What do GTAP Databases Tell Us About Technologies For Industries and Regions?

CoPS Working Paper No. G-340, June 2023

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ISSN 1 921654 02 3 ISBN 978-1-921654-48-0

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Citation

Dixon, P. B. and Maureen T. Rimmer, (2023), "What do GTAP databases tell us about technologies for industries and regions" Centre of Policy Studies Working Paper No. G-340, Victoria University, June 2023.

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by

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June 28, 2023

Acknowledgements:

Preparation of this paper has been a long and tortuous process. Along the way, we have received valuable encouragement from Bob Koopman, Tom Hertel, Bill Powers, Eddy Bekkers and Shenjie Chen. Bill Powers read an earlier draft in detail and made suggestions that led to significant improvements. We thank all these people but they are not responsible for any aspect of the paper.

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Abstract

We conduct an historical simulation from 2004 to 2014 with a 57-commodity, 13-region version of the GTAP model. The simulation generates estimates of changes in industry technologies, household preferences and several other unobservable variables by calculating the changes required to connect GTAP databases for the two years.

The historical simulation starts from the 2004 database and then in a single-period (10-year) computation produces a picture of 2014. We require this picture to be consistent with a large number of data points in the GTAP database for 2014 and with data on a selection of other variables brought in from non-GTAP sources.

The GTAP data are entirely in *values*. The non-GTAP sources provide movements between 2004 and 2014 in *quantity* variables. The combination of exogenously set GTAP value targets for 2014 and non-GTAP quantity targets enables the historical simulation to generate a comprehensive set of price movements for 2004 to 2014. Simultaneously, the historical simulation translates commodity and industry value movements into quantity movements. With input and output quantity movements in place, technology and preference movements are revealed.

JEL codes C68; C52; D24

Key words GTAP historical simulation; Industry technologies; Household preferences

Summary

We conduct an historical simulation from 2004 to 2014 with a 57-commodity, 13-region version of the GTAP model. The simulation generates estimates of changes in industry technologies, household preferences and several other unobservable variables by calculating the changes required to connect GTAP databases for the two years.

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The historical simulation reported here produces estimates of movements between 2004 and 2014 in:

- technologies disaggregated by industry, region and input; and
- preferences disaggregated by imported and domestic commodity, region and agent (households, government and investors).

These estimates are informed by data on movements between the two years in:

- real GDP, capital stock and employment for each region, and employment disaggregated for selected regions into skilled and unskilled;
- values in each region of expenditures by households, governments and investors disaggregated by commodity and source (imported or domestic);
- values in each region of expenditures on intermediate inputs disaggregated by commodity and source;
- values in each region of expenditure on labour and on capital aggregated over industries;
- values of exports from each region disaggregated by commodity;
- values of margins supplied from each region to facilitate international trade;
- the price index for investment in each region; and
- quantities of world output for 35 out of the 57 GTAP commodities.

In this paper, we analyse technology results. Later papers will consider a broader range of results. The technology results are encouraging. They are interpretable in terms of world-wide productivity by commodity, macro productivity by region, and Balassa-Samuelson effects. That the results are interpretable and seemingly plausible is evidence of the quality of the GTAP databases and their comparability through time.

An historical simulation opens the way to two types of application: decomposition and baseline. A decomposition simulation covers the same period as its parent historical simulation. Technology and preference trends are set exogenously and shocked with their values from the historical simulation. The decomposition simulation can then quantify the roles in economic development of technology and preference movements. In baseline

forecasting, technology and preference trends from an historical simulation can add industry texture. We are moving in this direction. As a preliminary step, we are conducting a validation test by assessing the extent to which the introduction of technology and preference trends from the historical simulation improves the ability of the GTAP model to reproduce developments in the world economy over the period 2014 to 2017. Subsequently we will create a baseline out to 2050 that incorporates technology and preference trends.

While working on applications of the historical simulation, we will also be deepening our understanding of the current set of results. Analysing results often suggests possibilities for improvement. The most exciting possibility to emerge from our analysis so far concerns new trade theory. We find that our historical simulation overstates the prices of exports and imports while doing a good job for each region on the terms of trade. This points to an idea prominent in new trade theory, that firms producing commodities for export have higher productivity than those confined to domestic markets. In our historical simulation, no distinction is made between export-oriented firms and non-exporting firms. In future research, we plan to introduce this distinction.

1. Introduction

Central among the valuable resources that the Global Trade Analysis Project (GTAP) has given to the world's economic modelling community are comparable, global databases for 2004, 2011, 2014 and 2017. For more than 140 countries, these databases include: input-output tables identifying 57 commodities/industries (65 in 2014 and 2017); the use by these industries of five types of primary factors; trade flows for each commodity between each pair of countries; tax collections associated with all domestic and international flows; and transport costs associated with each international flow. These databases (and earlier versions) have been the main input to global models, principally the GTAP model[1], since the 1990's. Many thousands of model-based studies using GTAP data have been undertaken to inform policy debates in every part of the world on issues in trade, environment, labour, public finance and economic development. Typically, in these studies, just the latest the GTAP database available to the researcher plays a role. Little use has been made of the time-series nature of the data.

In this paper, we use the GTAP databases for 2004 and 2014 to estimate changes over this period in industry technologies. Our method also generates estimates of preference shifts by households between commodities, and preference shifts by both households and industries between domestic and foreign supplies of each commodity. However, we focus on methodology and report results only for industry technologies. In future papers, we plan to analyze results for a broader range of variables.

Our estimation method relies on an historical stimulation[2] using the GTAP model with 57 commodities[3] and with the regions aggregated to 13. The historical simulation estimates changes in technologies, preferences and various other unobservable variables by calculating the changes required to connect GTAP databases for 2004 and 2014.

As described in section 2, the historical simulation starts from the 2004 database and then in a single-period (10-year) computation produces a picture of 2014. We require this picture to be consistent with a large number of data points in the GTAP database for 2014 and with data on a selection of other variables brought in from non-GTAP sources.

The GTAP data are entirely in *values*. The non-GTAP sources provide movements between 2004 and 2014 in *quantity* variables. Examples are real GDP for each region, employment for each region, employment of skilled and unskilled workers for selected regions, capital stocks for each region and world outputs of agricultural, mineral and most manufactured commodities. The combination of exogenously set GTAP value targets for 2014 and non-GTAP quantity targets enables the historical simulation to generate a comprehensive set of price movements for 2004 to 2014. Simultaneously, the historical simulation translates

[1] Key references for successive developments of the GTAP model are Hertel (1997), Ianchovichina and Walmsely (2012), Corong *et al.* (2017) and Aguiar *et al.* (2019)

[2] This technique has been used since the 1990s to estimate technology and preference shifts and to analyze structural aspects of economic growth for Australia, the U.S., Vietnam, China and several other countries. References include Dixon and McDonald (1993), Dixon *et al.* (2000), Dixon and Rimmer (2002, 2004), Giesecke (2002), Giesecke and Tran (2009), Dixon and Rimmer (2013), Dixon *et al.* (2013) and Peng (2023).

[3] The GTAP model and our historical simulation have 58 industries, one for each commodity plus the capital-goods industry which mixes inputs to investment to create capital goods. We aggregated the 2014 database from 65 to 57 commodities to make it comparable with the 2004 database.

commodity and industry value movements into quantity movements. With input and output quantity movements in place, technology movements are revealed.

Most of the targets for 2014 in the historical simulation are for naturally endogenous variables. These variables must be exogenous in the historical simulation so that they can be shocked with the 2004-to-2014 movements required to hit their targets. This requires novel allocations of variables to the endogenous and exogenous categories. While concerned with simulating into the future rather than reproducing the past, Wojtowicz *et al.* (2019, p. 3) see two problems with the general approach that we implement in this paper:

> *"First, the number of exogenously determined targets is generally very limited. The more targets are set, the more difficult calibration gets. This might make targets less achievable and might lead to strange/inconsistent parameter values. Second, baselines are created using a specific model and, therefore, are dependent on the structure of that model. This makes it difficult for other modelling teams to replicate the same baseline."* [In this quotation we interpret "parameter values" to include what we refer to technology and preference variables.]

It's worth considering these points at the outset.

Initially we did experience bewildering problems in simulating from 2004 to hit a large number (many thousands) of targets in 2014. These problems included computations generating no solution and computations generating "strange/inconsistent parameter values". Eventually we overcame the problems by developing the closure (division between endogenous and exogenous variables) for the historical simulation in a methodical, step-by-step fashion. A full account is in section 2. Nevertheless, here it may be useful to set out the overall strategy, without too much clutter from technical details.

We started with a bland long-run closure. In this closure, naturally exogenous variables (such as population, employment, technologies, preferences and tax rates) are exogenous, and naturally endogenous variables (such as industry outputs, trade volumes and relative prices) are endogenous. With a few simple modifications to this closure, we arrived at a simulation that hit targets (observations) in each region for movements between 2004 and 2014 in real GDP and its supply-side components: labour; capital; land; and natural resources. This simulation showed movements for each region in total factor productivity (real GDP per unit of primary factor input) and in factor prices relative to the numeraire. As in most GTAP simulations, the numeraire was the world price level represented by the average world-wide price of primary factors. We assumed in this preliminary simulation that the total factor productivity movement for a region applies uniformly across the region's industries. This was sufficient for the simulation to generate commodity prices in each region. Having checked the results for their computational robustness and their interpretability in terms of the shocks and the assumptions of the model, we moved on to a second group of simulations.

In this second group, we introduced movements for each region in the components of gross national expenditure (GNE=C+I+G). These are value movements calculated for each region and each commodity from the GTAP databases for 2004 and 2014. With commodity prices determined by the shocks to the world price level (the numeraire) and to real GDP and its supply-side components, we allowed the historical simulation to hit expenditure-side value targets through movements in preferences. Although an historical simulation determines quantities, prices and preferences simultaneously, we kept a sequential hierarchy in mind: first prices, then preferences.

In introducing expenditure value targets, we were faced with closure puzzles. An easy example concerns private consumption by commodity. When we introduced 57 exogenous value targets for region r, we endogenized only 56 independent preference variables. Preference shifts are relative. They must be in favour of some commodities and against others. So what is the 57th endogenization? The answer is region r's average propensity to consume. With the introduction of targets for expenditure on every commodity, aggregate private consumption expenditure for region r is determined. Consequently, we must free up the relationship between aggregate private consumption and income. Similarly, when we introduced 57 exogenous value targets for public consumption in r, we endogenized 56 independent public-consumption preference variables and freed up the link between aggregate public consumption in region r and the region's income.

The last component of GNE, investment, provided a more difficult closure puzzle. When we introduced 57 exogenous value targets for region r's investment expenditure by commodity, we endogenized 56 independent variables affecting inputs per unit of capital creation in region r. The 57th endogenization was r's relative risk variable, normally set exogenously to determine the share of global saving allocated to investment in region r. But only 12 of these 13 relative risk variables can be endogenous. So what is the last endogenization? It turns out to be the global price level (the previously exogenous numeraire). Setting targets in the historical simulation for real GDP and nominal GNE in each region determines global *real* GDP and global *nominal* GDP. [At the global level, the trade balance is zero.] Consequently, we have tied down the global price level, which now must be treated endogenously.

At this stage, we had a historical simulation that generated macro technology movements and commodity preference movements based on macro quantity data for supply-side variables and commodity value data for expenditure variables. This simulation provided a stable platform from which we were able to undertake a sequence of new simulations. Each of these included additional target variables for 2014, and added more texture to the technology and preference estimates. While it would be possible to embrace more targets, as practical matter, we had to bring the sequence of simulations to an end. The final simulation, for which results are reported in this paper, produced estimates of movements between 2004 and 2014 in:

- technologies disaggregated by industry, region and input; and
- preferences disaggregated by imported and domestic commodity, region and agent (households, government and investors).

These estimates were informed by data on movements between the two years in:

- real GDP, capital stock and employment for each region, and employment disaggregated for selected regions into skilled and unskilled;
- values in each region of expenditures by households, governments and investors disaggregated by commodity and source (imported or domestic);
- values in each region of expenditures on intermediate inputs disaggregated by commodity and source;
- values in each region of expenditure on labour and on capital aggregated over industries;
- values of exports from each region disaggregated by commodity;
- values of margins supplied from each region to facilitate international trade;
- the price index for investment in each region; and
- quantities of world output for 35 out of the 57 GTAP commodities.

With more work, data for additional variables could readily be introduced to the historical simulation. Two promising candidates that might make interesting differences to our results are the regional price deflators for exports and imports. However, even data left out of the historical simulation can play a useful role. This is illustrated in section 3 where we discuss the performance of the historical simulation in reproducing observed movements in price deflators in each region for GDP, private and public consumption, exports and imports.

Now let's turn to the second of Wojtowicz *et al.* (2019)'s worries, namely the model dependency of estimates. An example of what this means is that a technical change or a preference change in one model is a price-induced substitution effect in another. An implication is that in baseline work, involving projections of past technology and preference trends into the future, we should, ideally, use the same model for both estimating the trends and creating the baseline. Our historical simulation method offers this possibility and is consistent with ideas emphasized in new trade models in which, as explained by Bekkers *et al* (2020, section 2.3):

> *"... equations to estimate the parameters of the model are derived from the model and employed to run counterfactual experiments ..."* [Again, we interpret "parameters" to include what we refer to as technology and preference variables.]

As is probably already apparent, the remainder of the paper is organized as follows. Section 2 is a detailed description of the data inputs and closure swaps used in creating the historical simulation. Section 3 sets out and discusses the industry technology results. Concluding remarks and plans for future research are in section 4.

2. Developing the closure for the historical simulation

We start by setting up a CoPS-style[4], standard, long-run GTAP simulation. The base year for this simulation is 2004. The simulation moves the 2004 database to a picture of 2014 in a one-period computation (no intermediate years). In the closure for this standard long-run simulation:

(a) all technology, consumer preference and tax-rate variables are exogenous.
(b) population, employment, the availability of land and other natural resources in each region are exogenous.
(c) savings in each region in 2014 are determined as a function of the region's net national product. This is sufficient to tie down global savings in 2014 which in turn gives us global investment in 2014.
(d) global investment in 2014 is allocated across regions to equate risk-adjusted regional *expected* rates of return. The risk adjusted expected rate of return in 2014 in a region is determined in the usual GTAP way[5] as the *actual* rate of return in 2014 modified to incorporate risk through a downward sloping function of the region's capital growth in 2014 and an exogenous region-specific risk-adjustment factor. Actual rates of return in 2014 reflect rental rates for using capital and costs of creating capital.
(e) the equalized risk-adjusted expected rate of return in 2014 moves endogenously so that global investment in 2014 equals global saving in 2014. If global savings are scarce, then the equalized risk-adjusted expected rate of return will be high and vice versa.

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[4] At the Centre of Policy Studies (CoPS) we perform long-run simulations that take account of saving and capital accumulation between the initial and final years, see Dixon and Rimmer (2002), This is explained briefly in the dot points that follow. Our method dates back to Evans (1972) but doesn't seem to be generally used in the GTAP community.

[5] This specification of expected rates of return and investment comes from Dixon *et al.* (1982).

(f) capital stocks at start-of-2014 in each region are endogenous and relative *actual* rates of return across regions are exogenous.
(g) absolute actual rates of return are endogenous so that global capital accumulation between start-of-2004 and start-of-2014 equals global accumulated savings between 2004 and 2014.
(h) accumulated savings in each region is deduced from a straight-line extrapolation between 2004 and 2014 of the region's savings in the two years.
(i) exchange rates are implicitly set on one, and all values are in $US.
(j) the average price at the global level for the use of endowments is set exogenously, providing the numeraire.

In the historical simulation, we apply shocks to represent observed movements between 2004 and 2014 in a selection of variables. The selection can be seen in columns 2 and 3 of Table 2.1. Some of these selected variables are exogenous in the closure for the standard long-run simulation. For these variables, shocks can be applied without a closure change. An example of such a variable is regional population growth [pop(r), panel 1, Table 2.1]. Other selected 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(r), panel 2]. Movements in this variable from 2004 to 2014 can be observed from OECD and IMF data [column 4, panel 2]. 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 of panel 2 in Table 2.1, the variable that we chose for endogenization was primary-factor-saving technical change [afereg(r)].

In creating the historical closure, we used a step-by-step approach. Each step added to the previous step by introducing an observed 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.

The broad outline of our step-by-step strategy can be seen in the three-part organization of Table 2.1. In the first part, we put in place real GDP for each region, explained by factor inputs and macro technology (total factor productivity). In the second part, we put in place nominal gross national expenditure for each region, introduced with commodity detail. The commodity dimension gives us preliminary estimates of movements in preferences by households, governments and capital creators between different commodities and between domestic and imported varieties. The third part introduces several variables through which we can gain further insights on movements in preferences and industry technologies.

Table 2.1. Shocked variables and closure swaps

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	pop(r)	Population	OECD	No swap	
2	qgdp(r)	Real GDP	OECD & IMF	afereg(r)	Primary factor tech change by region
3	kb_obs(r)	Observed capital in r	Penn data, real capital services	f_rorc(r)	Shift in rate of return in r away from global rate
	ff_rorc	Shift in global rate of return	Zero shock	shift_kb	Uniform correction of regional capital
4	lsreg(r)	Employment, same as labour supply	Penn data on total hours of employment	No swap	Ratio lab supply to pop
5	qo(land,r)	Supply of land	Assumed no shock	No swap	
6	pm(natres,r)	Price of natural resources	Assumed shock 35%	qo(natres,r)	Use of natural resources
7	rat_vkl_obs(r)	K/L earnings ratio, observed	GTAP data	No swap	
	gap_rcaplab(r)	K/L earnings ratio: observed less simulated	Zero shock	twistKL(r)	Uniform cost-neutral K/L tech twist across all industries in r
Part 2: Gross national expenditure variables (C, G, I)					
8	v_vpa_obs(j,r)	Observed value of private cons of composite j in r	GTAP data	No swap	
	f_v_vpa_obs(j,r)	Links observed to simulation private cons of j,r	Zero shock	a3com(j,r)	Preference shift for private consumption of composite j in r
	ave_a3com(r)	Average preference shift	Zero shock	apcnnp(r)	Average propensity of hhlds to consume out of net national product
	sh_vpam(j,r)	Observed value of private cons of imported j,r	GTAP data	twist_srcp(j,r)	Dom/imp twist in preferences of hhlds

Table 2.1 continues …

… Table 2.1 continued

Panel no	Exo variable	Description	Source for shock	Swap variable *(goes endogenous)*	Description
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
9	v_vga_obs(j,r)	Obs value of govt cons of composite j in r	GTAP data	No swap	
	f_v_vga_obs(j,r)	Links observed to simulation private cons of j,r	Zero shock	f_qg(j,r)	Preference shift for government consumption of composite j in r
	ave_f_qg(r)	Average preference shift	Zero shock	dpgov(r)	Frees link between govt expend and NNP
	sh_vgam(j,r)	Observed value of imported govt cons of j,r	GTAP data	twist_srcg(j,r)	Dom/imp twist in preferences of govt
10	sh_viad(j,r)	Observed value of input of dom j to invest in r	GTAP data	afall(j,“CGDS”,r)	j-saving tech in capital creation in r
	sh_viam(j,r)	Observed value of input of imp j to invest in r	GTAP data	twist_srci(j,r)	Dom/imp twist in input of j to capital creation in r
	aveinvafall(r)	Average tech improvement in capital creation in r	Zero shock	cgdslack(r)	Risk-adjustment factor specific to region r
	rorg	Endo shift on risk-adjusted rors in std closure but must now be exo because risk-adjusted factors are endo	Zero shock	pfactwld	World price level
Part 3: Gaining insights on industry technologies					
11	sh_v_vint(j,r)	Observed value of intermed use of composite j in r	GTAP data	int_sh_d(j,r)	Tech change that saves inputs of domestic j in all industries in region r
	sh_v_vfam(j,r)	Observed value of intermed use of imported j in r	GTAP data	int_sh_m(j,r)	Tech change that saves inputs of imported j in all industries in region r

Table 2.1 continues …

… Table 2.1 continued

Panel no	Exo variable	Description	Source for shock	Swap variable *(goes endogenous)*	Description
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
12	vxwfob_obs(j,r)	Observed value of exports of j from r	GTAP data	f_twistmd(j,r)	World-wide preference change by importers of j towards r's variety of j
	ftwmd_ave(j)	Average world-wide preference change by importers of j	Zero shock	ff_vxwfob(j)	World-wide adjustment of observed export values of j to reconcile with aggregate import values for j
13	qworld(j), $j \in$Set32	World output of com j	FAO, and other sources	afsecall(j), $j \in$Set32	World-wide tech change in production of j
	qworld(j), $j \in$Set3	World output of com j	IEA	ff_pworld(j), $j \in$Set3	Gap between world price for j and average of regional prices: should be 0
	ff_pm(j,r), $j \in$Set3	Ratio, regional to world price	Zero shock	f_to(j,r), $j \in$Set3	Artificial tax on j in r: excess profits indicator
14	v_vst_obs(m,r), $m \in$Marg	Observed value of export of margin m from r	GTAP data	twqst(m,r) $m \in$Marg	Preference twist by global agent between suppliers of m
	twqst_ave(m), $m \in$Marg	Average preference twist by global agent between suppliers of m	Zero shock	atm(m) $m \in$Marg	Uniform tech change for all international trade flows affecting the use of margin m per unit of flow
15	f_p_i_obs(r)	Price index for capital formation	OECD data	a_cgds(r)	Technical change saving all inputs per unit of capital creation
16	r_sk_unsk(r) r = India, China	Ratio of skilled to unskilled emp	ILO and China population census	r_ls(sklab,r) r = India, China	Shift variable affecting the supply of skilled and unskilled labour

2.1. Step-by-step explanation of Table 2.1

Real GDP and supply-side determinants

Panel 1: population. Here we introduce OECD data on population growth in each region between 2004 and 2014. These population shocks can be seen in Table 2.2. As mentioned already, population growth is exogenous in the standard long-run closure. Consequently, no closure swap is required.

Panel 2: real GDP. As also mentioned earlier, in going from the standard long-run closure to the historical closure, we exogenized real GDP. This enables us to introduce OECD and IMF data on movements between 2004 and 2014 in real GDP. These are given in Table 2.2. 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 the choices, we are guided by back-of-the-envelope representations of 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:

$$\mathrm{RealGDP(r)} = \mathrm{A(r)} * \mathrm{F_r}\left(\mathrm{L(r), K(r), Land(r), NatRes(r)}\right) \tag{2.1}$$

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.

Table 2.2. Percentage growth between 2004 and2014

	Population (pop), data	Real GDP (qgdp), data	Capital stock (kb_obs), data	Employment (lsreg), data	Contribution of tech changes to GDP (tech_cont)	
					After panel 7	After full historical, panel 16
1 USA	8.61	17.39	24.61	3.44	5.83	6.88
2 Canada	11.44	20.75	28.46	8.53	2.96	3.82
3 Mexico	16.10	23.28	38.24	24.82	-7.56	-6.62
4 China	5.79	160.11	204.14	5.27	40.58	38.34
5 Japan	-0.04	6.04	8.04	-2.44	1.91	3.86
6 SKorea	3.89	45.63	54.75	-3.34	15.67	18.29
7 India	14.89	109.37	150.78	9.00	25.93	29.51
8 France	5.58	10.23	20.90	3.07	-0.91	1.21
9 Germany	-0.28	14.44	13.41	4.31	3.01	5.60
10 UK	8.57	14.20	17.04	9.02	0.19	4.05
11 RoEU	1.72	7.27	22.78	-3.10	-3.29	-1.95
12 SaudiArabia	32.49	49.11	106.88	54.09	-15.65	-11.88
13 RoW	18.04	52.61	44.07	26.24	11.08	10.63

At this stage in the transition from the standard long-run closure to the historical closure, employment and the use of land and natural resources are exogenous [see point (b) at the start of section 2]. Capital in each region is tied down by our assumptions for relative actual rates of return and accumulated global saving from 2004 to start-of-2014 [points (f) and (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 (2.1)]. 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 3: regional capital stocks. Now we introduce data from the Penn world tables on movements between start-of-2004 and start-of-2014 in capital stocks by region (measured by real capital services). These data are shown in Table 2.2. We make an endogenous scalar adjustment so that global growth in capital from start-of-2004 to start-of-2014 is compatible with simulated accumulated global savings over this period in accordance with point (g). The scalar adjustment is achieved by endogenizing the variable shift_kb which occurs in the model equation:

$$\mathrm{kb(r)} = \mathrm{kb\_obs(r)} + \mathrm{shift\_kb} \tag{2.2}$$

where

kb(r) is the simulated percentage growth in capital stock for region r from start-of-2004 to start-of-2014 ;

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 very small, indicating a high degree of compatibility between simulated accumulated global saving and the Penn capital data.

With start-of-year capital stocks for 2014 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:

$$\mathrm{rorc(r)} = \mathrm{f\_rorc(r)} + \mathrm{ff\_rorc} \tag{2.3}$$

where

rorc(r) is the simulated percentage change in the actual rate of return in region r between 2004 and 2014; and

f_ror(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 (f) and (g), this treatment of the shift variables exogenizes relative actual rates of return and endogenizes the global absolute actual rate of return. In the historical closure, we effectively endogenize actual rates for each region by endogenizing f_rorc(r) and exogenizing ff_rorc.

Panel 4: employment. Employment in each region is exogenous in the standard closure. Consequently, introduction of data on employment growth between 2004 and 2014 does not require a closure swap. As indicated in Table 2.1 [column 4, panel 4], in the historical simulation we shock regional employment with percentage movements between 2004 and 2014 derived from Penn world tables on aggregate hours worked. These shocks are in Table 2.2.

Panel 5: 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 historical closure. In the historical simulation, we assume no change in land-availability by region between 2004 and 2014.

Panel 6: natural resources. The GTAP database for 2004 shows that over 80 per cent of the returns to natural resources are in the oil, gas and coal industries. In the standard long-run closure, the treatment of natural resources is similar to that of land. In the closure for our historical simulation, we chose to treat 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 oil, gas, and coal adjusts to demand conditions. The shock that we apply to the rental price of natural resources in each region, 35 per cent, reflects the increase between 2004 and 2014 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 historical closure, we introduce data on movements in prices of oil, gas and coal. These over-rule the 35 per cent assumption in the determination of the prices of these energy commodities and endogenize profitability per unit of their production.

The other 20 per cent of returns to natural resources goes to the forestry and fishing industries. In later steps, we introduce data that ties down world prices of these products. Unlike our treatment of oil, gas and coal, we assume that prices in forestry and fishing reflect costs. To accommodate the price information for forestry and fishing, we adjust their production costs by endogenizing aspects of their technologies. Consequently, for these industries, our 35 per cent assumption *does* have an impact. If we had assumed larger increases in natural resource costs, then our historical simulation would have shown more technological improvement in forestry and fishing, and vice versa.

Panel 7: ratio of earnings of capital to labour. After completing the data inputs and closure swaps in the first 6 panels, we computed a solution. It gave highly unrealistic results for investment and returns to capital in China and India. It became apparent that our simulation could not cope with the huge observed increases for these two countries in K/L, see Table 2.2. As explained here, we solved this problem by introducing data on earnings by capital and labour accommodated by biased capital-labour technology twists.

Using the GTAP data for 2004 and 2014, we calculated the observed percentage changes in total capital/labour earnings ratios for each region. We forced the simulated percentage changes to equal the observed percentage changes via the following equation:

$$\text{gap\_rcaplab}(r) = \text{rat\_vkl\_obs}(r) - \text{rat\_vcap\_vlab}(r) \tag{2.4}$$

In this equation, rat_vkl_obs(r) and rat_vcap_vlab(r) are the percentage changes in the observed and simulated capital/labour earnings ratios in region r. The variable on the LHS of (2.4), gap_rcaplab(r), appears only in this equation. In the standard long-run closure, gap_rcaplab(r) is endogenous. In this closure, (2.4) has no significance beyond recording the gap between the observed and simulated movements in the capital/labour earnings ratios. In the historical closure, we exogenize gap_rcaplab(r) on zero change.

With the observed movements in the capital/labour earnings ratios now imposed in the historical simulation, we must allow endogenous adjustment in industry technologies in each region so that the simulated earnings ratios come into line with observed ratios. We did this by endogenizing twistKL(r). A movement in this variable 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. The technology changes imposed through twistKL(r) are cost neutral for r's economy: an increase in K is offset by a compensating reduction in L. By adopting cost-neutral technology changes to absorb capital and labour data on earnings, we avoided indeterminacy between the roles of the technology changes in this panel and the technology changes introduced to absorb real GDP data in panel 2. By using the capital/labour earnings data in ratio form only, we avoided conflict with the exogenous treatment of the average global price of endowments, point (j).

For China and India, the capital/labour technology twists were strongly in favour of capital. This enabled the historical simulation to cope with the observed huge increases in the K/L ratios while giving plausible results for investment and rates of return.

The data inputs and closure swaps to the end of panel 7 complete, to a large extent, the estimation of the contribution to GDP of technical change. This is indicated by the similarity of the last two columns of Table 2.2. These show the technology contributions after the end of panel 7, and the final estimated contributions at the end of panel 16. Beyond panel 7, the data inputs and closure swaps add industry and commodity detail to technology and preference estimates without having much effect on macro regional technology contributions.

Gross national expenditure variables (C, G, I)

Using the GTAP databases for 2004 and 2014, we calculated the percentage growth between 2004 and 2014 in the values of:

Private consumption of domestic and imported commodity j in region r;
Government consumption of domestic and imported commodity j in region r; and
Inputs of domestic and imported commodity j to capital creation in region r.

Panels 8 to 10 show how we took this information into the historical simulation.

Panel 8: expenditure on private consumption. The shocks for private consumption of composite commodities (domestic plus imported) were applied in the historical simulation via the equation:

$$\mathrm{v\_vpa\_obs}(j,r) = \mathrm{qp}(j,r) + \mathrm{pp}(j,r) + \mathrm{f\_v\_vpa\_obs}(j,r) \tag{2.5}$$

In this equation, qp(j,r) is the percentage change between 2004 and 2014 in the quantity of private consumption in region r of composite commodity j, and pp(j,r) is the percentage change in the corresponding price. In the standard long-run closure, v_vpa_obs(j,r) is exogenous and f_v_vpa_obs(j,r) is endogenous and neither appear in any other equation. With this setup, equation (2.5) has no influence in the rest of the model. In the historical simulation, we exogenized f_v_vpa_obs(j,r) and gave it zero shock. At the same time, we shocked v_vpa_obs(j,r) with the percentage movement observed from the GTAP databases in the value of private consumption of composite j in region r. Equation (2.5) now forces the simulated value to be equal to the observed value.

With the observed movements in consumption of composite commodities imposed in the simulation, we must free up consumer preferences. Before we could do this, it was necessary to add preference variables to the GTAP equations for private consumption of composite commodities in each region. These additions gave consumer demand equations of the form:

$$\mathrm{qp}(\mathrm{j},\mathrm{r}) = \{\text{terms pertaining to population income and prices}\} + \mathrm{a3com}(\mathrm{j},\mathrm{r}) - \mathrm{ave\_a3com}(\mathrm{r}) \qquad (2.6)$$

$$\mathrm{ave\_a3com}(\mathrm{r}) = \sum_{\mathrm{j}} \mathrm{SHPR}(\mathrm{j},\mathrm{r}) * \mathrm{a3com}(\mathrm{j},\mathrm{r}) \qquad (2.7)$$

where

qp(j,r) is the percentage change in private consumption of composite j in region r;
the terms in the brackets provide the usual GTAP specification of qp(j,r);
a3com(j,r) is a preference variable allowing shifts in consumption towards or away from composite j in region r;
ave_a3com(r) is the average preference movement in region r; and
SHPR(j,r) is the share of j in total private consumption expenditure in r.

In a standard long-run simulation, a3com(j,r) is exogenous with zero shock and ave_a3com(r) is endogenously determined at zero. In the historical simulation, we accommodated observed movements in the values of private consumption of composite commodities by allowing adjustments in the simulated quantities through endogenous movements in the a3com(j,r) for all j,r. At the same time, we exogenized ave_a3com(r) and gave it zero shock. Corresponding to the exogenization of ave_a3com(r) is endogenization of apcnnp(r), the average propensity to consume out of net national product. With the introduction of observations for expenditure on all composite commodities, aggregate consumption expenditure [or equivalently saving, point (c)] is no longer determined in each region by movements in net national product.

The GTAP version of (2.6), without the preference terms, is set up so that it satisfies an add-up condition. The percentage changes in the values of private consumption of composite commodities in region r added over all commodities with budget weights [SHPR(j,r)] equal the percentage change in the region's private consumption budget, irrespective of how that budget is determined. The inclusion of ave_a3com(r) in equation (2.6) means that our addition of preference terms to the GTAP private demand system maintains the add-up condition.

The values for the a3com(j,r) variables in our historical simulation give a conditional picture of changes in household preferences: conditional on the values of expenditure and price elasticities appearing in the consumer demand equations. In previous papers on historical simulations with the GTAP data for 2004 and 2014, we modified some of the GTAP values for expenditure elasticities to improve the plausibility of the implied preference changes, see Dixon and Rimmer (2021). In this way, the historical simulation became an informal estimation approach. However, we don't pursue this here.

Having imposed the observed movements in private consumption of composite commodities, our next task in the development of the historical simulation was to introduce the observed split in composites between imported and domestic commodities. In doing this, we used only the observations for imports: with the values of composites already incorporated in the historical simulation, the values for consumption of domestic varieties are implied as a residual.

To accommodate the import observations (and the implied domestic observations) we added import-domestic twist variables to GTAP's Armington specification of consumer choice between domestic and imported varieties. With this addition, we obtained equations of the form:

$$\mathrm{qpm}(j,r) = \mathrm{qp}(j,r) + \{\text{price terms}\} + \mathrm{SHPRD}(j,r) * \mathrm{twist\_srcp}(j,r) \tag{2.8}$$

$$\mathrm{qpd}(j,r) = \mathrm{qp}(j,r) + \{\text{price terms}\} - \mathrm{SHPRM}(j,r) * \mathrm{twist\_srcp}(j,r) \tag{2.9}$$

where

qpm(j,r) and qpd(j,r) are the percentage changes in private consumption of imported and domestic commodity j in region r;

qp(j,r) is, as defined already, the percentage change in private consumption of composite j in region r;

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

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

SHPRM(j,r) and SHPRD(j,r) are the share of imported and domestic j in private consumption expenditure on composite j in r.

In a standard long-run simulation, twist_srcp(j,r) is exogenous with zero shock. In our historical simulation, we accommodate observed movements in the values of private consumption of imported commodities (and implied movements for domestic commodities) by allowing adjustments in the simulated quantities through endogenous movements in twist_srcp(j,r).

The share coefficients attached to the twist terms in (2.8) and (2.9) preserve the condition that the share-weighted average of the percentage changes in consumption of imported and domestic commodity j in region r equals the percentage change in the consumption of composite j in region r.

One practical complication worth mentioning is the treatment of import observations for j,r cells in which the import share is either close to zero or close to one. For example, the import share for dwelling services is zero in all regions and the share for oil is close to one in some regions. If SHPRM(j,r) is close to zero or one, twist_srcp(j,r) is an ineffective instrument for accommodating import/domestic choice. In these cases, we left twist_srcp(j,r) exogenous and ignored the import shock.

Panel 9: expenditure on government consumption. Our approach for introducing GTAP regional expenditure data on public consumption of composite commodities and their domestic and imported constituents was similar to that explained in panel 8 for private consumption expenditure. We applied shocks to government expenditures on composite and imported commodities [v_vga_obs(j,r) and sh_vgam(j,r)]. Then we endogenized public consumption preference variables [f_qg(j,r)], exogenized average preference movements [ave_f_qg(r)], endogenized the link between public consumption and net national product [dpgov(r)], and endogenized import/domestic twist variables [twist_srcg(j,r)].

Panel 10: expenditure on investment. In the GTAP model, capital goods are created for region r by the region's capital goods [CGDS] industry. Growth in expenditure on inputs to this industry can be observed from GTAP databases. We imposed these observations in the historical simulation as shocks to the values of expenditure on domestic inputs and the values of expenditure on imported inputs [sh_viad(j,r) and sh_viam(j,r)], accommodated by endogenizing afall(j, "CGDS",r) and twist_srci(j,r).[6] These are a technology variable which controls the input of composite j per unit of capital creation in region r, and a twist variable that modifies import/domestic choice beyond what is explained by movements in relative prices.

At this stage, we assumed that the technology changes introduced through the movements in afall(j, "CGDS",r) for all j do not affect overall inputs per unit of output (productivity) in r's capital goods industry. This assumption is imposed by exogenizing aveinvafall(r), which is a cost-weighted average of the afall's for region r, and giving it a zero shock. Later, we introduced price information on capital goods [see panel 15]. This allowed the historical simulation to determine productivity changes in the regional capital-goods industries.

By imposing expenditures on inputs to the CGDS industries, we determined aggregate investment expenditure in each region. The starting point for explaining how we accommodated these regional aggregates for investment is the equation:

$$\mathrm{RORG} = \mathrm{RORC(r)} * \left(\frac{\mathrm{KE(r)}}{\mathrm{KB(r)}}\right)^{-\mathrm{RORFLEX(r)}} * \left(\frac{1}{\mathrm{CGDSLACK(r)}}\right) \tag{2.10}$$

The RHS of (2.10) is the risk-adjusted expected rate of return for region r. As described in point (d) in the introduction to section 2, this is the product of three factors:

- RORC(r), the actual rate of return on capital in region r;
- $\left(\mathrm{KE(r)}/\mathrm{KB(r)}\right)^{-\mathrm{RORFLEX(r)}}$, where KB(r) and KE(r) are capital stocks in region r at the start and end of 2014, and RORFLEX(r) is a positive parameter; and
- CGDSLACK(r), the risk-adjustment factor specific to region r.

The LHS of (2.10) is a scalar. Thus, in accordance with point (d), (2.10) equalizes risk-adjusted expected rates of return across regions. Readers familiar with GEMPACK representations of the GTAP model will recognize (2.10) 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).

In the standard long-run closure, CGDSLACK(r) is exogenous and RORG is endogenous. These settings are consistent with points (d) and (e): exogenous region-specific risk factors [CGDSLACK(r)] and an endogenous global adjustment factor to bring global investment into line with global saving. If, for example, global savings are scarce, then RORG moves up and KE(r)/KB(r) moves down for all r. Lower values for the KE(r)/KB(r) ratios mean less investment.

In the historical simulation, we endogenized CGDSLACK(r) and exogenized RORG. This left CGDSLACK(r) free to adjust in a way that moved the KE(r)/KB(r) ratio to the level compatible with the observed investment expenditure for region r. For a region r in which observed investment in 2014 was low [a low value for KE(r)/KB(r)], CGDSLACK(r) was

[6] This is a variation on the treatment in the previous two panels, in which we shocked expenditures on composites and imports. The two treatments are equivalent.

high, indicating a high risk factor for region r. Similarly, for regions in which observed investment was high, CGDSLACK(r) was low.

The variables RORG and CGDSLACK(r) have no role in any equation apart from (2.10). Consequently, in using endogenous movements in the CGDSLACK(r)s to accommodate observed investment levels, we had no choice but to exogenize RORG. Otherwise there would be an indeterminacy in endogenously determining the values of RORG and the CGDSLACK(r)s. For whatever solution we found for the model, another solution could be found by multiplying RORG by a factor *x* and dividing each of the CGDSLACK(r)s by the same factor *x*. However, exogenizing RORG left us with a puzzling problem.

When we exogenize RORG, what is the corresponding endogenization? The answer can be found in the identity:

$$P^{w}_{gdp} * RGDP^{w} = \sum_{r} C_{nom}(r) + \sum_{r} G_{nom}(r) + \sum_{r} I_{nom}(r) \qquad (2.11)$$

In (2.11), the LHS is the value of world GDP expressed as the product of the price per unit of real GDP (P^{w}_{gdp}) and the total quantity of real GDP ($RGDP^{w}$). The RHS is the sum over all regions in expenditures on private consumption, government consumption and investment. With the data introduced in panels 8, 9 and 10, the whole of the RHS of (2.11) is known. With the data introduced in panel 2, real GDP for the world is known. Consequently, P^{w}_{gdp} must be free to move. But recall from point (j) that the movement in the world price level [pfactwld] is exogenous in the standard long-run closure. This must now be endogenized, becoming the other half of the swap when we exogenize rorg (the percentage change in RORG).

Gaining further insights on industry technologies

In the remaining panels of Table 2.1, we make further closure swaps and introduce further data on movements in variables between 2004 and 2014. Our main objective is to achieve more-detailed estimates of changes in industry technologies.

Panel 11: expenditure on intermediate inputs. GTAP provides data for 2004 and 2014 on the values in each region of intermediate input use of all commodities. From these data we computed percentage growth for composites (imports plus domestic) and for imports alone, but excluded dwellings for which there is almost no intermediate use.

In the historical simulation we imposed the observed growth in intermediate use of composites and imports by shocking the variables sh_v_vint(j,r) and sh_v_vfam(j,r). Values for intermediate use of domestic products are derived in the model from the composite and import data. To accommodate the observed movements in imported intermediate inputs and implied movements in domestic intermediate inputs, we endogenized int_sh_m(j,r) and int_sh_d(j,r). These are intermediate-input-saving technology variables operating uniformly on all industries in region r, affecting their use of imported and domestically produced commodity j. Positive values for these variables mean reductions in the use of imported or domestic j per unit of output.[7]

Given our estimates for int_sh_m(j,r) and int_sh_d(j,r), we calculated intermediate-input-saving technical change for industry k in region r as:

$$\text{int\_tc}(k,r) = \sum_j \text{ShIntD}(j,k,r) * \text{int\_sh\_d}(j,r) + \sum_j \text{ShIntM}(j,k,r) * \text{int\_sh\_m}(j,r) \quad (2.12)$$

where

int_tc(k,r) is the percentage reduction in the use of intermediate inputs per unit of output in industry k in region r; and

ShIntD(j,k,r) and ShIntM(j,k,r) are the shares of total intermediate costs in industry k in region r accounted for by domestic and imported inputs of commodity j.

Partially offsetting intermediate-input technology by primary-factor technology in the opposite direction

We interpreted negative values for int_tc(k,r) as indicating increased "roundaboutness" in production techniques, that is substitution of intermediate inputs for primary factors, rather than as technological deterioration. Similarly, we interpreted positive values as indicating increased use of primary factors to replace intermediates in production. Thus, we assumed that intermediate-input technical change is largely offset by primary-factor technical change of the opposite sign. To implement this idea we used the equation:

$$\text{tcnew}(k,r) = -\text{DAMP}(k,r) * \{\text{INT\_INP}(k,r) / \text{PF}(k,r)\} * \left[\text{int\_tc}(k,r)\right] \quad (2.13)$$

where

tcnew(k,r) is the percentage change in a primary-factor-saving technology variable introduced to partially offset intermediate technical change in industry k in region r;

INT_INP(k,r) and PF(k,r) are the values of intermediate and primary factor inputs to (k,r) in the GTAP data for 2004; and

DAMP(k,r) is a positive parameter.

If DAMP(k,r) = 1, then equation (2.13) implies that intermediate-input-saving technical change in (k,r) is totally offset by primary-factor-saving technical change with the reverse sign. However, we were worried that when the $\text{INT\_INP}(k,r) / \text{PF}(k,r)$ ratio is large then tcnew(k,r) might go to large negative values (close to -100). To guard against this possibility, we introduced the DAMP(k,r) parameter which is a decreasing function of $\text{INT\_INP}(k,r) / \text{PF}(k,r)$. The particular form we chose for DAMP is the logistic:

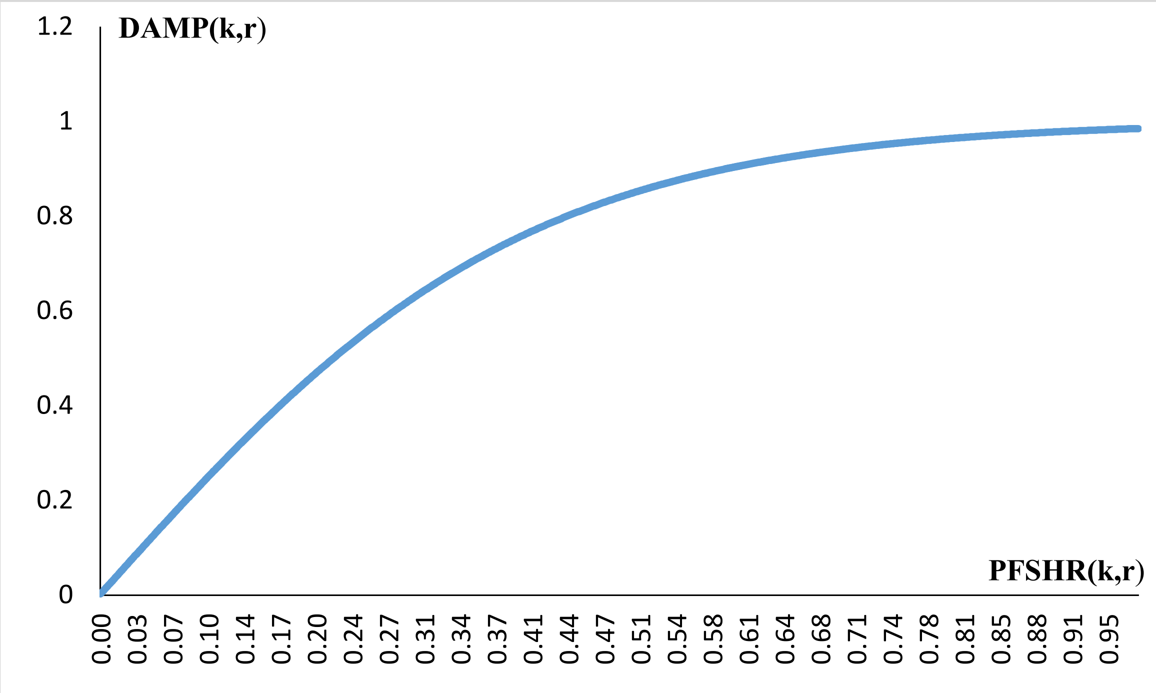
$$\text{DAMP}(k,r) = \frac{A + B * e^{C*\text{PFSHR}(k,r)}}{1 + e^{C*\text{PFSHR}(k,r)}} \quad (2.14)$$

where

A,B and C are parameters and

[7] In four cases [(prd,UK), (c_b,SaudiArabia), (coa, SaudiArabia) and (gdt,SKorea)], the intermediate flows were either negligible or the data appeared unreliable. For these cases we left the intermediate-input-saving technology variables exogenous on zero change and ignored the data on growth in intermediate use.

Figure 2.1. Damping factor used in deducing offsetting primary-factor technical change associated with intermediate-input technical change



PFSHR(k,r) is the base period (2004) share of total costs in (k,r) accounted for by primary factors, given by

$$\mathrm{PFSHR}(k,r) = \frac{\mathrm{PF}(k,r)}{\mathrm{PF}(k,r) + \mathrm{INT\_INP}(k,r)} \tag{2.15}$$

In our computations, A = -1, B = 1 and C = 5. This is illustrated in Figure 2.1. In most industries in all regions, the primary-factor share in total costs is greater than 0.3. As can be seen from Figure 2.1, this means that the damping factor is more than 0.6, implying that, for most industries, we assume that intermediate-input-saving technical change is largely offset by extra primary-factor-saving technical change in the opposite direction.

Panel 12: expenditure on exports. Here we introduce percentage movements between 2004 and 2014 in the values of exports of each commodity from each region. To help us accommodate these movements in the historical simulation, we equipped GTAP with twist variables that represent preferences by importing agents in each region between alternative supplying regions. In the standard long-run closure, these preference twist variables are exogenous, and averages of twists are consequently endogenous.

In taking the observed percentage movement in the value of exports of j from region r into the historical simulation, we endogenized the world-wide preference variable [f_twistmd(j,r)] by importing agents for commodity j from r. Observed rapid growth in exports of commodity j from region r [a large value for vxwfob_obs(j,r)] is accommodated by a large positive value for f_twistmd(j,r). This causes importers in every region to buy more j from r, and less from other regions, than can be explained by changes in relative prices. We set the average [ftwmd_ave(j)] over the exporting countries of the preference twists for commodity j [the average of f_twistmd(j,r) over r with export weights] exogenously at zero. This is because preferences are relative: the twists recognize that if preferences world-wide by importers are moving in favour of some exporting regions, then they must be moving against other exporting regions.

Via data on imports for private consumption, government consumption, investment and intermediate use [panels 8, 9, 10 and 11], we have already determined world-wide imports by commodity in the historical simulation. Now we must avoid conflict between world-wide imports and world-wide exports. To do this, we endogenize a shave variable for each commodity [ff_vxwfob(j)]. This makes equal percentage adjustments to the exports of j from each region so that exports of j aggregated over regions equal imports of j aggregated over regions.

A partial transformation of preference twists by importers into productivity improvements by exporters

After the introduction of export data, we computed an historical solution, referred to as the panel 12*Initial* solution. We noticed that for almost every commodity there was a preference change in favour of China and against Japan. We also compared the simulated terms-of-trade movements between 2004 and 2014 with the actual movements. This comparison showed an unrealistic positive simulated terms-of-trade movement for China. By contrast, the simulated result for Japan was too negative.

These preference and terms-of-trade results point to the following ideas. It seems likely that at least part of China's export performance is explained by rapid growth in traded-good productivity relative to non-traded-good productivity. This would reduce the prices of Chinese exports below the values indicated by the panel 12*Initial* solution and thereby reduce the simulated favourable preference changes required to generate results consistent with the observed values for Chinese exports. Simultaneously, introduction of pro-export productivity effects would reduce the simulated terms-of-trade movement for China. The corresponding argument in the reverse direction applies to Japan.

Rather than introducing pro-export productivity effects in a coarse macro form, we decided to share preference and technology effects for each commodity in each country. We started with the logistic equation:

$$\mathrm{TC2}(j,r) = \mathrm{DXsh}(j,r)\frac{A(j,r) + B(j,r) * \exp\left[C(j,r) * \left\{\mathrm{FTWISTMD}(j,r) - D(j,r)\right\}\right]}{1 + \exp\left[C(j,r) * \left\{\mathrm{FTWISTMD}(j,r) - D(j,r)\right\}\right]} \qquad (2.16)$$

In this equation,

TC2(j,r) and FTWISTMD(j,r) are levels of variables in our model. TC2(j,r) refers to an extra all-input-saving technical change for industry j in region r (extra to that already incorporated into our historical simulation) and FTWISTMD(j,r) refers to the preference change by importing agents throughout the world towards or against commodity j sourced from region r.

A(j,r), B(j,r), C(j,r) and D(j,r) are parameters. As discussed in more detail below, these parameters are set so that TC2(j,r) is an increasing function of FTWISTMD(j,r). The idea is that if our simulation requires a positive preference movement [an increase in FTWISTMD(j,r)] between 2004 and 2014 to explain exports of j from r, then there will be an extra positive technical change [an increase in TC2(i,r)] between 2004 and 2014. The positive technical change in industry j,r will generate a negative price movement for product j,r. This will reduce the favourable preference change towards j,r. In this way, we share the burden of explaining exports of j from r between a favourable preference change and a price competitiveness effect introduced through an extra technology improvement in j,r.

DXsh(j,r) is a zero-one dummy: 0 if the export share of r's output of j is less than 5 per cent. Thus, we let export growth inform technical change in industry j in region r only if exports are a significant part of the industry's total sales.

In discussing equation (2.16), it is convenient at this stage to omit the (j,r) arguments. We see that:

as FTWISTMD approaches infinity, TC2 approaches B; (2.17)

as FTWISTMD approaches negative infinity, TC2 approaches A; and (2.18)

if FTWISTMD =D, then TC2= (A+B)/2. (2.19)

We assume that in 2004, FTWISTMD and TC2 are both 1. Consequently we must set D according to:

$$D = 1 - \frac{1}{C} * LN\left(\frac{A-1}{1-B}\right) \tag{2.20}$$

With properties (2.17) and (2.18) in mind, we set A= 0.5 and B = 2 for all j and r. Given these settings, very large positive preference movements in favour of exports of j from r, generate values for TC2(j,r) of close to 2, that is TC2(j,r) doubles. Doubling TC2(j,r) gives industry (j,r) a technology boost that doubles its output per unit of total input. This approximately halves the factory-door price of commodity (j,r). In summary, if our simulation implies a very strong world-wide preference change towards exports of j from r, then we damp this preference change by introducing a technology change that approximately halves the price of j from r.

Similarly, very large preference movements against exports of j from r generate values for TC2(j,r) of close to 0.5, that is TC2(j,r) halves. Thus, if our simulation implies a very strong world-wide preference change against exports of j from r, then we damp this preference change by introducing a technology change that approximately doubles the price of j from r.

We experimented with values of C(j,r) in the range 1.5 to 4. Higher values of C cause the logistic curve to be steeper through its inflection point. However, varying C values did not have much effect on our results. In the end we settled on C(j,r) = 2 for all j,r.

In the final version of the Panel 12 simulation, we implemented the extra total productivity movement [movement in TC2(j,r) away from 1] via extra primary-factor-saving technical change. We didn't want to cause problems with intermediate-input-saving technical change that had been introduced by the observed movements in intermediate inputs. In implementing the extra total productivity movement through primary-factor-saving technical change we used equations of the form:

$$TC2(j,r) = TCPF(j,r)^{PFSHR(j,r)} \tag{2.21}$$

In this equation

TCPF(j,r) is additional primary-factor-saving technical change in industry (j,r); and

PFSHR(j,r) is, as defined earlier, the base period (2004) primary-factor share in (j,r)'s total costs.

As discussed in section 3, introduction of the productivity movements to damp preference movements improved the performance of the historical simulation in reproducing terms-of-trade movements.

Panel 13: quantities of world outputs. Dixon and Rimmer (2021) estimated percentage changes between 2004 and 2014 in quantities of world outputs of 35 out of the 57 GTAP commodities (excludes capital goods). These include: all of the 18 GTAP agriculture, forestry, fishing and mining commodities; 13 of the 24 manufacturing commodities; plus electricity, construction, air transport and water transport. Panel 13 shows how we included these estimates in the historical simulation.

Values of world outputs have already been put in place in the historical simulation through the observations at the commodity level of C, G, I and intermediate use. When we introduce quantity estimates for world outputs for 35 commodities we are determining their world prices.

The two equations in our version of the GTAP model that are critical for understanding how we introduced world prices for the 35 commodities into the historical simulation are:

$$\mathrm{pm}(j,r) = \mathrm{pworld}(j) + \mathrm{ff\_pm}(j,r) \tag{2.22}$$

and

$$\mathrm{pworld}(j) - \mathrm{ff\_pworld}(j) = \sum_r \mathrm{ShOutput}(j,r) * \mathrm{pm}(j,r) \tag{2.23}$$

where

pm(j,r) is the percentage change in the market price (factory-door price) of j in r;
pworld(j) is the percentage change in the world price;
ff_pm(j,r) is the gap between the world price and the regional price;
ShOutput(j,r) is r's share in world output of j; and
ff_pworld(j) is a shift variable.

In the standard long-run closure, ff_pm(j,r) is endogenous and ff_pworld(j) is exogenous on zero. With this setup, movements in the world price of j are determined as a weighted average of the movements in regional prices which are determined by costs in each region.

For oil, gas and coal (commodities in Set3 in panel 13, Table 2.1), we assumed in the historical simulation that world price movements apply to the prices in all regions. We did this by exogenizing ff_pm(j,r) on zero shock for $j \in$Set3 and for all r. With all the regional prices moving with the world price, we must endogenize ff_pworld(j) and allow it to return a solution of zero. Regional prices for oil, gas and coal must continue to reflect "costs". To achieve this we allowed artificial taxes to vary endogenously across regions [f_to(j,r), $j \in$Set3]. Results for these artificial taxes can be interpreted as changes in excess profitability.

For the remaining 32 commodities (commodities in Set32), we continued with the standard treatment of (2.22) and (2.23). To accommodate world price movements, we endogenized technical change variables that affect the use of all inputs in the relevant 32 industries in all regions [afsecall(j), $j \in$Set32]. For these commodities, market prices can vary across regions reflecting differences in costs.

Panel 14: margin services in facilitating international trade. In the GTAP model, each region supplies margin services to a global agent. These are the three commodities in the set MARG. They are water transport (wtp), air transport (atp) and other transport (otp). For each of these three commodities, the global agent forms a composite by mixing the varieties supplied by the regions according to a standard CES cost-minimizing problem. The global agent then sells the composites to traders to facilitate international trade.

Using GTAP data for 2004 and 2014, we calculated the percentage movement in the value of each margin sale to the global agent from each region [v_vst_obs(m,r), m∈Marg]. To accommodate these movements we endogenized twist variables [twqst(m,r), m∈Marg] that move the global agent's preferences between alternative sources of supply. These preference twists are relative: towards some regions and away from others. Consequently, for each m, it was necessary to exogenize the average twist [twqst_ave(m)]. We set these averages at zero.

With total purchases of each margin m by the global agent now tied down, we needed to introduce flexibility in the demands for the composite margin services sold by the global agent to international traders. We did this by endogenizing margin-saving technology variables, atm(m), m∈Marg. If atm(m) is 10, then this means that the use of margin m per unit (quantity) of all international trade flows is reduced by 10 per cent.

Panel 15: regional price indexes for investment. In panel 10, we introduced data on values of investment expenditures by commodity. We accommodated these data by endogenizing input-saving technical changes in the capital goods (CGDS) industry in each region. We assumed that these technical changes were cost neutral, that is, we assumed no productivity growth in capital creation. Now we introduce OECD data on percentage movements in the investment price index for each region. With these data, we were able to drop the assumption of cost-neutrality and endogenize productivity in regional capital creation.

The OECD also provides price indexes for private consumption, government consumption, exports and imports. Unlike investment, we did not find a way to introduce these other macro price indexes directly into the historical simulation. The problem is that commodities for private consumption, government consumption, exports and imports are not produced by a single industry in each region. We checked the performance of the historical simulation in reproducing movements in these other macro price indexes. As indicated in the next section, this performance can be assessed as good but far from perfect.

Panel 16: skilled and unskilled employment in India and China. ILO data for India and Census data for China show that between 2004 and 2014, the ratio of skilled to unskilled employment for these two countries increased by 54 and 93 per cent, where the definitions of skilled and unskilled are based on high-school completion. We introduced these data by endogenizing shifts in the supply functions for skilled and unskilled labour. This caused the historical simulation to generate lower wage increases for skilled workers relative to unskilled workers in these two countries and improved the performance of the historical simulation in reproducing the OECD data on the movements of price indexes for government consumption.

3. Results for industry technologies and expenditure-side price deflators for GDP

For each industry j in region r, the historical simulation generates percentage changes between 2004 and 2014 in: intermediate-input-saving technical change for inputs of each domestic and imported commodity; and primary-factor-saving technical change for inputs of each primary factor (endowment). We combine these into estimates for industry j,r of all input-saving technical change. The results are shown in Table 3.1. For example, the first entry means that for paddy rice (pdr) in the U.S., there was an overall deterioration in total input productivity: output per unit of input was 8.74 per cent lower in 2014 than in 2004.

Average world productivity by industry and average regional productivity

With 58 industries (includes capital creation) and 13 regions, Table 3.1 shows 754 total productivity estimates. In describing these estimates, we give most attention to row and column averages.

We start with the row averages, column 14, which show world-wide total productivity growth for each industry. At the broad sectoral level, we see rapid productivity growth in agriculture forestry and fishing (techwldsec, 16.63 per cent, column 15), rapid productivity decline in mining (-11.28 per cent), almost no change in manufacturing (0.36 per cent) and solid productivity growth in services (5.66 per cent).

Within each of these broad sectors, there is considerable variation (col 14). Other crops (ocr, industry 8, see appendix), and other animal products (oap, ind 10) were the best performers in the agriculture, forestry and fishing sector. At the other extreme, fishing (fsh, ind 14) suffered world-wide productivity decline.

All of the mining industries showed world-wide productivity decline over the period 2004 to 2014. This is consistent with the movement for this period in the mining productivity index published by McKinsey and co. (2020). It may reflect exhaustion of the most productive mining resources and the gradual adoption of less environmentally damaging practices.

In the manufacturing sector, there are 12 industries for which average productivity growth was positive and 12 for which it was negative. Most of the food manufacturing industries (industries 19 to 26) had negative productivity growth, contrasting with food-farming activities in which productivity growth was overwhelmingly positive. Among the remaining manufacturing industries, lumber (lum, ind 30) had the strongest productivity growth while non-ferrous metal products (nfm, ind 36) had the most rapid productively decline.

Among the service industries, air transport (atp, ind 50) achieved spectacular productivity growth. Water transport (wtp, ind 49) also had strong productivity growth. Electricity (ely, ind 43) and dwellings (dwe, ind 57) had small productivity declines. For electricity, an explaining factor might be environmental considerations leading to reduction in the use of cheap fossil-fuel generation methods. Dwellings is an artificial industry responsible for producing the services of the housing stock. Measured productivity changes in this industry probably have more to do with fluctuations in housing rental markets than with genuine changes in outputs per unit of input. Similarly, capital goods (CGDS, ind 58) is an artificial industry. Our historical simulation suggests that there was almost no world-wide change in the efficiency with which economies were able to combine inputs of construction, machinery, finance and other goods and services to create units of capital. Productivity improvements in capital creation were carried by the input-producing industries such as construction (cns, ind 46) which had strong productivity growth.

Table 3.1. All-input productivity: per cent change from 2004 to 2014 [tech(j,r)]

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	GTAP industries (see appendix)	**USA**	**Canada**	**Mexico**	**China**	**Japan**	**SKorea**	**India**	**France**	**Germany**	**UK**	**RoEU**	**Saudi Arabia**	**RoW**	**techwld**	**techwldsec**
1	**pdr**	-8.74	-3.22	13.48	26.45	31.37	65.86	36.49	-15.99	26.24	27.43	-15.36	-38.34	15.82	**23.99**	16.63
2	**wht**	-15.87	-3.95	-6.54	-4.85	1.85	14.82	-0.61	-16.89	-9.62	-24.09	-0.94	-12.23	14.52	**0.79**	16.63
3	**gro**	-30.68	-25.29	-20.68	-16.11	-9.56	4.13	-7.77	-17.69	-27.34	-7.91	9.16	-21.31	4.31	**-9.45**	16.63
4	**v_f**	4.69	15.74	3.50	23.74	28.25	55.32	34.21	-3.01	10.99	-0.97	3.42	6.72	28.11	**23.98**	16.63
5	**osd**	-3.02	18.85	-11.63	22.74	23.01	31.00	29.75	7.05	-5.87	-0.91	12.26	-35.28	25.21	**18.33**	16.63
6	**c_b**	19.41	19.45	7.72	18.04	24.79	-1.18	27.49	19.46	19.79	23.85	15.83	-17.47	9.33	**15.69**	16.63
7	**pfb**	-32.17	-16.95	-20.76	-15.52	-13.48	-23.78	43.38	5.39	-31.91	-37.77	-25.41	-48.48	-8.73	**-7.84**	16.63
8	**ocr**	19.02	31.21	15.17	177.12	57.88	100.63	63.31	48.56	18.78	14.16	22.63	31.76	68.53	**49.14**	16.63
9	**ctl**	6.87	8.55	-19.89	11.92	17.65	11.34	19.68	7.14	-9.79	-11.80	1.41	-13.05	8.44	**8.08**	16.63
10	**oap**	2.37	16.68	32.66	38.76	52.94	33.60	52.67	27.23	33.47	14.75	44.04	27.52	37.01	**35.18**	16.63
11	**rmk**	13.16	17.09	18.15	24.23	32.64	18.07	40.74	29.72	37.80	39.52	27.20	12.10	18.16	**25.69**	16.63
12	**wol**	-33.10	-20.63	19.91	22.39	31.83	36.93	21.43	-25.51	-21.81	-26.32	-19.56	-7.00	-10.13	**-0.90**	16.63
13	**frs**	-7.01	6.34	-0.82	4.92	12.29	32.20	16.31	-4.42	-14.63	-7.06	-4.67	-23.44	-1.51	**-0.03**	16.63
14	**fsh**	-18.32	-21.28	1.74	-12.47	-6.30	-9.74	-6.40	-36.93	-23.09	-18.58	-19.42	-19.20	-12.84	**-12.04**	16.63
15	**coa**	52.47	7.67	-4.43	-46.98	8.04	27.78	6.62	-0.56	7.74	8.86	-30.49	-12.18	0.72	**-19.72**	-11.28
16	**oil**	3.93	59.31	-43.61	-11.87	8.10	-6.84	3.21	-14.43	9.71	-19.38	-24.40	-8.64	-9.83	**-8.43**	-11.28
17	**gas**	-23.91	-17.79	-5.25	-54.16	9.52	-5.55	6.09	29.47	11.11	-5.01	20.61	-14.27	-1.34	**-5.82**	-11.28
18	**omn**	-15.97	1.21	-7.38	-19.54	-14.57	3.42	-48.57	-34.80	-23.74	-69.38	-30.51	-29.91	-7.80	**-15.65**	-11.28
19	**cmt**	-14.67	-16.76	-16.29	-22.40	-13.72	-10.62	-14.08	-39.83	-32.86	-24.27	-27.13	-19.26	-1.57	**-13.69**	0.36
20	**omt**	-7.38	12.58	-17.98	35.55	-20.87	-13.19	-38.18	-38.74	-31.81	-24.13	-30.53	-10.15	-4.34	**-12.91**	0.36
21	**vol**	-14.86	-29.57	-11.53	-12.06	-13.38	-48.81	-13.54	-43.65	-30.15	-30.51	-19.24	-12.51	-6.82	**-12.83**	0.36
22	**mil**	-13.53	-13.02	-16.96	-13.13	-13.76	-12.36	-16.72	-23.21	-19.75	-27.55	-18.70	-17.63	0.47	**-12.15**	0.36
23	**pcr**	-22.41	-4.37	4.45	6.37	-7.35	-14.59	16.10	-33.18	-5.90	-9.22	-15.13	-31.36	-1.97	**2.16**	0.36
24	**sgr**	-16.20	-17.36	-18.58	35.10	-12.65	-33.45	-24.73	-44.96	-29.72	-33.06	-23.78	-37.33	-20.12	**-20.48**	0.36
25	**ofd**	-12.10	-6.18	-6.87	45.38	6.46	-9.96	13.20	-18.49	-7.74	-11.22	-10.11	-11.12	5.66	**-0.07**	0.36
26	**b_t**	-1.83	-19.46	3.44	-11.33	6.53	5.30	4.79	-9.60	0.85	-11.28	-0.33	-1.46	15.10	**1.97**	0.36
27	**tex**	-9.66	-2.23	-8.58	27.87	-21.60	-2.50	0.56	-15.84	-10.82	-16.49	-10.95	-18.04	2.04	**3.38**	0.36
28	**wap**	4.87	-8.34	-13.07	11.87	11.57	-9.59	-9.82	-14.67	-10.32	-16.19	-14.15	-5.97	2.73	**1.33**	0.36
29	**lea**	-20.53	-5.32	-9.92	14.46	-37.28	-23.24	-13.68	-23.22	-18.02	-20.83	-21.50	-21.52	-3.81	**-5.23**	0.36
30	**lum**	6.12	-0.49	-13.44	37.04	11.20	13.19	-6.95	-7.51	-1.43	-1.98	-4.46	-6.48	12.31	**8.05**	0.36

Table 3.1 continues …

… Table 3.1 continued

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	GTAP industries (see appendix)	**USA**	**Canada**	**Mexico**	**China**	**Japan**	**SKorea**	**India**	**France**	**Germany**	**UK**	**RoEU**	**Saudi Arabia**	**RoW**	**techwld**	**techwldsec**
31	**ppp**	-8.30	-2.53	3.85	40.71	-3.53	-0.57	-6.99	-13.47	-10.62	-15.24	-9.22	11.62	6.51	**-2.14**	0.36
32	**p_c**	1.07	-0.79	-3.36	27.79	2.20	-9.88	13.03	-11.59	-13.86	-18.88	-7.30	-24.58	2.97	**1.34**	0.36
33	**crp**	-4.75	5.28	-1.97	31.95	-15.49	8.65	13.82	-6.19	-1.67	-8.64	-6.51	18.70	12.61	**3.53**	0.36
34	**nmm**	-15.07	-13.21	-12.64	23.92	-33.66	-6.44	-0.27	-20.84	-16.39	-11.25	-12.67	-20.65	-3.33	**-4.81**	0.36
35	**i_s**	-5.54	0.21	-4.79	42.06	-14.75	-2.67	10.88	-9.30	-6.33	8.25	-0.69	-27.19	5.51	**6.46**	0.36
36	**nfm**	-23.72	-31.69	-20.58	14.01	-38.25	-11.46	-16.30	-33.87	-27.72	-7.28	-21.80	-29.78	-13.47	**-14.21**	0.36
37	**fmp**	-5.90	-0.65	-1.56	24.68	-19.12	0.82	20.90	-10.40	-5.75	-9.71	-3.25	-16.45	10.26	**0.68**	0.36
38	**mvh**	6.00	-8.96	8.99	24.98	-7.96	-5.00	24.27	-4.38	0.89	9.08	8.64	-10.62	14.30	**5.03**	0.36
39	**otn**	-1.69	-3.25	-1.61	25.19	-11.76	5.68	21.00	-6.26	-1.36	5.88	0.68	-5.38	16.25	**3.77**	0.36
40	**ele**	-8.34	-4.86	-11.85	16.93	-24.29	-10.61	6.46	-11.48	-10.59	-10.92	-11.21	-14.04	8.79	**-2.61**	0.36
41	**ome**	-7.28	3.80	-1.50	27.73	-17.43	17.67	18.04	-7.05	-5.51	-7.75	-1.68	-10.15	13.67	**2.61**	0.36
42	**omf**	-4.95	-2.22	2.36	23.78	-33.59	-18.30	2.39	-13.57	-10.79	-15.88	-8.45	-8.66	7.07	**-2.70**	0.36
43	**ely**	4.74	2.90	-6.85	-9.67	2.98	14.75	1.02	-12.89	8.98	-3.33	-11.01	-2.54	-2.88	**-1.41**	5.66
44	**gdt**	2.38	-24.42	-15.72	6.04	3.92	-14.79	-5.13	-5.42	7.27	-4.49	-23.64	-6.04	16.14	**3.58**	5.66
45	**wtr**	3.16	2.55	-8.86	-6.51	7.67	19.25	4.39	2.77	12.42	12.64	1.79	-16.48	-5.70	**1.63**	5.66
46	**cns**	14.23	14.45	5.91	4.09	19.92	21.93	18.67	15.24	18.26	18.36	11.19	0.66	6.28	**12.46**	5.66
47	**trd**	4.73	5.57	-4.08	-5.08	9.53	15.87	4.72	5.87	9.48	10.04	2.04	-9.26	10.65	**6.69**	5.66
48	**otp**	4.31	5.61	-18.49	34.21	7.02	20.59	5.85	3.28	8.16	9.91	-4.18	25.40	14.84	**8.01**	5.66
49	**wtp**	12.75	29.88	8.50	34.79	-5.67	36.30	50.60	28.57	24.27	9.63	31.38	-12.74	42.05	**27.43**	5.66
50	**atp**	55.53	52.26	32.77	81.97	7.81	51.97	103.81	76.54	79.50	58.37	67.06	42.75	69.93	**61.75**	5.66
51	**cmn**	2.64	3.80	-3.94	-13.02	6.62	16.22	17.72	4.51	6.68	-5.02	-3.26	-14.09	19.16	**5.61**	5.66
52	**ofi**	5.47	3.98	-3.82	-12.57	7.51	29.35	3.36	4.70	7.96	-8.97	-6.23	-21.98	-5.33	**1.98**	5.66
53	**isr**	4.02	-6.91	-10.15	-12.01	10.24	25.85	5.68	-9.11	-5.26	-8.20	-2.03	-16.66	21.46	**4.13**	5.66
54	**obs**	5.50	4.15	-4.01	-5.61	6.47	17.77	31.43	5.93	-0.36	-6.81	-1.64	-6.94	24.26	**5.53**	5.66
55	**ros**	2.20	5.35	-4.01	-2.23	9.33	-18.19	4.07	0.39	10.83	-10.05	-2.08	0.64	21.16	**4.49**	5.66
56	**osg**	5.76	7.27	-5.76	1.64	11.50	28.69	20.86	9.81	12.47	10.63	4.74	-5.42	-1.67	**6.89**	5.66
57	**dwe**	2.35	0.57	-4.05	-15.64	9.52	24.89	-0.60	6.45	13.42	14.57	-0.78	-19.53	-11.33	**2.15**	5.66
58	**CGDS**	10.61	-5.89	5.93	8.37	5.80	-9.62	24.86	-8.21	0.75	11.19	-1.40	-4.78	-11.82	**-0.31**	5.66
59	**tech_ave**	**3.67**	**2.14**	**-3.76**	**11.92**	**1.75**	**6.49**	**13.20**	**0.66**	**2.68**	**2.07**	**-0.94**	**-8.30**	**4.90**		
60	**tech_cont**	**7.27**	**4.23**	**-6.69**	**42.20**	**3.82**	**17.85**	**32.52**	**1.31**	**5.70**	**4.09**	**-2.01**	**-13.73**	**10.52**		
61	**Rtt2tn**	**-7.17**	**-4.15**	**-5.89**	**18.74**	**-15.20**	**-7.14**	**-2.86**	**-7.28**	**-11.01**	**-13.21**	**-5.48**	**-6.09**	**9.57**		
62	**rel_pgdp**	-11.03	6.74	2.04	47.88	-30.91	-8.88	2.87	-11.59	-11.07	-15.42	-5.08	43.12	31.57		

We turn now to the column averages. Averaging across the industries of each region using output weights gives India the highest all-input productivity growth (13.20 per cent, see India entry for tech_ave, row 59, Table 3.1). This is just ahead of China (11.92 per cent). South Korea also has a high average productivity growth rate across industries (6.49 per cent). At the other extreme, industries in Saudi Arabia had an average productivity decline of 8.30 per cent. Productivity declines occurred not just in the Saudi oil industry, but in the majority of other industries.

Row 60 (tech_cont) translates tech_ave in the previous row into contributions to GDP. The variable tech_cont(r) can be thought of as the percentage increase in A(r) in the aggregate production function stylized in equation (2.1). The tech_cont entries for most regions are approximately twice as large as the corresponding entries for tech_ave. This is because GDP is approximately the sum of primary factor inputs and, on average, primary factor inputs in an industry are about half the value of output in the industry.

China's economy is more "roundabout" than India's (a higher ratio of intermediate inputs to GDP). This explains how the contribution to GDP of technical change was higher in China than India (42.20 per cent compared with 32.52 per cent) despite technical change averaged across industries being lower in China than in India.

Balassa-Samuelson effect

The foot of Table 3.1 contains two further rows. Row 61, marked Rtt2tn, shows the percentage change between 2004 and 2014 for each region in the ratio of productivity in traded goods industries to non-traded goods industries.[8] [9] Row 62, marked rel_pgdp, shows the percentage change in the ratio of a region's price deflator for GDP to the world price deflator. Although the entries in the rel_pgdp row are simulation results, they can be accepted as *actual* movements. As we will see in the discussion of Table 3.2, the simulation results for the GDP price deflators are close to the movements implied by OECD data. With all prices calculated in a common currency, rel_pgdp can be interpreted as the movement in r's real exchange rate.

The reason for computing Rtt2tn and rel_pgdp is to check the extent to which our productivity results conform to the Balassa-Samuelson hypothesis[10]. According to this hypothesis, an increase in the productivity of a country's traded industries relative to that of its non-traded industries strengthens its real exchange rate. The Balassa-Samuelson mechanism relies on the idea that, in a common currency, traded-goods prices are equalized across the world. Consequently, differences between countries in movements in their GDP price deflators reflect differences in movements in the prices of their non-traded goods. In countries where traded good productivity increases strongly relative to non-traded

---

[8] This was calculated for region r according to the formula:

$$\mathrm{Rtt2tn}(r) = 100 * \left\{ \left[\sum_{j \in T} (1 + \mathrm{tech}(j,r)/100) * \mathrm{SHT}(j,r) \right] \Big/ \left[\sum_{j \in NT} (1 + \mathrm{tech}(j,r)/100) * \mathrm{SHNT}(j,r) \right] - 1 \right\}$$ where: tech(j,r) is the percentage productivity change in Table 3.1 for industry j in region r; for j in the traded sector ($j \in T$), SHT(j,r) is j's share in the total output of traded goods in r; and for j in the non-traded sector ($j \in NT$), SHNT(j,r) is j's share in the total output of non-traded goods in r.

[9] With a few exceptions, we defined traded goods as those for which world exports in 2004 were more than 5 per cent of world output. The exceptions are commodities such as Cane & beet that are heavily traded in particular parts of the world but fail the 5 per cent rule at the world level.

[10] Balassa (1964) and Samuelson (1964).

productivity, non-traded goods become expensive relative to traded goods. Thus, these countries experience increases in their GDP price deflators relative to other countries, that is, they experience real appreciation.

As can be seen from Figures 3.1a & b, the Balassa-Samuelson hypothesis is supported by the results for 12 out of 13 regions. The outlier in Figure 3.1a is Saudi Arabia which had a large real appreciation but negative productivity growth in traded-goods industries relative to non-traded. Rather than a Balassa-Samuelson effect, real exchange rate appreciation for Saudi Arabia is explained by a massive increase between 2004 and 2014 in the prices of its principal exports, oil and gas. Then we move from Figure 3.1a to Figure 3.1b by omitting Saudi Arabia, the R^2 on the Balassa-Samuelson explanation of real appreciation improves from 0.6618 to 0.9563.

Is the support for the Balassa-Samuelson explanation of movements in real exchange rates purely data-driven or is it helped along by assumptions introduced in the historical simulation? In panel 12 (explained in section 2), we shared the burden of explaining movements in export values between preference shifts by importers and technology changes by exporters. It turns out that without this sharing mechanism, the Balassa-Samuelson explanation disappears. This is demonstrated in Figure 3.1c which relates real exchange rate movements (rel_pgdp) to movements in traded/non-traded productivity (Rtt2nt) in a simulation in which preference movements alone are used to accommodate export movements. This simulation is similar to 12*Initial* mentioned in the discussion of panel 12.

Beyond the common-sense justification given in panel 12, is there any objective evidence for our preference/productivity sharing mechanism? As mentioned there, and demonstrated later in this section (see Table 3.3), we can refer to the improved performance of the historical simulation in reproducing terms-of-trade movements.

Productivity by industry and region

At first glance, the 754 (= 13*58) numbers in the body of Table 3.1 look rather random. There is considerable variation across most rows and down most columns. For organizing our examination of the table, we derived a formula for our prior expectation [techE(j,r)] of the simulated value of productivity growth in j,r [tech(j,r), from Table 3.1]. Our priors were that the entries in the table were likely to reflect column and row averages and the Balassa-Samuelson effect. Thus, we expected that simulated productivity growth in industry j, region r would be:

- high if region r had high average productivity growth across its industries (a high entry in the tech_ave row), and the reverse to be true if region r had low productivity growth;
- high if industry j had high average productivity growth across the world (a high entry in the techwld column), and the reverse if j had low productivity growth; and
- high if r experienced real appreciation and j is traded or if r experienced real devaluation and j is non-traded, and the reverse if either of the opposite conditions apply.

Figure 3.1a. % movements for 13 regions in traded/non-traded productivity and relative GDP price: A Balassa-Samuelson explanation of real exchange rate movements

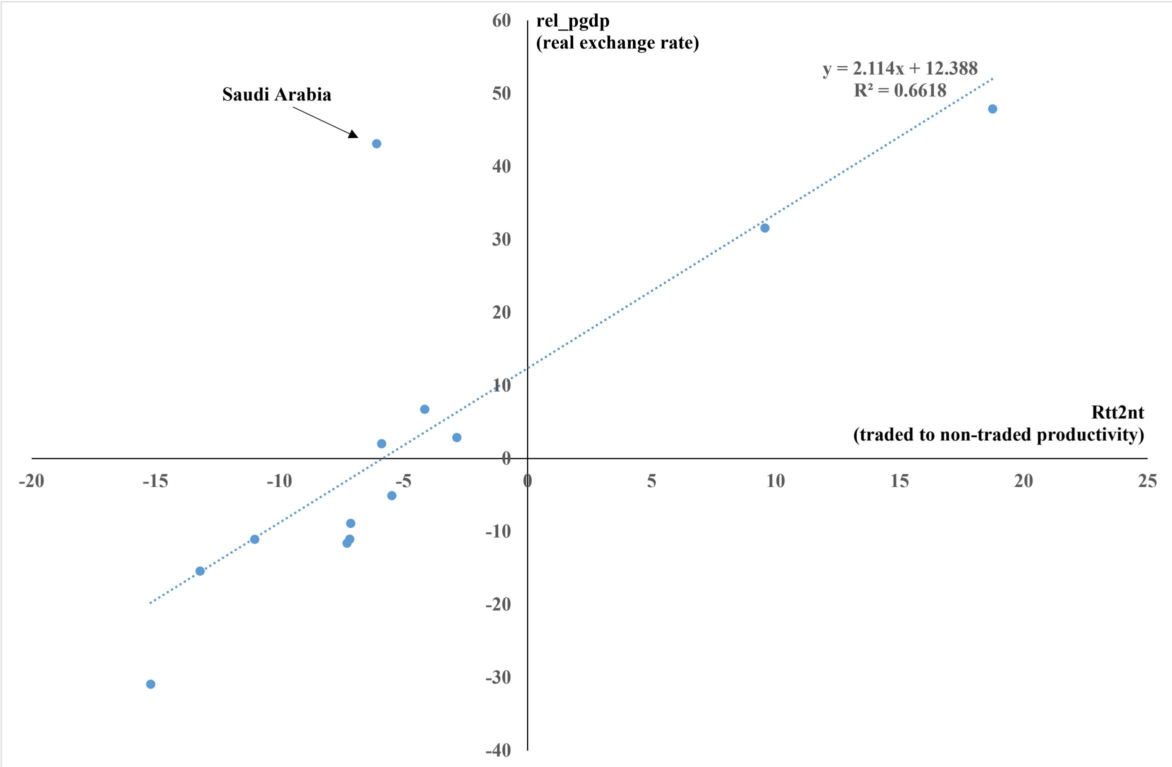


Figure 3.1b. % movements for 12 regions (excludes Saudi Arabia) in traded/non-traded productivity and relative GDP price: A Balassa-Samuelson explanation of real exchange rate movements

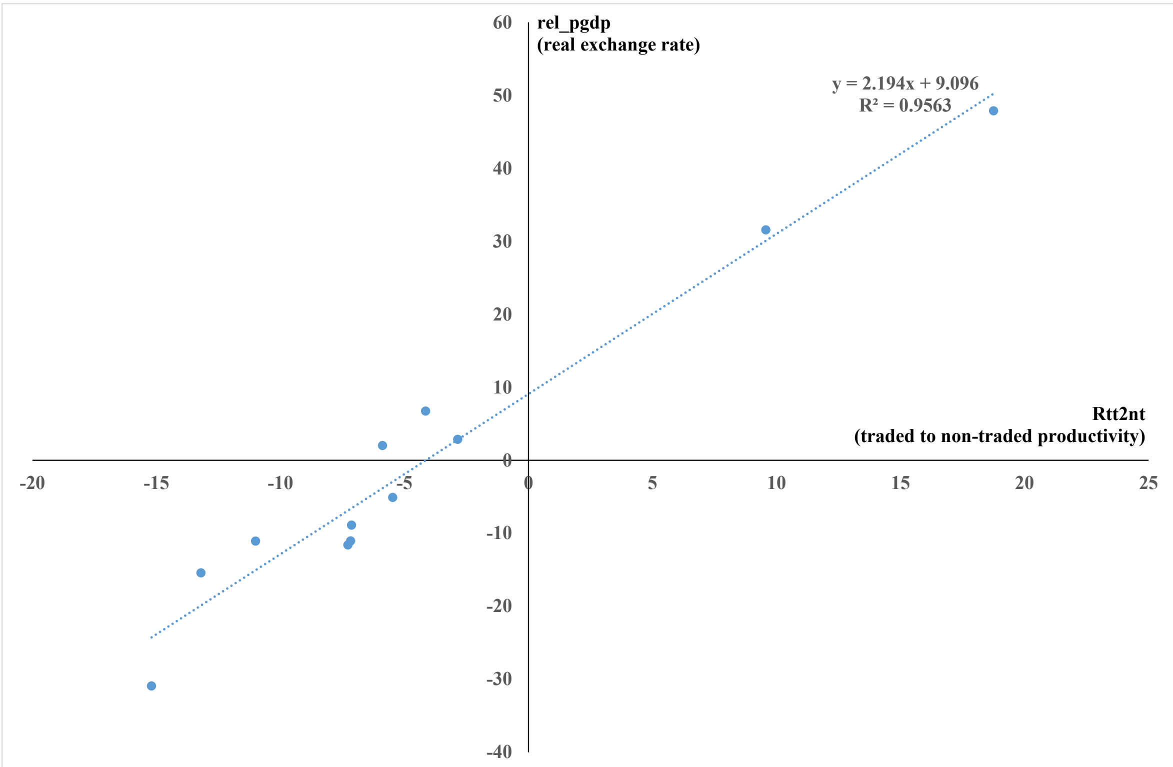
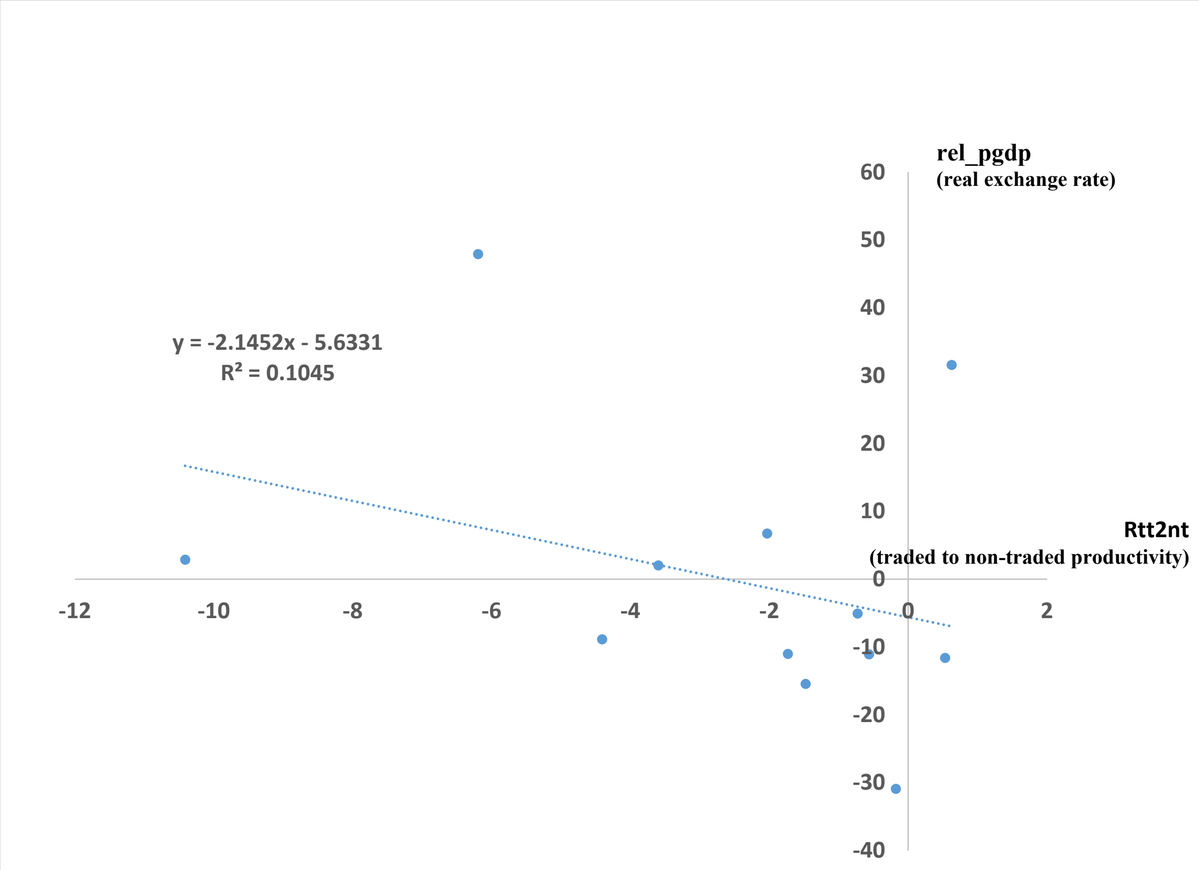


Figure 3.1c. % movements for 12 regions (excludes Saudi Arabia) in traded/non-traded productivity and relative GDP price: a simulation excluding preference/productivity sharing in the explanation of exports



In deriving our formula we used the following equations:

$$\text{techE}(j,r) = \text{techwld}(j) + \text{DT}(j) * \left(\text{tt}(r) - \text{ttw}\right) + \text{DN}(j) * \left(\text{tn}(r) - \text{tnw}\right) \quad (3.1)$$

$$\text{tech\_ave}(r) = \text{St}(r) * \text{tt}(r) + \text{Sn}(r) * \text{tn}(r) \quad (3.2)$$

$$\text{Rtt2tn}(r) = \text{tt}(r) - \text{tn}(r) \quad (3.3)$$

$$\text{rel\_pgdp}(r) = \beta_0 + \beta_1 * \text{Rtt2tn}(r) \quad (3.4)$$

Equation (3.1) sets out the percentage productivity change in j,r [techE(j,r] that we expect on the basis of prior reasoning. This expectation is determined by the world-wide percentage productivity growth in industry j [techwld(j), column 14 in Table 3.1] and to two additional terms that take account of regions r's productivity growth in traded-goods industries [tt(r)] and non-traded-goods industries [tn(r)]. The two additions are in relative terms, they express traded or non-traded productivity in a region relative to world productivity for traded or non-traded industries [ttw and tnw]. DT(j) is one if j is a traded industry and zero otherwise, and DN(j) is one if j is a non-traded industry and zero otherwise. These dummy variables ensure that techE(j,r) is related to relative productivity in traded-goods industries if j is traded and to relative productivity in non-traded-goods industries if j is non-traded.

Equation (3.2) defines the productivity change in region r [tech_ave(r), row 59] as a share-weighted average of the percentage changes in productivity in r's traded and non-traded industries. The weights [St(r) and Sn(r)] are the shares of traded and non-traded industries in the total over all industries of output values in r.

Equation (3.3) defines the percentage change in the productivity of traded-goods industries relative to non-traded. This is the variable Rtt2tn shown in row 61 of Table 3.1.

Equation (3.4) introduces the Balassa-Samuelson effect. In this equation, β_0 and β_1 are the coefficients (9.096 and 2.194) shown in Figure 3.1b.

We arrived at a formula for techE(j,r) by eliminating Rtt2tn(r), tt(r) and tn(r) from (3.1) to (3.4), obtaining:

$$\begin{aligned} \mathrm{techE}(j,r) &= \mathrm{tech\_ave}(r) + \left[\mathrm{techwld}(j) - \mathrm{DT}(j) * \mathrm{ttw} - \mathrm{DN}(j) * \mathrm{tnw}\right] \\ &\quad + \left[\mathrm{DT}(j) * \mathrm{Sn}(r) - \mathrm{DN}(r) * \mathrm{St}(r)\right] * \left(-\beta_0/\beta_1 + 1/\beta_1 * \mathrm{rel\_pgdp}(r)\right) \end{aligned} \tag{3.5}$$

All the terms on the RHS of (3.5) can be evaluated from: the historical simulation which gives values for tech_ave(r), techwld(j), ttw, tnw and rel_pgdp(r); the GTAP database for 2004, from which we can evaluate Sn(r) and St(r); and the regression in Figure 3.1b which gives β_0 and β_1.

To check how well our priors explain what is going on in Table 3.1, we regressed the tech(j,r)s from the table against the techE(j,r)s calculated on the RHS of (3.5), and estimated the coefficient α in the equation:

$$w(j,r) * \mathrm{tech}(j,r) = \alpha * w(j,r) * \mathrm{techE}(j,r) + \mathrm{error}(j,r) \tag{3.6}$$

The w's are a weighting scheme. We suspect that the GTAP data are more reliable for industry j in region r if j is a major industry in r than if j is a very small part of r's economic activity. Consequently, we set the w's according to

$$w(j,r) = \frac{\mathrm{VOA}(j,r)/\mathrm{VOA}(*,r)}{\sum_s \mathrm{VOA}(j,s)/\mathrm{VOA}(*,s)} \tag{3.7}$$

where

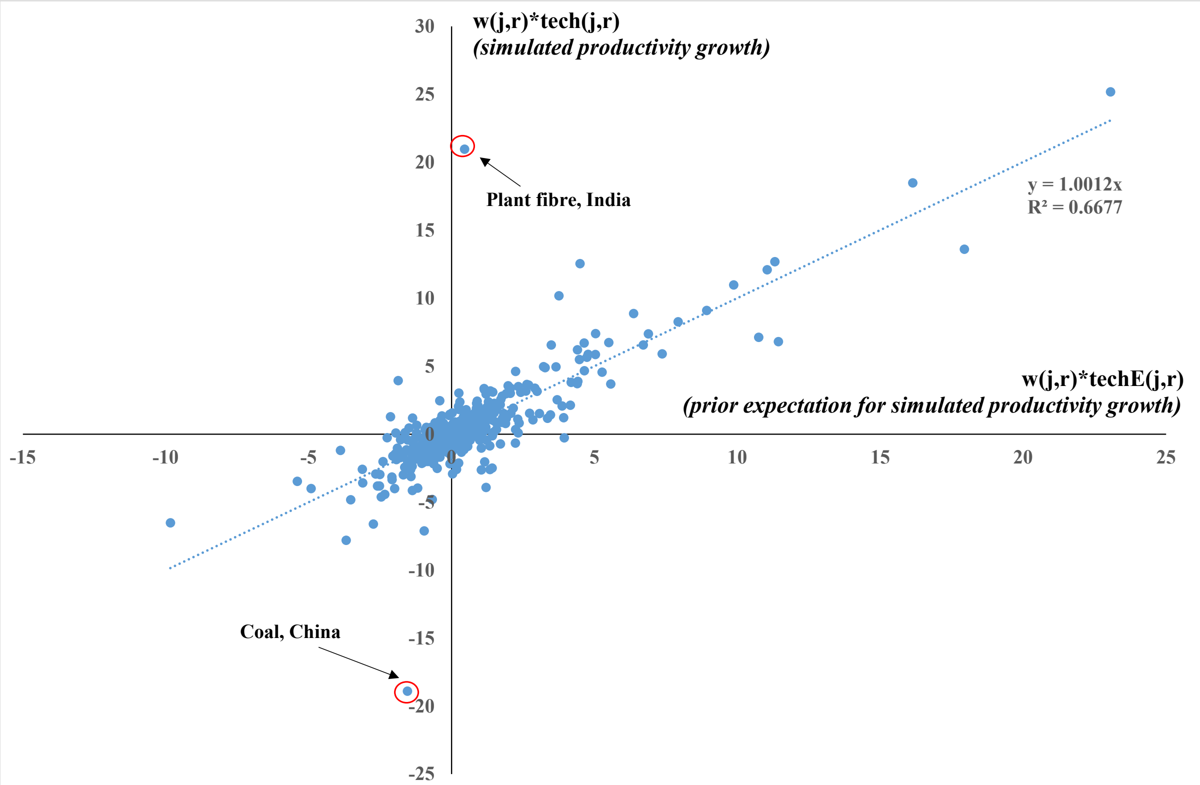
VOA(j,r) is the value in 2004 of the output of industry j in region r; and

VOA(*,r) is the total value, summed across all industries, of output in r.

The numerator in (3.7) is the share of industry j in r's total output. The denominator is a normalizing factor ensuring that the weights for each commodity sum across regions to one. Our weighting scheme avoids domination in the regression of either big industries or big regions.

The result for the regression, shown in Figure 3.2, broadly supports our priors about the determination of the tech(j,r)s. The coefficient on techE(j,r) is close to its expected value of one and the regression explains about 67 per cent of the variance across the tech(j,r)s. However, the regression shows that our estimation of the tech(j,r)s is picking up factors not included in (3.5). Working through outliers in Figure 3.2 is helpful in identifying these factors, assessing the plausibility of the results and locating problems. We present a couple of examples.

Figure 3.2. Simulation results for productivity by industry and region compared with expected results



The j,r industry with the largest positive percentage gap between its weighted simulated productivity change and the weighted expected value is (Plant fibre, India). The expected value is close to zero. India has a high column average in Table 3.1 [13.20 for tech_ave in row 59], but in the calculation of TechE(pfb, India) this is largely offset by the pfb row average [-7.84 per cent for techwld, row 7, col 14]. Plant fibre is a traded good but the Balassa-Samuelson effect is negligible for India but small because India's real appreciation was small [2.87 per cent, row 62]. While our expectation for TechE(pbf, India) was close to zero, the simulated outcome in Table 3.1 was 43.38 per cent [a little over 20 per cent when multiplied by the weighting factor]. Why is the simulated value so high and is this plausible?

Between 2004 and 2014, India's exports of pfb grew dramatically. In value terms, growth was 934 per cent. This can be compared with growth in the value of world pfb exports of 64 per cent. Exports as a share of India's pfb output grew from 7 per cent to 23 per cent, and India's share in world exports of pfb grew from 2.7 per cent to 17.5 per cent. This impressive export performance took place despite rapid increases in the cost of labour inputs to the pfb industry. With strong export growth despite labour cost increases, it is reasonable to suppose that the industry was benefiting from significant cost-reducing technical change. As explained in the discussion of panel 12 of Table 2.1, our historical simulation invokes rapid technical improvement in industry j,r when the industry's exports grow rapidly relative to the exports of j from other countries.

The j,r industry with the largest negative percentage gap between its weighted simulated productivity change and the weighted expected value is (Coal, China). The story here is similar to that for pfb in India but with the opposite sign. Between 2004 and 2014, the value of Chinese coal exports declined by 76 per cent while world exports increased by 90%.

Examining the China coal result focused our attention on the result for world productivity in coal (-19.72 per cent, row 15, col 14 in Table 3.1). Coal was one of the few commodities for which we thought it was necessary to adjust the GTAP data. Data from the U.S. Energy Information Administration and Our World in Data suggest that the average world price for coal increased by about 32 per cent and world output increased by 34 per cent giving an increase in the value of world output of about 76 per cent. The GTAP data for 2004 and 2014 imply a value increase of 255 per cent. Before implementing our historical simulation, we revised down the GTAP 2014 value data on world coal output to imply 76 per cent growth. We made corresponding revisions to coal sales. However, we did not make an adjustment to inputs to the coal industries in each region. Thus, our current historical simulation exaggerates inputs per unit of output in coal and exaggerates technological deterioration in coal industries. This will need revision in future research.

Price deflators for expenditure-side aggregates in GDP

The final set of results that we will look at in this paper are those in Table 3.2 and the associated charts. These compare simulation results in columns marked "sim" with observations from OECD data in columns marked "obs".

For the investment price deflator the fit is perfect. Recall from the discussion of panel 15 in Table 2.1 that the investment price deflators were imposed.

For the GDP price deflators, the gaps between the simulation results and the observations are very small. This is not surprising. The GTAP data for each region are highly consistent with OECD data for nominal GDP. We have imposed OECD data for movements in real GDP. Thus, it was to be expected that the historical simulation would generate OECD-compatible movements in the price deflators for GDP.

The historical simulation reproduces the observed movements in the price deflators for private and government consumption with reasonable accuracy. The only major discrepancies are for China. The simulated movement for private consumption in China is well above the observed OECD number (121.9 per cent compared with 79.5 per cent), while the simulated movement for government consumption is well below the observed OECD number (163.6 per cent compared with 324.9 per cent). We suspect that the historical simulation is underestimating the percentage increase in wages for skilled workers in China relative to wages for unskilled workers. As discussed in relation to panel 16 in Table 2.1, we included in the historical simulation a strong increase in the supply of skilled workers in China relative to unskilled. But it now appears that we may have underestimated the substitution elasticity between skilled and unskilled and consequently overestimated the reduction in the skilled-to-unskilled wage ratio. Further research will be required to resolve this issue.

With one exception, the simulated percentage increases in the price deflators for exports and imports by region exceed the observations from the OECD data. The exception is the price of imports for RoW. The systematic over-estimation in the historical simulation of movements in trade prices is evidence in favor of new trade theories. These theories, notably Melitz (2003), emphasize the idea that exported varieties of a country's manufactured products are produced predominantly by the country's highest productivity firms. On average, the exported varieties from these high productivity firms are cheaper than the

Table 3.2. % change in price deflators: 2004 to 2014

	GDP		Priv cons		Govt cons		Invest		Exports		Imports	
	obs	sim	obs	sim	obs	sim	obs	sim	obs	sim	obs	sim
USA	22.2	20.4	21.8	25.2	34.5	22.9	16.2	16.2	21.9	44.6	23.8	58.6
Canada	45.9	44.5	35.4	39.9	55.8	37.9	47.0	47.0	37.7	60.8	26.7	47.9
Mexico	35.4	38.1	37.5	40.2	53.6	47.9	26.3	26.3	32.1	51.3	36.8	51.1
China	94.0	100.1	79.5	121.9	324.9	163.6	72.8	72.8	29.1	55.3	34.7	62.2
Japan	-5.1	-6.5	-1.2	-5.2	0.0	-10.8	2.0	2.0	-0.6	40.1	37.7	65.4
SKorea	28.2	23.3	35.7	25.3	37.7	23.9	37.4	37.4	14.2	47.5	30.6	67.1
India	35.5	39.2	38.5	54.2	50.9	54.1	24.3	24.3	31.8	50.1	31.3	78.8
France	22.2	19.7	20.9	24.3	21.9	12.3	28.0	28.0	18.8	41.8	20.6	52.1
Germany	20.8	20.4	21.9	25.0	21.5	14.5	24.6	24.6	14.7	39.6	18.1	51.0
UK	10.6	14.5	11.8	21.9	11.4	9.0	5.4	5.4	17.7	45.3	16.7	48.9
RoEU	28.8	28.5	30.6	34.1	32.0	27.9	27.7	27.7	25.8	45.2	29.4	53.4
SaudiAr	95.8	93.6	41.5	56.6	68.4	49.6	47.4	47.4	138.6	141.7	38.5	48.1
RoW	78.4	78.0	80.2	64.8	69.4	88.1	76.1	76.0	68.5	78.1	64.9	56.6

Price deflators: OECD data observed (blue, left) and simulated (orange, right)

varieties produced by firms focused on the domestic market. In our historical simulation, no distinction is made between exported varieties of a good and varieties of the same good produced domestically for the domestic market. In future research, we plan to introduce this distinction in an historical simulation that imposes the observed price deflators for exports and endogenizes export/domestic price differences. We expect that if we hit targets for export price deflators then we will also hit targets for import prices.

While our current historical simulation considerably overestimates trade prices, it gives a reasonable representation of terms-of-trade movements. This can be seen by comparing columns (1) and (2) in Table 3.3. Comparison across all three columns substantiates the claim made earlier in this section that the preference-productivity sharing mechanism used in accommodating export movements improves the performance of the historical simulation in reproducing terms-of-trade movements. Whereas the average absolute difference between the simulated terms-of-trade movements in column (2) and the data in column (1) is 5.98 percentage points, the average absolute difference between the movements in column (3) computed without the sharing mechanism and the data in column (1) is 10.93. In future research, we expect to be able to refine the sharing mechanism so that the historical simulation reproduces observed terms-of-trade movements.

4. Concluding remarks

The original purpose of historical simulations was to update input-output tables, see Adams *et al.* (1994). The idea was to conduct a simulation which imposed movements in a selection of variables for which there were data covering the period from the year of the latest available input-output table to the current year. For many policy organization commissioning CGE work, it is important that their project is based on up-to-date data. Publication lags mean that the latest input-output table available to CGE modellers is often 5 or more years out of date. By conducting an historical simulation, CGE modellers are able to generate a database that is consistent with macro aggregates for the current year together with important aspects of the industrial structure.

It soon became apparent that there are major by-products from historical simulations. As demonstrated in this paper, historical simulations quantify trends in technologies and preferences. These trends can be used in decomposition simulations and in baseline forecasting.

A decomposition simulation covers the same period as its parent historical simulation and produces the same solution but uses a different closure. In a decomposition simulation, technology and preference trends return to their normal status as exogenous variables. They are shocked with the values they endogenously revealed in the historical simulation. Thus, a decomposition simulation can quantify the contributions of technology and preference trends to the evolution of the economy over the historical period. This is potentially important in policy work. An early example is a report by Australia's Industry Commission (1997) that used a decomposition simulation to show that the then sluggish performance of the Australian motor vehicle industry was caused primarily by preference shifts by consumers away from the domestic product in favour of imports and not by tariff reductions.

Table 3.3. Terms of trade: percentage changes 2004 to 2014

	OECD data (1)	Full historical (2)	Without pref-prod sharing[a] (3)
1 USA	-1.54	-8.90	-16.33
2 Canada	8.68	8.54	8.18
3 Mexico	-3.47	-0.01	3.74
4 China	-4.21	-4.34	29.49
5 Japan	-27.77	-15.43	-38.08
6 SKorea	-12.57	-11.87	-13.15
7 India	0.36	-16.21	-13.50
8 France	-1.50	-6.89	-12.04
9 Germany	-2.92	-7.65	-12.38
10 UK	0.86	-2.59	-9.94
11 RoEU	-2.84	-5.51	-7.02
12 SaudiArabia	72.34	62.90	63.18
13 RoW	2.18	13.56	19.13

[a] This simulation is the same as the final historical simulation except that we eliminated the link between preference shifts towards or away from region r's exports of j and productivity in industry j in region r. In other words, we did not share the burden of explaining exports between preferences and productivity. We relied just on preferences.

In baseline forecasting, technology and preference trends estimated in an historical simulation can be projected into the future. As demonstrated by Dixon and Rimmer (2010) and described in Dixon and Rimmer (2013), incorporating these trends can substantially improve the realism of a baseline. In the next stage of the project described in this paper, we will be undertaking a GTAP baseline simulation for 2014 to 2017 and checking its performance with and without the incorporation of trends from the 2004-to-2014 historical simulation. Then we will incorporate technology and preference trends into a baseline simulation out to 2050. In creating this baseline, we will be drawing on technology and preference trends in which the commodity/industry breakdown goes well beyond the 4-sector disaggregation (agriculture, mining, manufacturing and services) that can be found in previous baselines using global models (e.g. Britz and Roson, 2019).

To our knowledge, this paper reports the first GTAP historical simulation. The results so far are encouraging. The historical simulation generated technology trends for 58 industries (including capital goods) in 13 regions that are interpretable in terms of world-wide productivity by commodity, macro productivity by region, and Balassa-Samuelson effects. That the results are interpretable and seemingly plausible is evidence of the quality of the GTAP databases and their comparability through time.

We are hopeful that further progress can be made rapidly in implementing improvements and extensions. This optimism is based on section 2, which sets out a methodical, step-by-step approach for bringing into a GTAP historical simulation value data from GTAP and quantity data from non-GTAP sources. The key is to establish robust simulated price movements in the early steps by introducing real GDP and its macro supply-side determinants for each region. Then estimates of preferences are revealed as we introduce expenditure components of GDP disaggregated by commodity. In the final steps, an array of real and nominal variables, such as values of intermediate-input flows and quantities of world outputs, are added, where data allows. This gives the estimated technology and preference trends more and more texture.

Improvements and extensions will be suggested as we deepen the analysis of the results. For example, detailed examination of the technology results in section 3 pinpointed a weakness in our handling of revisions to the GTAP data for coal. This clearly won't be the last problem that we locate. Our analysis of the results for price deflators raised an exciting extension possibility. It suggested that the historical simulation will be enhanced by inclusion of an idea from new trade theory, namely that firms producing commodities for exports have higher productivity than those confined to domestic markets.

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Appendix. *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 …

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		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*