wol	5.23	3.31	-0.06	3.31	3.90	2.40	-0.24	2.63	2.08	-0.07	0.36	-0.44	0.94	-0.86	0.00	-0.86
13 frs	3.07	1.15	1.13	-0.01	0.40	-1.10	-1.09	-0.01	2.64	0.49	0.49	-0.02	1.81	0.00	-0.01	0.00
14 fsh	0.02	-1.89	0.36	-2.23	1.89	0.39	-0.20	0.58	2.67	0.52	0.63	-0.14	2.32	0.51	0.25	0.25
15 coa	-2.44	-4.36	0.70	-4.96	-2.25	-3.76	-0.42	-3.31	-0.17	-2.33	0.72	-3.00	-1.18	-2.98	0.06	-3.00
16 oil	0.90	-1.01	0.95	-1.94	0.49	-1.01	-0.12	-0.90	-1.79	-3.94	0.82	-4.66	-1.66	-3.46	0.25	-3.65
17 gas	0.29	-1.63	0.54	-2.14	-0.06	-1.56	-0.40	-1.15	-1.10	-3.25	0.42	-3.62	-1.13	-2.94	-0.04	-2.86
18 omn	2.27	0.35	0.15	0.18	1.57	0.07	-0.46	0.52	2.54	0.38	0.66	-0.30	1.84	0.04	-0.17	0.19
19 cmt	2.82	0.90	0.53	0.34	1.38	-0.12	0.14	-0.27	2.14	-0.01	0.02	-0.05	1.81	0.00	0.06	-0.07
20 omt	5.40	3.49	1.12	2.28	1.31	-0.19	-0.06	-0.14	3.65	1.50	0.53	0.93	2.97	1.17	0.27	0.87
21 vol	3.90	1.99	0.70	1.23	2.13	0.63	-0.25	0.86	2.99	0.84	0.68	0.13	1.71	-0.10	0.08	-0.19
22 mil	1.95	0.03	0.35	-0.34	1.52	0.02	0.39	-0.38	1.50	-0.65	-0.28	-0.38	1.30	-0.51	-0.04	-0.47
23 pcr	1.28	-0.63	0.14	-0.78	0.96	-0.54	0.18	-0.72	1.38	-0.77	-0.15	-0.63	1.14	-0.66	-0.01	-0.65
24 sgr	1.64	-0.28	0.34	-0.63	1.54	0.04	0.33	-0.30	2.06	-0.09	-0.01	-0.10	1.89	0.08	0.13	-0.05
25 ofd	1.82	-0.09	0.45	-0.56	1.67	0.17	0.01	0.15	2.80	0.65	0.26	0.36	2.41	0.60	0.09	0.50
26 b_t	1.21	-0.71	0.35	-1.06	1.94	0.44	0.34	0.08	2.22	0.07	-0.14	0.19	2.02	0.21	0.03	0.17
27 tex	3.69	1.77	0.35	1.38	0.55	-0.96	-0.33	-0.62	3.97	1.82	0.49	1.28	2.64	0.83	0.09	0.72
28 wap	3.18	1.26	0.48	0.75	1.14	-0.36	0.06	-0.43	3.97	1.82	0.15	1.63	2.42	0.62	0.05	0.55
29 lea	7.33	5.41	0.60	4.70	1.70	0.20	-0.19	0.38	4.49	2.34	0.45	1.84	2.59	0.78	0.07	0.70
30 lum	3.47	1.55	0.03	1.48	-0.19	-1.69	-0.72	-0.97	2.80	0.65	0.41	0.21	1.75	-0.06	-0.01	-0.06
31 ppp	3.22	1.31	0.42	0.85	0.85	-0.65	-0.28	-0.37	3.01	0.85	0.38	0.44	2.04	0.23	0.05	0.17
32 p_c	3.28	1.36	0.57	0.76	2.14	0.64	-0.11	0.73	2.99	0.84	0.34	0.46	2.22	0.41	0.06	0.35
33 crp	3.29	1.38	0.52	0.82	0.93	-0.57	-0.44	-0.14	3.34	1.19	0.63	0.52	2.08	0.28	0.08	0.18
34 nmm	0.82	-1.10	-1.01	-0.09	0.53	-0.97	-0.55	-0.42	2.44	0.29	-0.09	0.36	1.71	-0.10	-0.10	-0.01
35 i_s	1.48	-0.44	0.05	-0.50	-0.24	-1.74	-0.98	-0.76	2.92	0.76	0.69	0.05	1.28	-0.53	-0.10	-0.42

Table7.3 continued …

… Table 7.3 continues

Industry	2014-2019				2019-2030				2030-2040				2040-2050			
	Output	Gap	SME	IPE	Output	Gap	SME	IPE	Output	Gap	SME	IPE	Output	Gap	SME	IPE
36 nfm	2.61	0.69	0.60	0.06	1.46	-0.05	-0.60	0.55	3.23	1.08	0.86	0.18	1.26	-0.55	-0.02	-0.53
37 fmp	1.96	0.04	-0.55	0.57	-0.02	-1.52	-0.70	-0.81	2.87	0.72	0.24	0.45	1.51	-0.30	-0.08	-0.22
38 mvh	0.00	-1.92	0.30	-2.19	0.57	-0.93	-0.54	-0.39	3.10	0.95	0.67	0.25	2.23	0.43	0.08	0.33
39 otn	4.32	2.40	0.45	1.89	0.66	-0.84	-0.53	-0.31	3.63	1.48	0.65	0.79	1.80	-0.01	0.04	-0.05
40 ele	1.28	-0.64	0.24	-0.88	-0.58	-2.08	-0.59	-1.48	2.86	0.71	0.58	0.11	0.62	-1.19	-0.01	-1.17
41 ome	2.97	1.06	-0.09	1.12	-0.42	-1.92	-0.58	-1.34	3.48	1.33	0.40	0.89	1.38	-0.43	-0.02	-0.41
42 omf	2.08	0.16	-0.24	0.39	0.10	-1.40	-0.35	-1.05	3.24	1.09	0.14	0.91	1.66	-0.15	-0.02	-0.14
43 ely	2.77	0.85	0.43	0.39	1.67	0.17	0.04	0.11	2.45	0.30	0.18	0.10	1.83	0.02	-0.04	0.05
44 gdt	2.41	0.49	0.40	0.07	1.83	0.33	0.18	0.14	2.35	0.20	0.01	0.17	1.93	0.12	0.01	0.10
45 wtr	1.98	0.07	0.12	-0.08	1.56	0.06	0.21	-0.16	1.98	-0.17	-0.17	-0.02	1.78	-0.03	0.00	-0.04
46 cns	0.17	-1.75	-2.08	0.35	0.92	-0.58	-0.59	0.00	1.68	-0.48	-0.49	0.00	1.64	-0.17	-0.17	0.00
47 trd	2.06	0.14	0.16	-0.04	1.60	0.10	0.22	-0.14	1.99	-0.16	-0.18	0.00	1.78	-0.03	-0.01	-0.03
48 otp	2.44	0.53	0.25	0.25	1.51	0.01	-0.02	0.02	2.29	0.14	0.10	0.02	1.87	0.06	0.03	0.03
49 wtp	2.90	0.98	0.56	0.39	1.52	0.02	-0.33	0.34	2.36	0.21	0.50	-0.31	1.97	0.16	0.06	0.09
50 atp	2.06	0.14	0.38	-0.26	1.40	-0.10	-0.08	-0.03	2.09	-0.06	0.20	-0.28	1.68	-0.12	0.02	-0.15
51 cmn	1.95	0.03	0.22	-0.20	1.61	0.11	0.21	-0.11	2.01	-0.15	-0.15	-0.02	1.76	-0.05	0.00	-0.05
52 ofi	2.07	0.15	0.24	-0.10	1.57	0.07	0.21	-0.15	2.11	-0.04	-0.11	0.06	1.83	0.02	0.01	0.00
53 isr	1.98	0.06	0.39	-0.34	1.50	0.00	0.19	-0.20	2.28	0.13	0.00	0.11	1.88	0.07	0.03	0.03
54 obs	1.66	-0.25	-0.19	-0.08	1.29	-0.21	-0.08	-0.14	2.09	-0.07	-0.10	0.02	1.74	-0.06	-0.04	-0.03
55 ros	1.93	0.01	0.40	-0.41	1.52	0.01	0.32	-0.32	2.01	-0.15	-0.13	-0.03	1.78	-0.03	0.02	-0.06
56 osg	1.92	0.00	0.00	-0.01	1.95	0.45	0.51	-0.08	1.86	-0.29	-0.30	-0.01	1.82	0.01	0.02	-0.01
57 dwe	3.00	1.09	0.52	0.54	2.65	1.15	0.61	0.52	2.30	0.15	-0.32	0.45	2.16	0.36	0.03	0.32

Table 7.1. The second column is the gap between the industry and GDP growth rates [$g_{ind}(j,r) - gdp\_approx(r)$, the RHS of (7.3)]. The third and fourth columns are the decomposition of the gaps into sales-mix and industry-performance effects.[7]

Using the decomposition as a guide, we explain the output results in Table 7.3 for 16 selected industries. The selection was made to identify the factors that are important in determining industry results in our simulations. With different strengths for different industries, we find that all of the following play a role in determining the growth rates in the four periods for an industry's output:

- the distribution of the industry's sales to different sales categories and the growth rates of the categories;
- the capital-labour ratio in the industry's production function and the economy-wide movements in capital rental rates relative to wage rates;
- the expenditure elasticity of demand by households for the industry's product;
- the distribution of the industry's exports across trading partners (the proportions of its exports that go to the U.S., China, etc) and the changes in the prices of competitors in Canada's export markets relative to changes in the price of the Canadian product;
- the sources (U.S., China, etc) of imports that compete with the industry's product in the Canadian market and changes in the prices of these imported products relative to that of the Canadian product;
- technological/environmental changes affecting the use of fossil-fuel products; and
- assumptions about the availability of agricultural land and the share of the industry's costs accounted for by land.

Services of the housing stock (dwe, ind 57)

Growth in services to housing exceeds GDP growth in all simulation periods (gaps of 1.09, 1.15, 0.15 and 0.36 per cent, last row of Table 7.3).

Almost 100 per cent of the sales of this industry is to households. Consequently, its sales-mix effect (SME) is positive in 2014-19, 2019-30 and 2040-50 (0.52, 0.61 and 0.03, last row of Table 7.3) because growth in real private consumption in these three periods exceeds growth in real GDP, see Table 7.2. In 2030-40, growth in real private consumption is below that of GDP, giving the industry a negative value for SME.

The industry-performance effect (IPE) for ind 57 is positive an all periods. This indicates that demand for housing services increases relative to total real private consumption as a whole. There are two reasons. First, the expenditure elasticity of demand for housing services is greater than one, but only a little greater. The second, but more important reason, is that the price of housing services falls relative to the price of consumer goods in general, inducing substitution towards housing services.

Why does the price of housing services fall relative to price of consumer goods in general? We considered several possibilities. Our first thought was technical change. Does technical change in our simulations reduce costs in some industries relative to others? The answer is no. We imposed uniform primary-factor-saving technical change across all Canadian

[7] The third and fourth columns do not add precisely to the second column because we we do linear arithmetic rather than multiplicative arithmetic.

industries. Some industries rely on primary-factor inputs more than others. But the industries that rely mainly on intermediate inputs get their cost-reducing technical change via these intermediate inputs. Ultimately, all industries produce their output with primary factors used either directly or indirectly embedded in intermediate inputs. What about the bias in technical change that we introduced via twistKL, see the discussions of panel 6 in section 4 and panel 4 in section 5? twistKL biases technical change towards the use of capital, but we assumed that the bias was cost neutral in every industry. Consequently, the twists do not introduce cost saving technical change in one industry relative to another. Next, we investigated the idea that imported inputs might explain simulated changes for Canada in relative costs across industries. However, we found that this was only a minor factor.

It turned out that changes in factor prices are the explanation for the simulated reductions in the price of housing services relative to the price of consumer goods in general. As can be seen in Table 7.4, the price of using labour in Canada rises relative to the price of using capital in all four simulation periods. This lowers the price of capital-intensive commodities such as housing services relative to the price of labour-intensive commodities.

This leads to the question of why the cost of using labour increases relative to the cost of using capital. Recall from Table 6.1 that the capital to labour ratio increases in every country in every simulation period. Demographic factors dictate slow growth in labour input in nearly all regions, while high average saving rates for the world dictate rapid growth in capital stocks. Despite the introduction of capital-using bias in technical change, our simulations require reductions in capital-rental-to-wage ratios to absorb the increases in the K/L ratios.

A final question that worried us was the relationship between rates of return and the decline in capital rentals relative to wage rates. We were worried that continued increases in wage-rental ratios world generate unrealistic and continuing reductions in rates of return on capital. However, it is clear that this is not the case. Table 7.4 shows movements in rates of return for Canada, reproduced from Table 6.1. These rates of return increase in the third and fourth periods, despite the continuing increases in wages relative to rentals.

Movements in rates of return depend on movements in the ratio of capital rentals to the cost of creating units of capital. Capital is created in the GTAP model as a mix of commodities such as construction, machinery and financial services. As can be seen in Table 7.4, the cost of this mix in Canada moves approximately in line with the price of GDP. Given this correlation, a helpful stylized equation for understanding the relationship between movements in rates of return and movements in factor prices in Canada is:

$$\text{pgdp(r)} = S_{\ell}(r) * \text{wage(r)} + S_k(r) * \text{rent(r)} - \text{tech\_change(r)} \tag{7.8}$$

In this equation,

pgdp(r) is the percentage change in the price deflator for GDP in region r;

wage(r) and rent(r) are percentage changes in the wage and capital rental rates in region r;

$S_{\ell}(r)$ and $S_k(r)$ are the labour and capital shares in GDP in region r; and

tech_change(r) is total-factor-productivity growth in region r.

Assuming that tech_change(r) is positive and that wage(r) is greater than rent(r), (7.8) implies that either

Table 7.4. Macro price results for Canada: percentage changes through periods

	2014-19	2019-30	2030-40	2040-50
Price of using labour (wage rate)	-5.20	52.45	36.87	41.67
Price of using capital (rental rate)	-12.25	24.40	22.90	29.08
Price of creating a unit of capital	-8.10	31.56	22.30	25.96
Price of GDP	-11.81	33.67	21.32	26.65
Rates of return on capital	-1.46	-0.84	0.08	0.41

$$wage(r) > pgdp(r) > rent(r) \tag{7.9}$$

or

$$wage(r) > rent(r) > pgdp(r) \tag{7.10}$$

For Canada, (7.9) applies in the first two simulation periods and (7.10) in the second two periods. Consequently, rates of return on Canadian capital fall in the first two periods and rise in the second two periods.

Milk products (mil, ind 22)

This is another consumer-oriented industry, although with a lower share of its sales to households than is the case for ind 57. Consequently, the SME for milk products is positive for the first two simulation periods, negative in the third period, and negligible in the fourth period.

IPE for Milk products is negative in all periods and approximately offsets the positive SMEs for the first two periods. For the third and fourth periods, the negative IPEs leave growth in the industry's output well below that of GDP.

The IPEs for milk products are negative because the price of milk products increases relative to the price of consumer goods in general. Direct and indirect use of labour is a larger share of costs in ind 22 than in ind 57. However, the main component in the increase in the relative price of milk products is a steady increase in the price of its principal intermediate input, raw milk (rmk, ind 11). This reflects an increase in the price of agricultural land resulting from an increase in demand for agricultural products and a fixed supply of land.

Another factor contributing to the IPEs for milk products is a low expenditure of demand. This means that milk products loses ground against other consumer products as aggregate real expenditure per household rises.

Raw milk (rmk, ind 11)

Most of the sales of this product are to Canada's milk products industry. Consequently the SME for raw milk is closely in line with the gap for milk products (0.08 versus 0.03, 0.06 versus 0.02, -0.58 versus -0.65, and -0.44 versus -0.51). Raw milk faces very little competition in its principal market (intermediate sales to milk products). This means that the IPE for raw milk is small in all periods despite the increase in its price.

Recreation and other services (ros, ind 55)

This is a consumer-oriented, labour-intensive industry with an expenditure elasticity slightly less than one. Consumer-orientation gives the industry positive SMEs in periods 1, 2 and 4, and a negative SME in period 3. High labour-intensity increases the price of the product relative to other consumer goods and contributes to negative IPEs in all periods. The relatively low expenditure elasticity also contributes to the negative IPEs.

About 20 per cent of the Canadian market for ros is serviced by imports and about 13 per cent of the industry's product is exported. In the first period there is a general twist in Canadian preferences towards imports, see Table 4.5. This contributes negatively to the industry's IPE. In the second period, costs in the Canadian ros industry increase relative to the cost of competing imports. This again contributes negatively to the IPE. In the other two periods, the increase in the price of the domestic product moves broadly in line with that of imports, with little effect on the industry's IPE.

Government services (osg, ind 56)

This industry faces little competition from other industries and most of its sales are to government. In these circumstances, the IPE effect must be small and the gap between the industry's growth rate and that of GDP must be explained principally by SME. Thus, we see a negligible gap in periods 1 and 4 when average annual growth in government expenditure is close to that of GDP (1.89 per cent versus 1.88 per cent in period 1, and 1.84 per cent versus 1.81 per cent in period 4, see Table 7.2.). In period 2, the gap is positive because growth in government expenditure exceeds growth in GDP (2.13 versus 1.53). In period 3, the gap is negative because growth in government expenditure is less than the growth in GDP (1.84 versus 2.09).

Construction (cns, ind 46)

Most of the sales of construction (cns, ind 46) are intermediate inputs supplied to the capital goods industry (cgds). In the GTAP model, the output of cgds in region r is the region's real investment. Thus, the main sales category for cns is investment. In supplying investment via the cgds industry, cns faces almost no competition from other industries.

Given these characteristics, we can understand why the gap calculations for ind 46 in Table 7.3 are dominated by SMEs. In all periods, the output of cns grows slower than GDP with the negative gap explained almost entirely by negative SMEs reflecting slow growth in Canada's investment relative to GDP.

However, there is one curious aspect of the results in the cns row of Table 7.3. What explains the significantly non-zero result (0.35) for IPE in period 1?

Recall from the discussion in section 4 of panel 15 in Table 4.1 that in the 2014-19 simulation we introduced observations on movements in price deflators for investment. In exogenizing these movements, we allowed the model to generate input-saving or -using technical changes in the cgds industry. In the case of Canada, the technical changes were input using. Consequently, sales of cns (and all other inputs) to the cgds industry increased relative to the quantity of cgds output, which is investment. This generated a positive IPE for cns in period 1.

Coal (coa, ind 15), Oil (oil, ind 16)and Gas (gas, ind 17)

The growth gap in Canada for these three fossil fuels is negative in all four periods, dominated by negative IPEs.

In Canada and in all other countries, the forecasts from IEA that we introduced to the simulations imply partial replacement of fossil-fuel inputs with other inputs in all using industries (see Tables 4.6 and 6.5). This means that Canadian sales of fossil products exhibit slow or negative growth in both their domestic and export markets, explaining their strongly negative IPEs.

For Canada, the main sales category for the 3 fossil-fuel products is exports. In period 1, Canadian exports grew faster than GDP (2.63 per cent versus 1.88 per cent, Table 7.2), generating positive SMEs. Similarly, the SMEs in period 3 are positive because export growth is significantly greater than GDP growth. The opposite holds in period 2. In period 4, export growth is only slightly greater than GDP growth (1.89 versus 1.81). Consequently, the SMEs for this period are small.

Electricity (ely, ind 43)

Electricity sales are distributed across all industries and households. The product faces only a minor amount of competition from other products in its domestic markets and has only a small exposure to export markets. Thus, it is not surprising that the gaps between the growth rates of electricity output and GDP in periods 2, 3 and 4 are modest (0.17, 0.30 and 0.02).

Major markets for electricity include households and electricity-intensive, export-oriented industries such as other mining (omn, ind 18), non-ferrous metals (nfm, ind 36), and paper and paper products (ppp, ind 31). In period 1, all of these markets grow strongly relative to GDP. This gives electricity a relatively strong SME (0.43). Electricity production is capital intensive. Consequently, the price of electricity falls relative to that of prices in general. This gives electricity positive IPEs in all periods, particularly period 1.

Wheat (wht, ind 2)

The output-GDP growth gap for wheat moves from strongly positive to negative through the four simulation periods. In the first period, SME and IPE are both positive. In the second period, SME becomes negative but is outweighed by a positive IPE. In the third and fourth periods, the SMEs are positive but are outweighed by negative IPEs.

The Canadian output of wheat is almost entirely exported. Consequently, the SMEs for wheat are strongly positive (0.69 and 0.84) in periods 1 and 3 because growth in aggregate exports in these periods significantly exceeds growth in GDP. The SME in period 2 is negative because growth in aggregate exports is less than growth in GDP, and the SME in period 4 is close to zero because growth in aggregate exports is close to growth in GDP.

About 60 per cent of Canadian wheat sales go to RoW. The main competitors to Canada in the RoW wheat market are the U.S., France, RoEU and RoW itself. In the first period, RoW wheat imports grow very strongly. At the same time, high capital intensity in the Canadian wheat industry relative to other wheat producers gives the Canadian industry an edge in price competitiveness. Sales to RoW and Canadian price competitiveness combine to generate strongly positive growth in Canadian wheat exports relative to growth in Canadian exports in general, a positive IPE. In later periods, growth in wheat demand by RoW slows and Canadian price competitiveness in the RoW market declines. These developments take the grown rates for Canadian wheat exports below the growth rates for Canadian exports in general producing negative IPEs in the third and fourth periods.

Iron and steel (i_s, ind 35)

The output-GDP growth gap for this industry is negative in periods 1, 2 and 4, with the IPEs making significant negative contributions. In period 3, the IPE is slightly positive, and combines with a strongly positive SME to give a growth gap of 0.76.

Canada's i_s industry exports nearly 50 per cent of its output, overwhelmingly to the U.S., and sells the rest as intermediate inputs mainly to the Canadian industries that produce fabricated metal products (fmp, ind 37), motor vehicles (mvh, ind 38), other machinery and equipment (ome, ind 41), and construction (cns, ind 46). In its Canadian markets, the i_s industry faces considerable import competition from the U.S.

In the first period, the reliance of the i_s industry on exports contributes positively to its SME but its reliance on intermediate sales contributes negatively (positive gaps for fmp and ome, heavily outweighed by negative gaps for mvh and cns). The opposing export and intermediate-input effects leave the overall SME at close to zero (0.05). In period 2, the export contribution to SME for i_s is negative and the composition of intermediate i_s sales remains unfavourable (negative gaps for fpm, mvh, ome and cns). This explains period 2's strongly negative SME (-0.98). In period 3, strong growth in aggregate exports and positive gaps for fmp, mvh and ome produce a strongly positive SME (0.69). In the fourth period, both the export and the intermediate-input contributions to SME for i_s are small, with a net outcome that is slightly negative (-0.10).

To help us understand the IPE results for the i_s industry, we looked at the movements in the price of the Canadian product relative to prices in other regions. Keeping in mind that most of Canada's trade in iron and steel is with the U.S., we were particularly interested in the Canada/U.S. price comparison.

In the first period, the price of the Canadian product fell relative to that of the U.S. product, mainly because of real appreciation by the U.S. relative to Canada. We expected this to generate a positive IPE for i_s via replacement in Canadian industries of imports from the U.S. by iron and steel produced in Canada, and possibly via price-induced growth in Canadian exports to the U.S. However, the IPE result for period 1 is negative, -0.50. We traced this surprising result to the endogenous preference twist that we introduced in the 2014-19 simulation in favour of U.S. products (see Table 4.7). This preference twist affects imports of all products from the U.S to all regions. In particular, it restrains Canadian output of iron and steel by stimulating i_s imports from the U.S. by the Canadian fmp, mvh, ome and cns industries.

In periods 2, 3 and 4, the preference shift is not operating. In period 2, the IPE result is negative reflecting an increase in the price of i_s produced in Canada relative to i_s produced by the U.S. In period 3 the price changes for the Canadian and U.S. products are approximately the same and approximately match the average price changes across other regions. This gives an IPE result for Canada of close to zero (0.05). In period 4, the U.S. and Canadian price movements were again approximately the same. Nevertheless, the IPE result for period 4 is significantly negative (-0.42). We found that growth in Canadian exports of i_s to the U.S. was restrained in period 4 by loss of competitiveness relative to other suppliers to the U.S., particularly China, India and RoW.

Motor vehicles (mvh, ind 38)

The output-GDP growth gap for this industry is negative in periods 1 and 2, and positive in periods 3 and 4.

Canada's mvh industry produces finished cars and parts. Nearly 80 per cent of Canada's mvh output is exported, overwhelmingly to the U.S. About 8 per cent is sold as an intermediate input to the mvh industry itself. The rest of the sales from Canada's mvh industry are spread widely across households, industries and capital creation. In all parts of the Canadian market for mvh products imports dominate, accounting for 78 per cent of sales of mvh products in Canada. The U.S. supplies 77 per cent of Canada's mvh imports.

The high export share in mvh sales generates significantly positive SMEs in periods 1 and 3 when Canada's aggregate export growth is well above GDP growth. In period 2, when aggregate export growth is below GDP growth, the SME for mvh is negative. In period 4, aggregate export and GDP growth are approximately the same, leading to an SME result for mvh that is close to zero.

As was the case for i_s, in period 1 the Canadian mvh industry gains considerable price advantage over the U.S. via exchange-rate appreciation of the U.S. relative to Canada. However, this is more than offset by the twist in preferences in favour of U.S. products that was introduced endogenously in the 2014-19 simulation. With the twist, Canadian users of mvh products shift their purchases towards imports from the U.S., generating a negative IPE.

Again, as was the case for i_s, the Canadian mvh price rises relative to the U.S. price in period 2 and then moves approximately in line with the U.S. price in period 3 and 4. The loss of competitiveness in period 2 generates a negative IPE for the Canadian mvh industry. In periods 3 and 4, the IPEs are moderate positives (0.25 and 0.33). We traced these favourable IPEs to an improvement in competitiveness of Canadian mvh producers supplying the U.S. market relative to other suppliers of the U.S. market, particularly Mexico.

Electronic equipment (ele, ind 40)

Canada's ele industry shares important characteristics with its mvh industry. It is highly export-oriented: 69 per cent of Canadian ele is exported. About 18 per cent of Canadian ele output goes to a wide variety of industries as an intermediate input. Investment takes 9 per cent and households take 4 per cent. Similar to mvh, imports dominate in all parts of the Canadian market for ele products. They account for nearly 90 per cent of ele sales in Canada.

In the case of mvh, the U.S. is overwhelming Canada's main trade partner for both imports and exports. For ele, the U.S. takes about 50 per cent of Canada's exports, but supplies only about 21 per cent of Canada's imports. China supplies about 50 per cent of Canada's ele imports. China is also the main supplier of U.S. imports of ele.

Similar to mvh, the ele output-GDP growth gaps are negative in periods 1 and 2 and positive in period 3. In period 4, mvh has a positive gap but the gap for ele is negative, driven by a large negative IPE.

The U.S.-Canada ele price movements are similar to those for mvh: improved competitiveness for Canada in period 1; reduced competitiveness for Canada in period 2; and very little change in periods 3 and 4. But for ele, competitiveness against China is also important. In periods 1 and 3, the Canada price for ele falls relative to the China price. In periods 2 and 4 the Canada price rises relative to the China price.

Export orientation gives Canada's ele industry positive SMEs in periods 1 and 3 and a negative SME in period 2. The SME is close to zero in period 4 in which growth in Canada's aggregate exports is close to growth in GDP.

Despite competiveness improvements for Canada against both the U.S. and China in period 1, the Canadian ele industry suffers a negative IPE (-0.88). This is explained by the twist in favour of U.S. products, but also by a twist in favour of Chinese products (37.56 per cent, see Table 4.7). In period 2, loss of competitiveness against both the U.S. and China generates a negative IPE for Canada's ele industry. In period 3, the improvement in Canadian competiveness against China produces a positive IPE and in period 4 the deterioration in Canadian competiveness against China produces a negative IPE.

Water services (wtr, ind 45)

Trade is of only minor importance for this industry. For such industries, output-GDP growth gaps are usually small, and this industry is no exception.

Water services are sold mainly to households and government. The sales to government are via sales to the government services industry (osg, ind 56). With this sales pattern, the SME for wtr is positive in periods 1, 2 and 4. In these periods, private and public consumption growth exceeds GDP growth (but only slightly in period 4). In period 3, private and public consumption growth is less than GDP growth giving a negative SME.

Canadian exports of water services are negligible. However, imports, mainly from the U.S., account for about 12 per cent of wtr sales in Canada. Given the presence of these imports, the twist in favour of U.S. products in period 1 produces a negative IPE (-0.08) despite a competitive advantage for the Canadian industry from U.S. exchange rate appreciation. In period 2, the Canadian wtr industry loses competitiveness relative to imports from the U.S. This produces a negative IPE. In periods 3 and 4, Canadian and U.S. prices for wtr move approximately in line. Consequently, the IPEs for wtr in these periods are small. They are slightly negative (-0.02 and -0.04) because the expenditure elasticity of demand for this product in Canada is a little less than one. This inhibits growth in demand relative to growth in aggregate consumption.

Wholesale and retail trade (trd, ind 47)

Like water services, wholesale and retail trade in the GTAP model is essentially non-traded with sales spread across households and a wide range of industries. Consequently, the results in Table 7.3 for this industry are similar to those for wtr. Their main features are: small positive SMEs in periods 1 and 2, and small negative SMEs in periods 3 and 4; IPEs close to zero in all periods; and small positive output-GDP growth gaps in periods 1 and 2 followed by small negative gaps in periods 3 and 4.

8. Concluding remarks

This is our third paper for the USITC and the WTO prepared under a contract concerned with baseline projections (Req 6400-00EC-22-0008, modification no. 34300021P0044 and VU/WTO agreement, September 2021). Since February 2023, Global Affaires Canada has also supported the project.

The first paper, Dixon and Rimmer (2023a), described an historical simulation for 2004 to 2014, both of which are GTAP database years. The main purpose of the simulation was to deduce changes in industry technologies and in preferences by agents between commodities and between countries of origin from which they source their imports.

The second paper (Dixon and Rimmer, 2023b) described a validation exercise. We simulated from 2014 to 2017 building in technology and preference trends from the 2004-14 historical simulation. Then we assessed the performance of the 2014-17 simulation by comparing the results with the GTAP database for 2017. The assessed performance was unsatisfactory. The 2014-17 simulation produced a picture of 2017 that was no closer to the 2017 GTAP database than could have been produced by assuming no technology or preference changes. However, the 2017 GTAP database has subsequently been revised and various problems rectified. We think it would be worthwhile to repeat the validation exercise.

For this paper, our initial intention to build into the 2014-2050 baseline comprehensive technology and preference trends from the two earlier papers. However, in view of the unsatisfactory results in the validation exercise, we went only a small way down that path: we built in trends in technology biases favouring the use of capital relative to labour.

While the research in this paper has not taken us as far as we would have liked, there are positives.

First, we have developed and applied a method to generate linked long-run simulations. The links include accumulation relationships for capital and foreign assets and liabilities. Under our method, we link disjoint years: 2014 to 2019, 2019 to 2030, etc. The computational burden is kept manageable by avoiding explicit modelling of intermediate years through smooth-growth assumptions applied to saving. We were able to work at the full GTAP industry dimension. Although, we aggregated to 13 regions, it would not be computationally prohibitive to work at a much higher level of regional disaggregation.

Second, we have introduced to the GTAP baseline simulations macro, demographic and energy forecasts for each region made by international organizations such as OECD, IMF, IEA, IIASA and Penn World Tables. This required new variables and equations and the creation of closures in which the extraneous forecasts could be introduced as exogenous shocks. The development of the closures was undertaken in step-by-step processes set out in tables and documented in this paper.

Third, we have implemented a simple iterative method for undertaking linked simulations in which investors have forward-looking expectations. In our 2019 to 2030 simulation, investment in region r depends on the region's capital growth for 2030 to 2040. In the 2030 to 2040 simulation, investment in region r depends on the region's capital growth for 2040 to 2050. Forward-looking expectations are important in our simulations. For example, investors in China in 2030 will know that demographic factors will reduce growth over the following decade relative to that over the previous decade. Consequently, an investment forecast *for* 2030 based on capital growth between 2019 and 2030 is likely to be an overestimate, with unrealistic implications for other variables such as the trade balance.

Fourth, the simulations show some interesting results. These include:

- A slowdown in the Chinese economy with weak investment growth to 2030 and a turnaround in its trade accounts after 2030 with import growth exceeding export growth (Table 6.2);

- Extremely strong growth in trade for India with annual export growth sustained out to 2050 at between 6 and 8 per cent and import growth between 4 and 5 per cent (Table 6.2);
- Strong wage growth in most regions out to 2050 and reductions in rates of return on capital reflecting continuing high rates of global saving supporting fast growth in capital relative to labour (Table 6.1);
- Sluggish growth and a poor wage outcome for Saudi Arabia reflecting declining markets for oil and gas (Table 6.1);
- Weak GDP growth for Japan reflecting declining employment but, nevertheless, a moderate improvement in wages (Table 6.1);
- Rapid reductions in coal per unit of output in using industries in most regions but relatively slow decline in global use of coal because of strong growth in GDP and electricity production in major using economies such as India (Tables 6.4 and 6.5);
- Reductions in use of oil and gas per unit of output in using industries in most regions but almost no decline in global use (Tables 6.4 and 6.5).

Fifth, we found back-of-the-envelope (BoTE) explanations for the major macro and industry features of our simulation results. BoTE explanations are important in understanding and communicating results, and in locating modelling and data weaknesses.

Finally, the paper points to promising directions for future research.

Most obviously, we would like to complete the original research plan. This involves taking on board detailed scenarios for variables describing industry technologies, consumer preferences and importer choices between alternative supplying regions. As already mentioned, we estimated trends in these variables at a highly detailed level in our 2004 to 2014 historical simulation. We worked out a methodology for incorporating these trends into a baseline simulation and applied it in our 2014-17 validation simulation. The results from the validation simulation were disappointing but we think more-satisfactory results could be obtained after a thorough audit of the GTAP databases.

In our 2014-17 validation paper, we documented a large number of data problems at the industry/commodity level. Spotting such problems is facilitated by simulations in which the model is forced to track history. In preparing the current paper, we stumbled into data problems at the macro level. Our linked simulations from 2014 out to 2050 account for accumulation by each region of foreign assets and liabilities. We did not report results for these variables because they did not look reasonable. We have traced the problems back to two factors: modelling and data.

With regard to modelling, we need to be improve our projection method for public and private consumption. In the current paper, we assumed that regional average propensities to consume out of net national product converge towards the world average. Thus, high-saving regions such as China move to higher consumption propensities, while low-saving regions move to lower propensities. This seems a reasonable assumption but it still left simulated net foreign assets for some regions stabilizing at unrealistic levels with related unrealistic ratios of trade balances to GDP. We probably need to use simulated movements in net foreign assets to inform movements in consumption propensities. We also need to improve our modelling of rates of return on foreign assets relative to rates of return on foreign liabilities. In the current model, based on GTAP's global bank, the foreign assets of a region earn a worldwide interest rate while the interest rate paid on foreign liabilities reflects the average rate of return on the region's capital. These assumptions are important in projecting net foreign assets, but they could and should be better informed.

With regard to data, we found some disconnects between GTAP and OECD data on trade balances. For example, OECD data in Table A1.2a (in Appendix 1) implies that Canada had a trade deficit in 2014 worth 0.9 per cent of GDP [= 100*(589-573)/1806]. The GTAP data that we are using for 2014 implies that Canada's trade deficit was 4.8 per cent of GDP. Discrepancies such as this don't matter in most GTAP simulations which are comparative static and concerned with the effects of a specific policy. However, for building a baseline projection taking account of asset and liability accumulation, we need to get the starting point right. An unrealistic starting point for the trade deficit accumulates over time into unrealistic levels for net foreign assets with unrealistic implications for projections of other macro variables including private and public consumption.

As recognized by other researchers (e.g. Bekkers *et al.* , 2020 and Britz and Roson, 2019), baselines are important. This is for several reasons. First, users of economic modelling results in the policy arena want baselines. They don't just want to know how different an economy would be with a particular policy in place from the way it would be without the policy (the effect of the policy), they want to know where the economy is going with and without the policy. Second, baselines matter even if the main interest *is* the effects of policies. For example, in assessing the future employment effects of policy-dictated closures of coal mines, we need to have a baseline view about where employment in the coal industry was going without the policy. Third, by producing baselines we can validate our models (or otherwise). In this paper, and in our two earlier papers for this project, we have been trying to contribute to the development of GTAP baselines by exploiting the time series dimension of GTAP databases.

Building a baseline out to 2050 proved to be difficult and it is clear that the research reported in this paper did not meet our ambitious targets. However, all is not gloom. As well as revealing many things that *need* to be done, an immediate spin-off from what we *have* done might be the development of comprehensive checking and updating methods for GTAP databases.

For checking a newly developed database for year $t + \tau$, e.g. 2017, we can imagine conducting a simulation starting from year t, e.g. 2014, and building in known movements in macro and trade variables together with technology and preference trends. Examination of differences between the synthetic $t + \tau$ database created in this checking simulation and the newly developed database for year $t + \tau$ could provide a framework for detecting database problems.

For updating from the most recent database, e.g. for 2017, to a recent year, e.g. 2022, we can imagine conducting a simulation starting from 2017 and building in known movements between 2017 and 2022 in macro and trade variables together with technology and preference trends. This would be similar to our 2014-19 simulation reported in this paper. But of course we would want to make sure that the starting database for our update simulation was compatible with the data sources for the update shocks.

GTAP databases have not been developed with time-series analysis as their primary focus. Nevertheless, our 2004-14 historical simulation (Dixon and Rimmer, 2023a) showed that the databases for these two years are highly comparable and imply interesting and plausible trends in technologies and preferences. After about three years work on the three parts of this project (historical, validation and baseline) we think that further development of the time-series dimension of the GTAP databases has enormous potential for improving the ability of the GTAP community to contribute to the analysis of global issues. Steps in realizing this potential include:

- work on the GTAP databases at both the macro and micro levels guided by historical, validation and baseline simulations; and
- theoretical work on accumulation relationships and macro relationships more generally.

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Appendix 1. Notes on data

Capital stocks

Column (1) in Table A1.1 shows the average annual growth rates in capital stocks that we used in our historical simulation for 2004 to 2014 (Dixon and Rimmer, 2023a). This was based on Penn data for capital services in constant national prices. Similarly, columns (2) and (3) are based on Penn data for capital services in constant national prices.

Column (2) in Table A1.1 shows the average annual growth in capital stocks from 2004 to 2014 calculated from the latest Penn data (PWT1001.xlsx downloaded from https://www.rug.nl/ggdc/productivity/pwt/?lang=en on July 3, 2023. We processed the data for the rkna variable in PWT.tab in c:\dixon\consult\ITC\2023\WTO). Comparison of columns (1) and (2) shows that the Penn data have been significantly revised. Revisions are described in the Penn documentation but it is impractical for us to revise our 2004-14 historical simulation. In any case, the revisions depend on adoption by Penn of new theory of doubtful relevance for our historical simulation.

Column (3) in Table A1.1 shows the average annual growth in capital stocks from 2014 to 2019 calculated for all regions except RoW from the latest Penn data. We use these data to represent average annual changes in capital stocks from start of 2014 to start of 2019. We calculated the RoEU numbers by aggregating over 25 EU countries (EU27 less France and Germany). We used percentage changes in rkna with rnna weights. The entry for RoW in column at (3) was derived by extrapolating capital growth in our 2014-17 validation simulation (see Dixon and Rimmer, 2023b).

Table A1.1. Average annual percentage growth in capital

	2004-2014 old (1)	2004-2014 new (2)	2014-19 (3)
1 USA	2.51	2.38	2.13
2 CAN	2.82	3.43	2.20
3 MEX	3.57	2.93	2.44
4 CHN	12.07	11.46	9.10
5 JPN	1.05	0.89	0.94
6 KOR	4.75	4.91	4.01
7 IND	9.93	9.16	6.91
8 FRA	2.20	2.07	1.98
9 DEU	1.55	1.51	1.73
10 UK	1.87	1.96	2.22
11 RoEU	2.35	2.27	1.96
12 SA	7.83	9.53	5.35
13 RoW	4.00	*NA*	3.54

GDP and expenditure components

Table A1.2a shows GDP and its expenditure components in $US billion at current prices. These data were extracted from OECD stats (https://stats.oecd.org/). We understand that OECD derives these data from national sources and converts to $US using average exchange rates through a year. Data marked 2021 for India are actually for 2020. The add-up rows differ from the GDP rows because of statistical discrepancies.

Our interest is mainly in 2014-19. The statistical discrepancies for these two years are generally small except for Mexico. For Mexico the discrepancy in 2014 is 1.23 per cent of

GDP. In 2019, it is 2.84 per cent of GDP. In our simulation for 2014-19, we effectively eliminate statistical discrepancies by allowing the model to calculate GDP by adding up observed expenditure movements.

Table A1.2b shows GDP and its expenditure components in $US billion at constant 2015 prices, also extracted from OECD stats (https://stats.oecd.org/). Again, the data marked 2021 for India are actually for 2020. The statistical discrepancies for 2014 are generally small. However for India in 2019 the statistical discrepancy is 2.81 per cent of GDP.

Tables A1.3a and A1.3b show percentage changes calculated from Tables A1.2a and A1.2b. Table A1.4old is re-produced from our earlier work. As a check, we compared Table 1.4old with the 2004-14 panels in A1.3a and A1.3b. The check revealed that we incorrectly recorded data for real movements for Germany in Table 1.4old, but this didn't affect our historical simulation. The nominal value for government expenditure in China now increases by 479 per cent revised up from 413 per cent in Table 1.4old. This seems to be a genuine revision. Apart from that, the new numbers for 2004-14 are closely compatible with the old numbers.

We deduced the RoEU numbers as differences between OECD data for EU27 and the data for France and Germany.

The RoW numbers in the 2014-19 panel of Table A1.3b were derived by extrapolation from our 2014-17 validation simulation.

We impose the numbers in bottom panel of Table 1.3b in our 2014-19 simulation.

Table A1.2a. GDP and expenditure components in $US billion, current prices

		USA	Canada	Mexico	China	Japan	SKorea	India	France	Germany	UK	RoEU	Saudi Arabia	RoW	EU27
2004	GDP	12217	1026	782	1955	4893	793	694	2120	2814	2423	6470	259		11404
	C	8232	562	534	794	2678	409	404	1146	1580	1580	3595	79		6320
	G	1852	199	82	286	867	98	74	488	530	471	1287	59		2305
	I	2767	219	173	818	1255	258	245	464	558	429	1515	51		2538
	X	1176	383	202	607	626	291	125	561	1005	581	2534	132		4100
	M	1811	337	216	556	532	264	138	540	859	639	2461	62		3859
	Addup	12217	1026	775	1949	4893	793	710	2120	2814	2423	6470	259		11404
2014	GDP	17551	1806	1315	10476	4897	1484	2043	2856	3889	3065	8907	756		15653
	C	11848	1008	866	3845	2822	741	1188	1551	2078	1980	4938	243		8567
	G	2566	366	160	1657	976	226	213	689	762	609	1866	197		3316
	I	3647	449	288	4800	1226	442	700	649	792	540	1740	217		3181
	X	2377	573	419	2524	853	710	469	847	1774	870	4527	355		7148
	M	2887	589	435	2261	980	635	530	880	1517	934	4163	255		6560
	Addup	17551	1806	1299	10566	4897	1484	2040	2856	3889	3065	8907	756		15653
2019	GDP	21381	1744	1269	14280	5118	1651	2851	2729	3888	2857	9077	804		15694
	C	14393	1007	824	5605	2792	803	1738	1463	2021	1838	4839	310		8323
	G	3009	360	145	2395	1021	282	313	627	787	543	1815	192		3229
	I	4558	402	269	6176	1320	520	862	665	860	522	2082	234		3607
	X	2538	564	493	2641	894	649	533	862	1815	893	5057	286		7734
	M	3117	590	496	2476	909	602	606	888	1595	939	4716	219		7199
	Addup	21381	1744	1234	14341	5118	1651	2838	2729	3888	2857	9077	804		15694
2021	GDP	23315	2001	1273	17820	5006	1811	2672	2958	4260	3122	9977	834		17194
	C	15903	1089	831	6805	2679	836	1624	1558	2098	1892	5104	346		8759
	G	3354	438	150	2817	1072	329	323	717	943	699	2123	204		3783
	I	4920	476	264	7688	1281	581	745	740	992	571	2279	197		4012
	X	2540	619	523	3554	911	761	500	871	2003	900	5790	290		8665
	M	3401	620	545	3091	938	696	510	929	1777	938	5320	203		8025
	Addup	23315	2002	1223	17772	5006	1810	2682	2958	4260	3123	9977	834		17194

Table A1.2b. GDP and expenditure components in national currencies, 2015 prices

		USA	Canada	Mexico	China	Japan	SKorea	India	France	Germany	UK	RoEU	Saudi Arabia	RoW	EU27
2004	GDP	14400	1593	13574	24713	502882	1107416	50284	1950	2606	1786		1581		9385
	C	9749	814	9376		281553	589947	27870	1043	1458	1137		425		5208
	G	2377	326	1599		91386	144259	5505	448	489	349		379		1909
	I	3124	341	2826		138213	368707	16268	447	534	313		277		2102
	X	1427	556	3472		66045	333378	8833	502	875	452		721		3380
	M	2293	447	3809		72155	318370	9103	490	752	474		317		3214
	Addup	14384	1589	13464		505041	1117921	49373	1950	2604	1778		1484		9386
2014	GDP	16932	1923	16741	64354	529813	1612718	105277	2150	2982	2021		2357		10304
	C	11515	1078	11052		300717	787410	59127	1168	1573	1277		926		5583
	G	2449	384	2036		103556	240901	10542	519	579	398		749		2161
	I	3543	475	3718		131098	459679	37408	488	608	381		795		2105
	X	2372	604	5451		90897	711110	25121	638	1347	581		812		4832
	M	2948	617	5596		96372	586859	26676	662	1125	615		938		4368
	Addup	16932	1924	16661		529895	1612240	105522	2150	2981	2022		2344		10313
2019	GDP	19036	2110	18483	89165	552535	1852666	145160	2332	3242	2238		2547		11485
	C	13092	1216	12495		300738	894075	82597	1258	1718	1440		1102		6160
	G	2649	421	2165		110489	304190	14843	548	652	426		652		2330
	I	4166	462	3671		141057	558469	48838	567	690	409		769		2624
	X	2572	685	6859		103927	779368	28136	753	1580	700		871		6028
	M	3465	674	6851		103604	684517	33216	796	1400	736		856		5651
	Addup	19014	2111	18339		552608	1851585	141198	2330	3240	2238		2538		11490
2021	GDP	19610	2103	17810	98867	540226	1915778	135585	2297	3204	2143		2520		11427
	C	13754	1199	12056		287894	882460	77637	1235	1627	1328		1133		5954
	G	2743	454	2146		117047	337685	15376	560	704	444		677		2452
	I	4285	472	3333		134412	576617	43277	570	691	398		658		2598
	X	2367	633	6809		102620	849147	25537	681	1573	629		798		6104
	M	3600	659	6835		101497	729825	28629	750	1396	656		710		5677
	Addup	19549	2099	17510		540476	1916084	133198	2296	3198	2143		2556		11431

Table A1.3a. Percentage changes in $US values of nominal GDP and its expenditure components: OECD data (downloaded July 2023)

		USA	Canada	Mexico	China	Japan	SKorea	India	France	Germany	UK	RoEU	Saudi Arabia	RoW	EU27
2004-2014	GDP	43.7	75.9	68.2	435.7	0.1	87.3	194.5	34.7	38.2	26.5	37.7	192.3	*170.46*	37.3
	C	43.9	79.4	62.1	384.3	5.4	81.3	193.9	35.4	31.5	25.3	37.4	208.6	*NA*	35.5
	G	38.6	83.6	95.5	479.4	12.5	130.2	188.8	41.1	43.9	29.3	45.0	233.3	*NA*	43.9
	I	31.8	104.6	66.3	486.7	-2.3	71.4	185.8	39.8	41.9	25.8	14.8	323.1	*NA*	25.4
	X	102.1	49.6	107.4	315.6	36.3	143.8	274.8	51.0	76.5	49.8	78.6	168.8	*NA*	74.3
	M	59.5	74.7	101.0	306.6	84.1	140.9	284.8	63.1	76.6	46.2	69.2	309.6	*NA*	70.0
2014-2019	GDP	21.8	-3.4	-3.5	36.3	4.5	11.2	39.5	-4.5	0.0	-6.8	1.9	6.2	*-3.10*	0.3
	C	21.5	0.0	-4.9	45.7	-1.1	8.3	46.3	-5.7	-2.7	-7.2	-2.0	27.9	*NA*	-2.9
	G	17.2	-1.5	-9.9	44.5	4.6	24.8	46.5	-9.0	3.3	-10.9	-2.7	-2.4	*NA*	-2.6
	I	25.0	-10.5	-6.7	28.7	7.7	17.6	23.1	2.5	8.6	-3.3	19.6	7.7	*NA*	13.4
	X	6.8	-1.6	17.5	4.6	4.8	-8.7	13.6	1.8	2.3	2.6	11.7	-19.4	*NA*	8.2
	M	8.0	0.0	14.1	9.5	-7.3	-5.1	14.4	0.9	5.1	0.6	13.3	-14.3	*NA*	9.7

Table A1.3b. Percentage changes in $US values of real GDP and its expenditure components: OECD data (downloaded July 2023)

		USA	Canada	Mexico	China	Japan	SKorea	India	France	Germany	UK	RoEU	Saudi Arabia	RoW	EU27
2004-2014	GDP	17.6	20.7	23.3	160.4	5.4	45.6	109.4	10.2	14.4	13.2	7.6	49.1	*NA*	9.8
	C	18.1	32.5	17.9	169.4	6.8	33.5	112.2	12.0	7.8	12.3	5.4	118.1	*NA*	7.2
	G	3.0	17.9	27.3	45.1	13.3	67.0	91.5	15.7	18.4	13.9	10.1	97.9	*NA*	13.2
	I	13.4	39.2	31.5	239.6	-5.1	24.7	130.0	9.2	13.9	21.7	-7.7	187.0	*NA*	0.1
	X	66.2	8.6	57.0	222.1	37.6	113.3	184.4	27.2	53.9	28.8	42.1	12.6	*NA*	42.9
	M	28.6	37.9	46.9	201.8	33.6	84.3	193.0	35.3	49.5	29.9	31.3	195.8	*NA*	35.9
2014-2019	GDP	12.4	9.7	10.4	38.6	4.3	14.9	37.9	8.5	8.7	10.7	13.6	8.1	14.16	11.5
	C	13.7	12.9	13.1	48.5	0.0	13.5	39.7	7.7	9.2	12.8	11.6	19.0	8.15	10.3
	G	8.2	9.8	6.3	45.3	6.7	26.3	40.8	5.7	12.6	7.0	6.6	-13.0	20.97	7.8
	I	17.6	-2.7	-1.3	30.2	7.6	21.5	30.6	16.2	13.5	7.3	32.8	-3.3	14.91	24.6
	X	8.4	13.5	25.8	11.1	14.3	9.6	12.0	18.1	17.3	20.3	28.9	7.3	19.08	24.8
	M	17.5	9.4	22.4	15.2	7.5	16.6	24.5	20.1	24.4	19.6	33.1	-8.8	11.49	29.4

Table A1.4old. Percentage growth from 2004 to 2014, mainly OECD (extracted from baseline paper of August 13, 2020)

%ch Nominals $US	US	Canada	Mexico	China	Japan	Korea	India	France	Germany	UK	RoEU	Saudi Arabia	RoW
GDP	43.50	75.92	68.05	433.84	0.73	87.14	194.48	34.74	38.19	26.76	37.68	192.32	171.82
C	43.96	79.38	62.01	390.73	5.94	81.12	193.87	35.38	31.49	24.89	37.45	208.58	
G	38.47	83.61	95.53	413.61	12.14	130.01	188.85	41.06	43.85	28.95	44.79	233.26	
I	31.77	104.61	66.42	487.49	-1.06	71.27	185.77	39.79	41.89	22.97	14.59	323.08	
X	101.40	49.57	107.41	315.59	36.21	143.54	274.78	51.02	76.52	52.36	79.39	168.75	
M	60.26	74.73	101.03	306.56	84.03	140.71	284.77	63.09	76.63	44.31	69.77	309.59	

%ch Reals $US	US	Canada	Mexico	China	Japan	Korea	India	France	Germany	UK	RoEU	Saudi Arabia	RoW
GDP	17.39	20.75	23.28	160.11	6.04	45.63	109.37	10.23	14.44	14.20	7.27	49.11	52.61
C	18.17	32.46	17.82	173.46	7.18	33.47	112.15	11.99	14.44	11.66	5.23	118.10	
G	2.96	17.89	27.34		12.16	66.99	91.47	15.68	7.82	15.80	9.66	97.88	
I	13.42	39.17	31.80		-3.02	24.67	129.95	9.22	18.40	16.67	-10.28	187.00	
X	65.27	8.58	57.03	221.97	36.97	113.30	184.39	27.16	80.97	29.48	42.65	12.63	
M	29.48	37.86	46.92	201.73	33.67	84.33	193.04	35.26	53.92	23.69	31.18	195.83	

%ch $US prices	US	Canada	Mexico	China	Japan	Korea	India	France	Germany	UK	RoEU	Saudi Arabia	RoW
GDP	22.24	45.69	36.32	105.24	-5.00	28.50	40.65	22.23	20.75	11.00	28.35	96.04	78.11
C	21.82	35.43	37.51	79.46	-1.16	35.70	38.52	20.89	21.95	11.85	30.62	41.49	80.15
G	34.49	55.75	53.56	324.93	-0.02	37.74	50.86	21.94	21.50	11.36	32.04	68.41	69.35
I	16.18	47.02	26.26	72.76	2.03	37.38	24.27	27.98	24.60	5.40	27.72	47.42	76.05
X	21.86	37.74	32.08	29.08	-0.56	14.17	31.78	18.76	14.68	17.67	25.75	138.62	68.54
M	23.77	26.74	36.83	34.74	37.67	30.58	31.30	20.57	18.13	16.67	29.42	38.46	64.94

Baseline forecasts for real and nominal GDP, population and working age population

Tables A1.5 to A1.8 give data and projections for real and nominal GDP, population and working-age population (WAP). With one exception, the *data* were extracted from IMF and ILO sources. The exception was real GDP growth for RoW for 2014-19. As explained earlier, this is an estimate based on our 2014-17 validation simulation.

The *forecast* numbers (beyond 2020) for both population and WAP were taken from SSP2 [Shared Socioeconomic Pathway 2 (middle of the road projections) published by the International Institute for Applied System Analysis, IIASA].

Real GDP and productivity assumptions for 2029-2050

The data up to 2021 for real and nominal GDP are from the IMF. Then up to 2028 we use IMF forecasts.

We calculated actual and implied productivity growth for each region up to 2028 using data and forecasts for real GDP and working-age population (WAP). For all regions except China, India, Saudi Arabia and RoW, we assumed that the average annual productivity growth for the 19 years from 2010 to 2028 will continue to apply from 2029 to 2050. Combining this productivity assumption with the WAP projections gave us real GDP growth from 2029 to 2050.

For China, the IMF real GDP forecasts and the SSP2 WAP forecasts imply considerably slower productivity growth for 2022 to 2028 than in the earlier decade, down to 4.28 per cent from over 6 per cent in the earlier period. We assume that this slowdown reflects the maturing nature of the Chinese economy and that the 4.28 per cent productivity growth will apply to 2050.

For India, we used the average productivity growth for the 16 years from 2013 to 2028. 2012 was the first year for which we had WAP data.

For Saudi Arabia, we used the average productivity growth for the 15 years from 2014 to 2028. This seems rather arbitrary since we simply assumed that WAP moved with population in the years 2014 to 2021.

For RoW, we used the average productivity growth for the 14 years from 2015 to 2028. 2015 was the first year for which we had seemingly reliable growth rates for WAP.

Table A1.9 shows our productivity growth assumptions for 2029-2050.

Miscellaneous comments

The data (up to 2020) for working-age population from the ILO were incomplete for China, India and Saudi Arabia.

For China there is no working-age population data from ILO before 2020. We deduced growth rates for WAP for 2018, 2019 and 2020 from SSP2 data. For earlier years we assumed that annual growth in WAP for China is 0.5 percentage points lower than that in population.

For India we had levels data from ILO for WAP for 2012 and 2018. We filled in the intervening years by extrapolation.

Table A1.5. Real GDP: IMF data and projections up to 2028, then our projections based on productivity and ILO projections of working-age population

	% Growth				Average annual % growth			
	2014-19	2019-30	2030-40	2040-50	2014-19	2019-30	2030-40	2040-50
US	12.43	21.36	23.99	22.44	2.37	1.78	2.17	2.04
Canada	9.70	18.23	22.92	19.62	1.87	1.53	2.08	1.81
Mexico	10.41	13.93	12.91	11.15	2.00	1.19	1.22	1.06
China	38.32	56.61	35.03	37.63	6.70	4.16	3.05	3.25
Japan	4.29	4.56	1.59	2.37	0.84	0.41	0.16	0.23
Korea	14.88	24.96	18.22	19.26	2.81	2.05	1.69	1.78
India	38.06	75.44	71.89	64.37	6.66	5.24	5.57	5.10
France	8.46	12.72	13.83	14.64	1.64	1.09	1.30	1.38
Germany	8.71	9.33	10.46	13.10	1.68	0.81	1.00	1.24
UK	10.74	11.14	16.42	16.61	2.06	0.96	1.53	1.55
RoEU	20.73	31.64	29.93	26.41	3.84	2.53	2.65	2.37
Saudi Arabia	10.96	35.16	16.47	11.17	2.10	2.78	1.54	1.06
RoW	18.73	34.23	35.00	29.83	3.49	2.71	3.05	2.64

Table A1.6. Nominal GDP: IMF data up to 2019, then our real GDP projections combined with IMF price projections up to 2030

	% Growth				Average annual % growth			
	2014-19	2019-30	2030-40	2040-50	2014-19	2019-30	2030-40	2040-50
US	21.82	63.79	*NA*	*NA*	4.03	4.59	*NA*	*NA*
Canada	-3.43	63.24	*NA*	*NA*	-0.70	4.56	*NA*	*NA*
Mexico	-3.52	70.25	*NA*	*NA*	-0.71	4.96	*NA*	*NA*
China	36.26	119.01	*NA*	*NA*	6.38	7.39	*NA*	*NA*
Japan	4.51	15.68	*NA*	*NA*	0.89	1.33	*NA*	*NA*
Korea	11.25	40.15	*NA*	*NA*	2.15	3.12	*NA*	*NA*
India	39.06	130.18	*NA*	*NA*	6.82	7.87	*NA*	*NA*
France	-4.46	29.48	*NA*	*NA*	-0.91	2.38	*NA*	*NA*
Germany	-0.04	34.87	*NA*	*NA*	-0.01	2.76	*NA*	*NA*
UK	-6.79	66.00	*NA*	*NA*	-1.40	4.72	*NA*	*NA*
RoEU	6.25	59.50	*NA*	*NA*	1.22	4.34	*NA*	*NA*
Saudi Arabia	9.39	62.35	*NA*	*NA*	1.81	4.50	*NA*	*NA*
RoW	*NA*	*NA*	*NA*	*NA*	-0.30	5.22	*NA*	*NA*

Table A1.7. Population: ILO data and SSP2 projections

	% Growth				Average annual % growth			
	2014-19	2019-30	2030-40	2040-50	2014-19	2019-30	2030-40	2040-50
US	3.12	8.42	6.15	4.98	0.62	0.74	0.60	0.49
Canada	6.07	10.86	7.63	6.84	1.19	0.94	0.74	0.66
Mexico	5.54	9.41	5.52	3.06	1.08	0.82	0.54	0.30
China	2.44	0.25	-2.97	-5.71	0.48	0.02	-0.30	-0.59
Japan	-0.71	-3.81	-4.70	-5.36	-0.14	-0.35	-0.48	-0.55
Korea	2.01	0.71	-2.07	-5.03	0.40	0.06	-0.21	-0.51
India	5.80	11.18	7.67	5.34	1.13	0.97	0.74	0.52
France	1.67	5.86	4.81	3.79	0.33	0.52	0.47	0.37
Germany	2.61	-0.59	-1.22	-1.79	0.52	-0.05	-0.12	-0.18
UK	3.41	6.23	4.80	4.35	0.67	0.55	0.47	0.43
RoEU	0.47	1.03	-0.04	-0.40	0.09	0.09	0.00	-0.04
Saudi Arabia	14.07	23.28	16.12	11.94	2.67	1.92	1.51	1.13
RoW	9.60	16.07	11.42	8.85	1.85	1.36	1.09	0.85

Table A1.8. Working age population: ILO data and SSP2 projections

	% Growth				Average annual % growth			
	2014-19	2019-30	2030-40	2040-50	2014-19	2019-30	2030-40	2040-50
US	1.62	2.52	4.91	3.60	0.32	0.23	0.48	0.35
Canada	2.97	3.34	6.48	3.62	0.59	0.30	0.63	0.36
Mexico	6.53	8.57	2.85	1.25	1.27	0.75	0.28	0.12
China	-0.21	-3.45	-11.22	-9.51	-0.04	-0.32	-1.18	-0.99
Japan	-3.60	-6.31	-11.69	-11.00	-0.73	-0.59	-1.24	-1.16
Korea	0.55	-10.41	-12.29	-11.51	0.11	-0.99	-1.30	-1.22
India	4.33	13.69	7.92	3.20	0.85	1.17	0.77	0.32
France	-0.73	1.41	1.62	2.35	-0.15	0.13	0.16	0.23
Germany	1.55	-9.51	-6.75	-4.51	0.31	-0.90	-0.70	-0.46
UK	1.56	1.91	2.10	2.27	0.31	0.17	0.21	0.22
RoEU	-3.15	-3.32	-4.01	-6.61	-0.64	-0.31	-0.41	-0.68
Saudi Arabia	14.07	26.13	12.08	6.98	2.67	2.13	1.15	0.68
RoW	3.13	17.66	12.71	8.39	0.62	1.49	1.20	0.81

Table A1.9. Average annual productivity growth (% change in real GDP/WAP) assumed for 2029-2050

US	1.6849
Canada	1.4459
Mexico	0.9377
China	4.2821
Japan	1.4101
Korea	3.0295
India	4.7648
France	1.1410
Germany	1.7075
UK	1.3209
RoEU	3.0743
Saudi Arabia	0.3853
RoW	1.8214

For Saudi Arabia there is no ILO data on WAP. Up to 2021 we assumed that WAP growth was the same as population growth.

The Saudi population growth rate in 2021 in the original data was -2.57. This is out of line with population growth in other years and with growth in WAP. We corrected the 2021 population number to 2.0 per cent growth.

The nominal GDP numbers from the IMF in Table A1.6 for 2014-19 are in line with those from the OECD in Table A1.3a for all regions except RoEU and Saudi Arabia. We have to make a choice. We chose to use the OECD numbers because they have expenditure-side detail.

Energy data and projections from IEA

We extracted the data and projections in Tables A1.10 – A1.17 from https://www.iea.org/data-and-statistics/data-product/world-energy-outlook-2022-free-dataset. The data refer to energy supply. We interpret supply as being what we would call absorption. Thus, for example, the data show considerable supply of oil in Japan but production is not given – we suspect it is negligible.

Table A1.10. USA: Energy data and projections from IEA

	Oil Million barrels	Natural gas Billion cub metres	Coal Million tonnes	Renewables EJ (=10^18 J)	Electricity generation Twh (=10^12 watt-hrs)
2010	18	678	716	7	4354
2020	17	867	317	9	4239
2021	18	871	363	10	4371
2030	17	864	91	16	4625
2050	13	575	26	28	6270
% changes					
2010-20	-7.30	27.88	-55.73	37.91	-2.65
2020-30	1.21	-0.35	-71.29	69.47	9.11
2030-50	-24.55	-33.45	-71.43	76.97	35.58
Ave annual % ch					
2010-20	-0.76	2.49	-7.82	3.27	-0.27
2020-30	0.12	-0.03	-11.73	5.42	0.88
2030-50	-1.40	-2.02	-6.07	2.90	1.53

Table A1.11. China: Energy data and projections from IEA

	Oil Million barrels	Natural gas Billion cub metres	Coal Million tonnes	Renewables EJ (=10^18 J)	Electricity generation Twh (=10^12 watt-hrs)
2010	9	110	2565	5	4236
2020	14	324	3037	12	7767
2021	15	368	3157	14	8539
2030	16	443	2974	26	11136
2050	13	442	1866	50	14342
% changes					
2010-20	57.95	194.55	18.40	161.50	83.38
2020-30	16.55	36.73	-2.07	108.81	43.38
2030-50	-22.84	-0.23	-37.26	92.24	28.79
Ave annual % ch					
2010-20	4.68	11.41	1.70	10.09	6.25
2020-30	1.54	3.18	-0.21	7.64	3.67
2030-50	-1.29	-0.01	-2.30	3.32	1.27

Table A1.12. Japan: Energy data and projections from IEA

	Oil Million barrels	Natural gas Billion cub metres	Coal Million tonnes	Renewables EJ (=10^18 J)	Electricity generation Twh (=10^12 watt-hrs)
	4	95	165	1	1164
2020	3	104	146	1	1009
2021	3	103	143	1	1024
2030	3	64	103	2	969
2050	2	43	62	3	992
% changes					
2010-20	-23.81	9.47	-11.52	49.65	-13.31
2020-30	-15.63	-38.46	-29.45	65.66	-3.93
2030-50	-37.04	-32.81	-39.81	52.72	2.28
Ave annual % ch					
2010-20	-2.68	0.91	-1.22	4.11	-1.42
2020-30	-1.68	-4.74	-3.43	5.18	-0.40
2030-50	-2.29	-1.97	-2.51	2.14	0.11

Table A1.13. India: Energy data and projections from IEA

	Oil Million barrels	Natural gas Billion cub metres	Coal Million tonnes	Renewables EJ (=10^18 J)	Electricity generation Twh (=10^12 watt-hrs)
2010	3	64	399	3	974
2020	5	61	542	5	1533
2021	5	66	614	6	1686
2030	7	115	773	10	2708
2050	8	170	671	24	5298
% changes					
2010-20	36.36	-4.69	35.84	90.50	57.35
2020-30	48.89	88.52	42.62	82.17	76.60
2030-50	23.88	47.83	-13.20	145.72	95.67
Ave annual % ch					
2010-20	3.15	-0.48	3.11	6.66	4.64
2020-30	4.06	6.55	3.61	6.18	5.85
2030-50	1.08	1.97	-0.71	4.60	3.41

Table A1.14. Rest of North America (Can & Mex): Energy data and projections from IEA

	Oil Million barrels	Natural gas Billion cub metres	Coal Million tonnes	Renewables EJ (=10^18 J)	Electricity generation Twh (=10^12 watt-hrs)
2010	4	157	52	2	878
2020	4	229	25	3	966
2021	4	235	26	3	985
2030	4	254	16	4	1146
2050	4	245	16	6	1545
% changes					
2010-20	-18.18	45.86	-51.92	14.83	10.00
2020-30	5.56	10.92	-36.00	37.64	18.64
2030-50	-5.26	-3.54	0.00	44.00	34.81
Ave annual % ch					
2010-20	-1.99	3.85	-7.06	1.39	0.96
2020-30	0.54	1.04	-4.36	3.25	1.72
2030-50	-0.27	-0.18	0.00	1.84	1.50

Table A1.15. European Union: Energy data and projections from IEA

	Oil Million barrels	Natural gas Billion cub metres	Coal Million tonnes	Renewables EJ (=10^18 J)	Electricity generation Twh (=10^12 watt-hrs)
2010	11	446	360	8	2956
2020	9	397	206	10	2758
2021	9	421	238	11	2963
2030	8	340	125	15	3238
2050	5	235	56	20	3689
% changes					
2010-20	-16.04	-10.99	-42.78	32.60	-6.71
2020-30	-13.48	-14.36	-39.32	44.15	17.43
2030-50	-41.56	-30.88	-55.20	31.76	13.92
Ave annual % ch					
2010-20	-1.73	-1.16	-5.43	2.86	-0.69
2020-30	-1.44	-1.54	-4.87	3.72	1.62
2030-50	-2.65	-1.83	-3.94	1.39	0.65

Table A1.16. Middle East: Energy data and projections from IEA

	Oil Million barrels	Natural gas Billion cub metres	Coal Million tonnes	Renewables EJ (=10^18 J)	Electricity generation Twh (=10^12 watt-hrs)
2010	7	391	5	0	829
2020	7	554	5	0	1203
2021	8	567	5	0	1233
2030	9	689	8	1	1651
2050	11	833	12	5	2886
% changes					
2010-20	4.23	41.69	0.00	87.83	45.01
2020-30	20.27	24.37	60.00	382.87	37.30
2030-50	22.47	20.90	50.00	398.27	74.78
Ave annual % ch					
2010-20	0.41	3.55	0.00	6.51	3.79
2020-30	1.86	2.20	4.81	17.05	3.22
2030-50	1.02	0.95	2.05	8.36	2.83

Table A1.17. Rest of World: Energy data and projections from IEA

	Oil Million barrels	Natural gas Billion cub metres	Coal Million tonnes	Renewables EJ (=10^18 J)	Electricity generation Twh (=10^12 watt-hrs)
2010	31	1388	958	19	6147
2020	31	1491	1069	27	7232
2021	33	1582	1098	28	7533
2030	40	1603	1059	43	9359
2050	48	1814	1119	80	14822
% changes					
2010-20	-0.32	7.42	11.59	42.17	17.67
2020-30	28.48	7.51	-0.94	59.33	29.40
2030-50	20.91	13.16	5.67	86.21	58.37
Ave annual % ch					
2010-20	-0.03	0.72	1.10	3.58	1.64
2020-30	2.54	0.73	-0.09	4.77	2.61
2030-50	0.95	0.62	0.28	3.16	2.33

The data and projections are for the Stated policy scenario (STEPS). STEPS shows the trajectory implied by today's policy settings.

We require energy use projections for each of the 13 regions in our model. The free download data from IEA identifies USA, China, Japan and India as separate regions. Data and projections for these regions are shown in Tables A1.10 – A1.13.

We deduced Table A1.14 (Rest of North America) from data and projections for North America less USA. We use the percentage changes in Table A1.14 for both Canada and Mexico.

Table A1.15 contains data and projections for the European Union. We use the percentage changes in Table A1.15 for France, Germany, U.K., and the Rest of EU.

Table A1.16 contains data and projection for the Middle East. We use the percentage changes in Table A1.16 for Saudi Arabia.

Table A1.17 contains data and projections for the Rest of World. This was calculated by subtracting data for North America, China, Japan, India, European Union, and Middle East from data for World.

Features of the data and projections

For all regions except India and Middle East, the use of coal declines between 2020 and 2030. After 2030, the use coal declines or is flat in all regions except Middle East.

Use of renewables increases in all regions after 2020.

Use of oil increases between 2020 and 2030 for the US, China, India, Rest of North America, Middle East and Rest of World. For Japan and the European Union use of oil decreases. After 2030, use of oil decreases in all regions except India, Middle East and Rest of World.

Use of natural gas increases between 2020 and 2030 in China, India, Rest of North America, Middle East and Rest of World. It continues to increase after 2030 in India, Middle East and Rest of World.

With regard to electricity generation, absorption increases from 2020 to 2050 in all regions except Japan. While the annual growth rates in electricity use are quite strong, we suspect that they are below what IEA is likely to have assumed about GDP growth.

Prices of oil, gas and coal from 2014 to 2019

For prices of oil, gas and coal see:

…\ITC\WTO\ CMO-Historical-Data-Annual.xlsx published by the World Bank

and

…\ITC\WTO\WB\ CMO-April-2023-Energy-Fertilizers.xlsx

Oil

From the World Bank there are data showing percentage changes in oil prices for 2004-14 and 2014-19 of about 160 and -35.28 (see range in excel sheet, this is the data for Brent).

Our previous source of oil price movements was the Saudi National accounts (see Saudi price of commodities.xlsx). That showed 167.81 and -29.86)

Natural gas

The World Bank shows 3 types of natural gas with price growths of -25.88, 134.99 and 212.74 for 2004-14, the price growths for 2014 to 2019 are -52.2, -34.1 and -45.3.

Coal

In the World Bank data there are 2 types of coal (Australian & South African) with price growths of: 32.25 and 32.28 for 2004-14, and 11.06 and -0.55 for 2014-19.

https://tradingeconomics.com/commodity/coal shows coal prices ($US/T) of 71.10 in 2014 and 70.90 in 2019, a fall of 1%. So this looks like the South African coal. Australia is the largest exporter of coal, then Indonesia and Russia. South Africa doesn't get a mention.

Index mundi (https://www.indexmundi.com/commodities/?commodity=coal-australian&months=240) shows growth in price of coal of 20.64 in 2004-14 https://ourworldindata.org/grapher/coal-prices has several estimates of growth in prices of coal across the periods 2004-2014 and 2014-19. The Japanese coking coal figures for these two periods are 87.69 and 29.81.

On the basis of these data, we assume the following $US price increases for 2014 to 2019:

Oil -29.86 (Saudi data)

Gas -43.87 (World Bank, average of 3 gas prices in CMO-Historical-Data-Annual.xls)

Coal 11.06 (World Bank, Aust. Coal price in CMO-Historical-Data-Annual.xls).

Net foreign liabilities

Table A1.18 shows net foreign liabilities at the start of 2014 and the start of 2019. We impose the changes between these two years in the 2014-19 simulation. The data for NFL are from the IMF's *World and Regional Tables: Balance of Payments and International Investment Position by Indicator (BPM6)*, available at: https://data.imf.org/?sk=7a51304b-6426-40c0-83dd-ca473ca1fd52&sid=1542633711584 .

Table A1.18. Net foreign liabilities (NFL)

	NFL, $USt		NFL/GDP	
	2014	2019	2014	2019
USA	5.44	9.80	0.314	0.463
Canada	0.03	-0.45	0.014	-0.257
Mexico	0.57	0.56	0.436	0.445
China	-2.58	-3.39	-0.255	-0.248
Japan	-3.09	-3.08	-0.670	-0.639
SKorea	0.04	-0.44	0.029	-0.286
India	0.32	0.43	0.154	0.148
France	0.48	0.52	0.170	0.192
Germany	-0.96	-2.01	-0.246	-0.518
UK	0.45	0.08	0.151	0.030
RoEU	1.26	-0.11	0.142	-0.012
SaudiArabia	-0.76	-0.66	-1.022	-0.841
RoW	-1.21	-1.25	-0.060	-0.064
Total	0	0		

Employment by broad sector in Canada

We downloaded data on jobs by broad sector in Canada for 2014 and 2019 and calculated percentage growth between these two years. The data source was Statistics Canada, https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610048901 [9]. However, we have not yet been imposed these percentage movements in the 2014-19 simulation.

[9] In our own files, these data are stored at C:\dixon\consult\ITC\2023\WTO\Shenjie\ JobsDataCanada171023.xlsx.

Appendix 2. Start-of-year stock variables in disjoint years: the initial-solution problem and the homotopy method

Calculating real wealth for year T starting from year t: applying the smooth-growth assumption for saving

We assume that

$$RW_T = RW_t + \sum_{q=0}^{T-t-1} RS_{t+q} \tag{A2.1}$$

where

RW_t is real wealth for a region at the start of year t; and

RS_t is real net saving (net of depreciation) for the region in year t.

Equation (A2.1) gives real wealth at the start of year T as real wealth at the start of year t plus accumulated real savings over years t to T-1.

The real wealth of a region has two components: the part of the region's capital stock owned by the region's residents; and foreign assets owned by the residents of the region. Correspondingly, in converting from nominal to real, the price index we use is a composite of the price of the region's capital goods and the price of the region's foreign assets represented by prices of capital goods in other regions.

We adopt a smooth growth assumption for real saving:

$$RS_{t+q} = RS_t + \left(RS_T - RS_t\right) * \frac{q}{T-t} \qquad q=0, \ldots, T\text{-}t \tag{A2.2}$$

An alternative to (A2.2) is the multiplicative form

$$RS_{t+q} = RS_t \left(\frac{RS_T}{RS_t}\right)^{\frac{q}{T-t}} \tag{A2.3}$$

However, (A2.3) is not usable if saving turns negative, which happened for some regions in exploratory simulations. For this reason, we prefer (A2.2).

Substituting from (A2.2) into (A2.1) gives:

$$RW_T = RW_t + \sum_{q=0}^{T-t-1} \left[RS_t + \left(RS_T - RS_t\right) * \frac{q}{T-t} \right] \tag{A2.4}$$

Including wealth equations in simulations for disjoint years

In our computation for year T, we require (A2.4) to hold.

The inclusion of (A2.4) in our model for year T destroys the simplicity of (2.1) in section 2. It must now be rewritten for year T as:

$$F(X, RS_t, T-t) = 0 \tag{A2.5}$$

From the point of view of the T computation, RS_t and T-t are parameters. So can they be left out of a stylized representation of the model? The answer is yes, but then we would have to write the stylized version as:

$$F_T(X) = 0 \tag{A2.6}$$

If we don't explicitly include RS_t and T-t as arguments of the F function then we must recognize that the appropriate form of the F function depends on the year. It won't be the same for 2014, 2019, 2030, etc. The parameter values in the 2019 model include real saving for 2014 and a T-t value of 5. The parameter values in the 2030 model include real saving for 2019 and a T-t value of 11, etc.

This immediately tells us that a solution for 2014 won't necessarily solve the 2019 model and therefore can't be used as the initial solution in the GEMPACK computation for 2019. Similarly, the solution for 2019 won't necessarily solve the 2030 model and therefore can't be used as the initial solution in the GEMPACK computation for 2030, etc.

The inaccuracy of the stylized representation (2.1) is not of prime importance. However, the problem of finding an initial solution needs to be solved. As set out in Dixon and Rimmer (2002), this was done via the homotopy approach suggested to us by Mark Horridge[10].

The homotopy form

To see that the year t solution does not satisfy the year T model, we replace T values in (A2.4) with year t values. This gives

$$LHS = RW_t$$

$$RHS = RW_t + \left[RS_t * (T - t)\right]$$

Only in the special case that $RS_t = 0$ do we have LHS = RHS.

To deal with this problem, rather than (A2.4), the equation we introduce into the model for year T is

$$RW_T = RW_t + \sum_{q=0}^{T-t-1}\left[RS_t + \left(RS_T - RS_t\right) * \frac{q}{T-t}\right] - RS_t * (T-t) * (1-U) \qquad \text{(A2.7)}$$

In this equation, U is a new exogenous variable. Its value in the initial solution for year T is zero. With this value, the year t solution *does* satisfy (A2.7) in the year T model:

$$LHS = RW_t$$

$$RHS = RW_t + \left[RS_t * (T - t)\right] - RS_t * (T-t) = RW_t = LHS$$

In the required solution for year T, U =1, establishing the required equation (A2.4). Consequently, in going from the initial solution for year T to the required solution, we shock U from zero to one. We apply this shock together with all the other shocks representing movements in variables from their year t values to their year T values.

[10] The homotopy idea was originally developed in the field of numerical analysis, see for example Zangwill and Garcia (1981).

Appendix 3. Giving regional investors forward-looking expectations

Strategy

We consider a sequence of four simulations connecting disjoint years t(0), t(1), t(2), t(3) and t(4), (think 2014, 2019, 2030, 2040 and 2050). We refer to the simulation that connects t(i) and t(i+1) as the t(i+1) simulation.

In the simulation for year t(i), i = 1, 2, 3, we wish to impose the condition that growth in r's capital *in* year t(i) is proportional to average annual growth from start of t(i) to start of t(i+1), that is there exists FF_KE(t(i)) such that

$$\frac{\mathrm{KE(r,t(i))}}{\mathrm{KB(r,t(i))}} = \left(\frac{\mathrm{KB(r,t(i+1))}}{\mathrm{KB(r,t(i))}}\right)^{\frac{1}{\mathrm{t(i+1)-t(i)}}} * \mathrm{FF\_KE(t(i))} \qquad \text{for all r and i=1,2,3} \qquad \text{(A3.1)}$$

where KE(r,t(i)) is capital in region r at the end of year t(i) and KB(r,t(i)) is capital in region r at the start of year t(i). KE(r,t(i)) and KB(r,t(i)) together tie down region r's investment in year t(i). The factor of proportionality, FF_KE(t(i)), is determined so that global investment (the sum of regional investments) in year t(i) equals global saving in t(i).

As the terminal condition we use

$$\frac{\mathrm{KE(r,t(4))}}{\mathrm{KB(r,t(4))}} = \left(\frac{\mathrm{KB(r,t(4))}}{\mathrm{KB(r,t(3))}}\right)^{\frac{1}{\mathrm{t(4)-t(3)}}} * \mathrm{FF\_KE(t(4))} \qquad \text{for all r} \qquad \text{(A3.2)}$$

When we are undertaking the computation for year t(i), i=1,2,3,4, we impose the equation

$$\frac{\mathrm{KE(r,t(i))}}{\mathrm{KB(r,t(i))}} = \mathrm{G(r,t(i))} * \mathrm{FF\_KE(t(i))} \qquad \text{for all r and i=1,2,3,4} \qquad \text{(A3.3)}$$

In this equation G(r,t(i)) is a guess of $\left[\mathrm{KB(r,t(i+1))}/\mathrm{KB(r,t(i))}\right]^{1/\{\mathrm{t(i+1)-t(i)}\}}$ for i=1,2,3.

G(r,t(4)) is a guess of $\left[\mathrm{KB(r,t(4))}/\mathrm{KB(r,t(3))}\right]^{1/\{\mathrm{t(4)-t(3)}\}}$, with G(r,t(4))= G(r,t(3)). We treat FF_KEt(i)) as endogenous and the guesses, G(r,t(i)), as exogenous.

To obtain accurate guesses, we conduct an iterative process, each step of which requires four connected simulations. We denote the first step by q = 1.

First step in the iterative process: static expectations

In the first step (q=1), we conduct a sequence of 4 simulations in which global saving in year t(i) is distributed to investment across regions using the normal GTAP specification. We refer to this step as static expectations.

The simulations in this step rely on equalization of risk-adjusted expected rates of return. The risk adjusted expected rate of return in t(i) in a region is determined in GTAP as the *actual* rate of return in t(i) modified to incorporate risk through a downward sloping function of the region's capital growth in t(i) and a region-specific risk-adjustment factor. Actual rates of return in t(i) reflect rental rates for using capital and costs of creating capital.

In this sequence of simulations, we introduce all of the shocks for macro and energy variables described in the main text. We do this without forward-looking expectations. Investment in region r in t(i) does not depend on values of variables beyond year t(i). Thus, no iterative procedure is required.

The role of this sequence of simulations is simply to get the iterative process started.

Subsequent steps in the iterative process

In subsequent steps (q>1), we set the guesses for G(r,t(i)) according to:

$$G_q\left(r,t(i)\right)=\left(\frac{KB_{q-1}(r,t(i+1))}{KB_{q-1}(r,t(i))}\right)^{\frac{1}{t(i+1)-t(i)}} \quad \text{for all r, for i=1,2,3 and for q>1} \tag{A3.4}$$

and

$$G_q\left(r,t(4)\right)=\left(G_q\left(r,t(3)\right)\right) \quad \text{for all r and q>1} \tag{A3.5}$$

We continue the iterative steps until the movements in the guesses between steps are negligible.

GEMPACK implementation

The initial solution for almost all variables in the t(i) simulation is provided by the t(i-1) solution [the database in the case of the t(1) simulation]. In equation (A3.3), we set the initial solution for F(t(i)) at 1 and the initial solution for G(r,t(i)) at KE(r,t(i-1))/KB(r,t(i-1)).

The percentage change version of (A3.3) that we include in the GEMPACK representation of the model is:

$$ke(r)-kb(r)=g(r)+ff\_ke+f\_ke(r) \quad \text{for all r} \tag{A3.6}$$

where ke(r), kb(r),g(r) and ff_ke are percentage deviations in KE(r,t(i)), KB(r,t(i)), G(r,t(i)) and FF_KE(t(i)) from their initial solutions, and f_ke(r) is a shift variable.

In the first iteration (q=1) we make (A3.6) inactive. We do this by endogenizing f_ke(r) and exogenizing ff_ke. Rather than relying on (A3.6), we determine investment in each region in year t(i) according to the GTAP mechanism using equalization of risk-adjusted expected rates of return (described above). With (A3.6) inactive, the value we choose for g(r) is unimportant: g(r) equals 0 will do.

In subsequent iterations, q > 1, (A3.6) remains inactive in the 2014-19 simulation in which regional investment is given by data. However, for the 2019-30, 2030-40 and 2040-50 simulations, (A3.6) is activated: f_ke(r) is exogenous and ff_ke is endogenous. Now the guesses for g(r) play their intended roles of determining growth in capital in the simulation year.

In the t(i) simulation, with q>1, we want to move G(r,t(i)) from its initial value to the value given by (A3.4) or (A3.5). Consequently the shock we apply to g(r) in the t(i) simulation in the qth iteration is given by

$$g_q(r,t(i)) = 100*\left[\frac{\left(\dfrac{KB_{q-1}(r,t(i+1))}{KB_{q-1}(r,t(i))}\right)^{\frac{1}{t(i+1)-t(i)}} - \left(\dfrac{KE_{q-1}(r,t(i-1))}{KB_{q-1}(r,t(i-1))}\right)}{\left(\dfrac{KE_{q-1}(r,t(i-1))}{KB_{q-1}(r,t(i-1))}\right)}\right] \quad \text{for all r, i=1,2,3} \qquad (A3.7)$$

and

$$g_q(r,t(4)) = 100*\left[\frac{\left(\dfrac{KB_{q-1}(r,t(4))}{KB_{q-1}(r,t(3))}\right)^{\frac{1}{t(4)-t(3)}} - \left(\dfrac{KE_{q-1}(r,t(3))}{KB_{q-1}(r,t(3))}\right)}{\left(\dfrac{KE_{q-1}(r,t(3))}{KB_{q-1}(r,t(3))}\right)}\right] \quad \text{for all r,} \qquad (A3.8)$$

The results in the main text are highly converged solutions obtained with q = 8.

Do forward-looking expectations matter?

To answer this question we prepared Tables A3.1 – A3.3 which show capital and investment results computed under static expectations (q=1) and converged forward-looking expectations (q=8)

Table A3.1 gives average annual percentage growth rates in capital stocks from the start of 2014 to the start of 2019, from the start of 2019 to the start of 2030, etc. For 2014 to 2019, these growth rates are the same in both panels of the table: they are determined by data. For the other periods, there are differences in growth rates between the two panels but they are relatively minor.

Table A3.2 shows percentage growth in capital stocks *in* 2019, 2030, 2040 and 2050. These compare start-of-year capital stocks with end-of-year capital stocks. The 2019 growth rates are derived from data and consequently are the same in both panels. However, there are considerable differences in the results for the other years as we move from static-expectations to converged forward-looking expectations.

Table A3.3 shows average annual percentage growth rates in investment across periods: 2019 compared with 2014; 2030 compared with 2019; etc. The growth rates in the 2014-19 columns are the same in both panels because they are derived from data. The growth rates in the other columns follow in a mechanical way from the results in Tables A3.1 and A3.2 according to a generalized version of equation (6.2):

$$i\left[t(i-1),t(i)\right] = 100*\left[\left\{\left\{1+\frac{kb\left[t(i-1),t(i)\right]}{100}\right\}^{t(i)-t(i-1)} * \frac{\left[\dfrac{k\left[t(i)\right]}{100}+D)\right]}{\left[\dfrac{k\left[t(i-1)\right]}{100}+D)\right]}\right\}^{\frac{1}{t(i)-t(i-1)}} - 1\right] \qquad (A3.9)$$

where

$i\left[t(i-1),t(i)\right]$ is the average annual percentage growth in investment in a region from t(i-1) to t(i), results in Table A3.3;

$kb\left[t(i-1), t(i)\right]$ is the average annual percentage growth in start-of-year capital for a region, results in Table A3.1; and
$k[t(i)]$ is the percentage growth of capital in a region across year t(i), results in Table A3.2.

(A3.9) means that the investment results in Table A3.3 don't need a separate explanation once we have understood the results in Tables A3.1 and A3.2.

In Table A3.1, capital growth over the simulation periods 2019-30, 2030-40 and 2040-50 depends mainly on our assumptions concerning growth in real GDP and employment. These assumptions don't vary as we go from q=1 to q=8. This is the reason that the differences in the growth rates between the two panels in Table A3.1 are relatively minor. Consequently, in explaining the differences in the investment results in left and right panels of Table A3.3, we can focus on Table A3.2.

The relationship between capital growth through a period and capital growth through a year under converged forward-looking expectations

The results for 2030 in the right panel of Table A3.2 are tightly related to those for 2030-40 in the right panel of Table A3.1. Under forward-looking expectations, the growth rates *in* 2030 reflect the average annual growth rates for the period 2030 to 2040. The 2030 growth rates in the right panel of Table A3.2 are about 0.3 percentage points greater than the 2030-40 growth rates in the right panel of Table A3.1. Why the discrepancy? The answer is that global saving as a share of global GDP declines as we go from 2030 to 2040. This means that capital growth *in* 2030 can't be sustained over the following decade.

Similarly, the growth rates in 2040 in the right panel of Table A3.2 are tightly related to those for 2040-50 in the right panel of Table A3.1. With our terminal condition, the growth rates in 2050 in the right panel of Table A3.2 are also explained by those for 2040-50 in the right panel of Table A3.1.

The relationship between capital growth through a period and capital growth through a year under static expectations

To understand the relationships between the results in the left panels of Tables A3.1 and A3.2, we need to set out the details of the GTAP specification of capital growth in a year under static expectations. This specification can be expressed as[11]:

$$\text{RORG} = \text{RORC}(r, t(i)) * \left(\frac{\text{KE}(r, t(i))}{\text{KB}(r, t(i))}\right)^{-\text{RORFLEX}} * \left(\frac{1}{\text{CGDSLACK}(r, t(i))}\right) \qquad \text{(A3.10)}$$

The RHS of (A3.10) is the risk-adjusted expected rate of return on investment in region r. It is the product of three factors:

- RORC(r,t(i)), the actual rate of return on capital in year t(i) in region r;
- $\left(\text{KE}(r, t(i))/\text{KB}(r, t(i))\right)^{-\text{RORFLEX}}$ where RORFLEX(r) is a positive parameter; and
- CGDSLACK(r,t(i)), the risk-adjustment factor specific to region r.

[11] This specification of expected rates of return and investment comes from Dixon *et al.* (1982). Readers familiar with GEMPACK representations of the GTAP model will recognize (A3.10) as a levels representation of a combination of the GTAP equations ROREXPECTED and RORGLOBAL. Also see equations (6) and (7) in Britz and Roson (2019).

The LHS of (A3.10) is a scalar. This equalizes risk-adjusted expected rates of return across regions in t(i).

In the 2014-19 simulation in all steps of the iterative process, the movements in RORC(r,t(1)) vary across regions, to accommodate observed movements in regional capital stocks. CGDSLACK(r,t(1)) also varies across regions, to accommodate observed movements in regional investment.

In the static-expectations simulations (q=1) for later periods, the movements in RORC(r,t(i)), i > 1, are equated across regions: it is assumed that regional capital flows between t(i-1) and t(i) are determined in a way that equalizes percentage movements in current rates of return. CGDSLACK(r,t(i)), i > 1, is set exogenously on zero change. Under this setup, (A3.10) can be thought of as determining the allocation of global saving to investment in regions by determining $KE(r,t(i))/KB(r,t(i))$.

With no variation in the relative movements across regions in either RORC or CGDSLACK, (A3.10) doesn't allow variation across regions in the relative movements in KE/KB. Thus, there is no variation across regions in relative rates of capital growth in years t(2), t(3) and t(4). If region r had high observed capital growth in 2019 relative to other regions then it will have high simulated capital growth relative to other regions in 2030, 2040 and 2050.

This is far from ideal. Observed capital growth in 2019 in region r may reflect transient factors that are not relevant to future years. The relevant factors we *can* take into account in determining capital growth (and hence investment) *in* 2030 are those that explain capital growth for 2030-40. Similarly, the relevant factors we can take into account in determining capital growth (and hence investment) *in* 2040 are those that explain capital growth for 2040-50.

Mishandling capital growth *in* 2030, 2040 and 2050 doesn't have much effect on the results for capital growth *between* 2019 and 2030, *between* 2030 and 2040, and *between* 2040 and 2050. However, it means that the simulated picture for 2030 is not necessarily representative of the years 2031 up to 2040, and the simulated picture for 2040 is not necessarily representative of the years 2041 up to 2050.

Consider, for example, the results in the left panels of Tables A3.1 and A3.2 for China. In Table A3.1, China's capital growth slows from an average annual rate of 9.61 per cent in 2014-19 to 5.43 per cent in 2019-30 to 4.12 per cent in 2030-40 and to 3.94 per cent in 2040-50. However, in Table A3.2 China has strong capital growth *in* 2030, *in* 2040 and *in* 2050. This reflects strong capital growth in 2019. This leaves the simulated capital growth rates in the particular years 2030, 2040 and 2050 too high compared with the growth rates for the relevant decades, making the simulated results for investment levels in these particular years too high. A consequence of the investment levels for the particular years being too high is that the trade balances are too low.

More generally, the static expectation results give macro pictures for 2030, 2040 and 2050 that are unrealistic in the context of the macro developments implied by our simulations for the intermediate years.

Table A3.1. Average annual % growth rates in start-of-year capital stocks

	Static expectations (q=1)				Converged forward-looking expectations (q=8)			
	2014-19	2019-30	2030-40	2040-50	2014-19	2019-30	2030-40	2040-50
USA	2.61	1.93	1.87	1.69	2.61	1.98	1.87	1.70
Canada	2.68	2.25	2.36	1.95	2.68	2.30	2.39	1.97
Mexico	2.92	0.90	0.89	0.55	2.92	1.01	0.89	0.54
China	9.61	5.43	4.12	3.94	9.61	5.36	4.09	3.94
Japan	1.42	1.36	0.27	0.17	1.42	1.37	0.24	0.17
SKorea	4.50	2.56	1.87	1.87	4.50	2.61	1.86	1.88
India	7.41	5.62	5.58	4.77	7.41	5.48	5.62	4.79
France	2.46	1.70	1.39	1.35	2.46	1.64	1.41	1.37
Germany	2.21	0.82	0.55	0.60	2.21	0.79	0.57	0.61
UK	2.70	0.90	1.21	1.07	2.70	0.95	1.22	1.07
RoEU	2.44	2.62	2.31	1.89	2.44	2.65	2.31	1.89
SaudiArabia	5.84	4.39	2.76	1.88	5.84	4.30	2.74	1.89
RoW	4.02	3.49	3.33	2.78	4.02	3.51	3.33	2.79

Table A3.2. Percentage growth in capital from start to end of year

	Static expectations (q=1)				Converged forward-looking expectations (q=8)			
	2019	2030	2040	2050	2019	2030	2040	2050
USA	4.73	3.87	3.53	3.40	4.73	2.19	1.92	1.70
Canada	3.93	3.07	2.73	2.60	3.93	2.71	2.20	1.97
Mexico	0.29	-0.54	-0.86	-0.99	0.29	1.19	0.77	0.54
China	6.73	5.65	5.08	4.68	6.73	4.44	4.17	3.95
Japan	2.55	1.71	1.38	1.26	2.55	0.55	0.39	0.17
SKorea	3.63	2.78	2.44	2.31	3.63	2.18	2.10	1.88
India	4.76	3.91	3.58	3.46	4.76	5.91	5.04	4.80
France	3.98	3.06	2.62	2.35	3.98	1.73	1.59	1.37
Germany	2.09	1.25	0.89	0.72	2.09	0.87	0.83	0.61
UK	1.42	0.58	0.26	0.14	1.42	1.52	1.29	1.07
RoEU	2.52	1.60	1.20	0.99	2.52	2.61	2.12	1.90
SaudiArabia	1.79	0.97	0.64	0.52	1.79	3.03	2.13	1.90
RoW	2.79	1.94	1.60	1.46	2.79	3.63	3.02	2.79

Table A3.3. Average annual % growth rates in real investment

	Static expectations (q=1)				Converged forward-looking expectations (q=8)			
	2014-19	2019-30	2030-40	2040-50	2014-19	2019-30	2030-40	2040-50
USA	3.30	0.97	1.42	1.52	3.30	-1.16	1.42	1.31
Canada	-0.55	1.19	1.85	1.75	-0.55	0.76	1.59	1.59
Mexico	-0.26	-1.07	-0.09	0.15	-0.26	2.77	0.03	0.07
China	5.42	4.42	3.50	3.47	5.42	3.09	3.76	3.65
Japan	1.48	0.10	-0.32	-0.05	1.48	-1.92	-0.11	-0.34
SKorea	3.97	1.46	1.35	1.66	3.97	0.67	1.73	1.50
India	5.48	4.65	5.13	4.60	5.48	6.68	4.65	4.51
France	3.05	0.58	0.74	0.94	3.05	-1.37	1.17	0.96
Germany	2.56	-0.53	-0.15	0.23	2.56	-1.23	0.48	0.14
UK	1.42	-0.63	0.46	0.78	1.42	1.13	0.79	0.64
RoEU	5.84	1.22	1.57	1.45	5.84	2.78	1.53	1.51
SaudiArabia	-0.67	2.94	2.07	1.62	-0.67	6.15	1.33	1.51
RoW	2.82	2.24	2.72	2.54	2.82	4.60	2.48	2.45

Appendix 4. GTAP industries

		Description
1	pdr	Paddy Rice: rice, husked and unhusked
2	wht	Wheat: wheat and meslin
3	gro	Other Grains: maize (corn), barley, rye, oats, other cereals
4	v_f	Veg & Fruit: vegetables, fruitvegetables, fruit and nuts, potatoes, cassava, truffles,
5	osd	Oil Seeds: oil seeds and oleaginous fruit; soy beans, copra
6	c_b	Cane & Beet: sugar cane and sugar beet
7	pfb	Plant Fibres: cotton, flax, hemp, sisal and other raw vegetable materials used in textiles
8	ocr	Other Crops: live plants; cut flowers and flower buds; flower seeds and fruit seeds; vegetable seeds, beverage and spice crops, unmanufactured tobacco, cereal straw and husks, unprepared, whether or not chopped, ground, pressed or in the form of pellets; swedes, mangolds, fodder roots, hay, lucerne (alfalfa), clover, sainfoin, forage kale, lupines, vetches and similar forage products, whether or not in the form of pellets, plants and parts of plants used primarily in perfumery, in pharmacy, or for insecticidal, fungicidal or similar purposes, sugar beet seed and seeds of forage plants, other raw vegetable materials
9	ctl	Cattle: cattle, sheep, goats, horses, asses, mules, and hinnies; and semen thereof
10	oap	Other Animal Products: swine, poultry and other live animals; eggs, in shell (fresh or cooked), natural honey, snails (fresh or preserved) except sea snails; frogs' legs, edible products of animal origin n.e.c., hides, skins and furskins, raw , insect waxes and spermaceti, whether or not refined or coloured
11	rmk	Raw milk
12	wol	Wool: wool, silk, and other raw animal materials used in textile
13	frs	Forestry: forestry, logging and related service activities
14	fsh	Fishing: hunting, trapping and game propagation including related service activities, fishing, fish farms; service activities incidental to fishing
15	coa	Coal: mining and agglomeration of hard coal, lignite and peat
16	oil	Oil: extraction of crude petroleum and natural gas (part), service activities incidental to oil and gas extraction excluding surveying (part)
17	gas	Gas: extraction of crude petroleum and natural gas (part), service activities incidental to oil and gas extraction excluding surveying (part)
18	omn	Other Mining: mining of metal ores, uranium, gems. other mining and quarrying
19	cmt	Cattle Meat: fresh or chilled meat and edible offal of cattle, sheep, goats, horses, asses, mules, and hinnies. raw fats or grease from any animal or bird.
20	omt	Other Meat: pig meat and offal. preserves and preparations of meat, meat offal or blood, flours, meals and pellets of meat or inedible meat offal; greaves
21	vol	Vegetable Oils: crude and refined oils of soya-bean, maize (corn),olive, sesame, ground-nut, olive, sunflower-seed, safflower, cotton-seed, rape, colza and canola, mustard, coconut palm, palm kernel, castor, tung jojoba, babassu and linseed, perhaps partly or wholly hydrogenated,inter-esterified, re-esterified or elaidinised. Also margarine and similar preparations, animal or vegetable waxes, fats and oils and their fractions, cotton linters, oil-cake and other solid residues resulting from the extraction of vegetable fats or oils; flours and meals of oil seeds or oleaginous fruits, except those of mustard; degras and other residues resulting from the treatment of fatty substances or animal or vegetable waxes.
22	mil	Milk: dairy products
23	pcr	Processed Rice: rice, semi- or wholly milled
24	sgr	Sugar
25	ofd	Other Food: prepared and preserved fish or vegetables, fruit juices and vegetable juices, prepared and preserved fruit and nuts, all cereal flours, groats, meal and pellets of wheat, cereal groats, meal and pellets n.e.c., other cereal grain products (including corn flakes), other vegetable flours and meals, mixes and doughs for the preparation of bakers' wares, starches and starch products; sugars and sugar syrups n.e.c., preparations used in animal feeding, bakery products, cocoa, chocolate and sugar confectionery, macaroni, noodles, couscous and similar farinaceous products, food products n.e.c.
26	b_t	Beverages and Tobacco products
27	tex	Textiles: textiles and man-made fibres
28	wap	Wearing Apparel: Clothing, dressing and dyeing of fur
29	lea	Leather: tanning and dressing of leather; luggage, handbags, saddlery, harness and footwear
30	lum	Lumber: wood and products of wood and cork, except furniture; articles of straw and plaiting materials

Table continues …

… Table continued

		Description
31	ppp	Paper & Paper Products: includes publishing, printing and reproduction of recorded media
32	p_c	Petroleum & Coke: coke oven products, refined petroleum products, processing of nuclear fuel
33	crp	Chemical Rubber Products: basic chemicals, other chemical products, rubber and plastics products
34	nmm	Non-Metallic Minerals: cement, plaster, lime, gravel, concrete
35	i_s	Iron & Steel: basic production and casting
36	nfm	Non-Ferrous Metals: production and casting of copper, aluminium, zinc, lead, gold, and silver
37	fmp	Fabricated Metal Products: Sheet metal products, but not machinery and equipment
38	mvh	Motor Motor vehicles and parts: cars, lorries, trailers and semi-trailers
39	otn	Other Transport Equipment: Manufacture of other transport equipment
40	ele	Electronic Equipment: office, accounting and computing machinery, radio, television and communication equipment and apparatus
41	ome	Other Machinery & Equipment: electrical machinery and apparatus n.e.c., medical, precision and optical instruments, watches and clocks
42	omf	Other Manufacturing: includes recycling
43	ely	Electricity: production, collection and distribution
44	gdt	Gas Distribution: distribution of gaseous fuels through mains; steam and hot water supply
45	wtr	Water: collection, purification and distribution
46	cns	Construction: building houses factories offices and roads
47	trd	Trade: all retail sales; wholesale trade and commission trade; hotels and restaurants; repairs of motor vehicles and personal and household goods; retail sale of automotive fuel
48	otp	Other Transport: road, rail ; pipelines, auxiliary transport activities; travel agencies
49	wtp	Water transport
50	atp	Air transport
51	cmn	Communications: post and telecommunications
52	ofi	Other Financial Intermediation: includes auxiliary activities but not insurance and pension funding (see next)
53	isr	Insurance: includes pension funding, except compulsory social security
54	obs	Other Business Services: real estate, renting and business activities
55	ros	Recreation & Other Services: recreational, cultural and sporting activities, other service activities; private households with employed persons (servants)
56	osg	Other Services (Government): public administration and defense; compulsory social security, education, health and social work, sewage and refuse disposal, sanitation and similar activities, activities of membership organizations n.e.c., extra-territorial organizations and bodies
57	dwe	Dwellings: ownership of dwellings (imputed rents of houses occupied by owners)
58	CGDS	Capital goods: this is an artificial industry that collects the inputs to capital creation

* *Source: downloaded from https://www.gtap.agecon.purdue.edu/databases/contribute/detailedsector57.asp*

Appendix 5: Project storage

Stored in: C:\Dixon\Consult\ITC\2023\WTO\Shenjie\ZipsPaper\FinalZipsPaper

Simulations were run in: C:\Dixon\Consult\ITC\2023\WTO\Shenjie

Main simulation : GTAP19A71-C72B-R01R-P01P.ZIP

Relevant files stored in this directory :

1st step in forward-looking iteration	GTAP19A71-C63B-R01R-P01P.ZIP
final step in forward-looking iteration	GTAP19A71-C72B-R01R-P01P.ZIP
final forward-looking iteration part 1 only	GTAP19A71-D72B-R01R-P01P.ZIP (see Table4.3)
Static simulation: used in Appendix 3	GTAP19A71-C73B-R01R-P01P.ZIP
Excel sheet	ResultsC72Canada.xlsx
Paper	WTO_ITC_GAC_BaselinePaper141123.docx