

SUPPLEMENTARY MATERIAL:

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

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This supplementary material has three parts. They provide details on: data sources; simulations connecting disjoint years and the homotopy method; and the modeling of investment with forward-looking expectations.

Part 1. Notes on data

Capital stocks

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

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

Column (3) in Table A.1 shows the average annual growth in capital stocks from 2014 to 2019 calculated for all regions except Rest of World (RoW) from the latest Penn data. We use these data to represent average annual changes in capital stocks from start of 2014 to start of 2019. We calculated the Rest of European Union (RoEU) numbers by aggregating over 25 European Union (EU) countries (EU27 less France and Germany). We used percentage changes in *rkna* with *rnna* weights.

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The entry for RoW in column at (3) was derived by extrapolating capital growth in our 2014-17 validation simulation (see Dixon and Rimmer, 2023b).

Table A.1. Average annual percentage growth in capital.

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

Source: Author calculations.

GDP and expenditure components

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

Our interest is mainly in 2014-19. The statistical discrepancies for these two years are generally small except for Mexico. For Mexico, the discrepancy in 2014 is 1.23 per cent of GDP. In 2019, it is 2.84 per cent of GDP. In our simulation for 2014-19, we effectively eliminate statistical discrepancies by allowing the model to calculate GDP by adding up observed expenditure movements.

Table A.2. GDP and expenditure components in \$US billion, current prices.

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

Source: Data extracted on 03 Jul 2023 06:13 UTC (GMT) from OECD.Stat.

Table A.3 shows GDP and its expenditure components in \$US billion at constant 2012 prices, also extracted from OECD stats (<https://stats.oecd.org/>). Again, the data marked 2021 for India are actually for 2020. The statistical discrepancies for 2014 are generally small. However, for India in 2019, the statistical discrepancy is 2.81 per cent of GDP.

Table A.3. GDP and expenditure components in national currencies, 2012 prices.

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

Source: Data extracted on 03 Jul 2023 06:13 UTC (GMT) from OECD.Stat.

Tables A.4 and A.5 show percentage changes calculated from Tables A.2 and A.3. Table A.6 is reproduced from our earlier work. As a check, we compared Table A.6 with the 2004-14 panels in A.4 and A.5. The check revealed that we incorrectly recorded data for real movements for Germany in Table A.6, but this did not affect our historical simulation. The nominal value for government expenditure in China now increases by 479 per cent revised up from 413 per cent in Table A.6. This seems to be a genuine revision. Apart from that, the new numbers for 2004-14 are closely compatible with the old numbers.

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

The RoW numbers in the 2014-19 panel of Table A.5 were derived by extrapolation from our 2014-17 validation simulation.

We impose the numbers in bottom panel of Table A.5 in our 2014-19 simulation.

Table A.4. Percentage changes in \$US values of nominal GDP and its expenditure components: OECD data (from Table A.2).

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

Source: Author calculations.

Table A.5. Percentage changes in \$US values of real GDP and its expenditure components: OECD data (from Table A.3).

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

Source: Author calculations.

Table A.6. Percentage growth from 2004 to 2014, mainly OECD (extracted from baseline paper of August 13, 2020).

%ch Nominals \$US	US	Canada	Mexico	China	Japan	Korea	India	France	Germany	UK	RoEU	Saudi Arabia	RoW
GDP	43.50	75.92	68.05	433.84	0.73	87.14	194.48	34.74	38.19	26.76	37.68	192.32	171.82
C	43.96	79.38	62.01	390.73	5.94	81.12	193.87	35.38	31.49	24.89	37.45	208.58	
G	38.47	83.61	95.53	413.61	12.14	130.01	188.85	41.06	43.85	28.95	44.79	233.26	
I	31.77	104.61	66.42	487.49	-1.06	71.27	185.77	39.79	41.89	22.97	14.59	323.08	
X	101.40	49.57	107.41	315.59	36.21	143.54	274.78	51.02	76.52	52.36	79.39	168.75	
M	60.26	74.73	101.03	306.56	84.03	140.71	284.77	63.09	76.63	44.31	69.77	309.59	
%ch Reals \$US	US	Canada	Mexico	China	Japan	Korea	India	France	Germany	UK	RoEU	Saudi Arabia	RoW
GDP	17.39	20.75	23.28	160.11	6.04	45.63	109.37	10.23	14.44	14.20	7.27	49.11	52.61
C	18.17	32.46	17.82	173.46	7.18	33.47	112.15	11.99	14.44	11.66	5.23	118.10	
G	2.96	17.89	27.34		12.16	66.99	91.47	15.68	7.82	15.80	9.66	97.88	
I	13.42	39.17	31.80		-3.02	24.67	129.95	9.22	18.40	16.67	-10.28	187.00	
X	65.27	8.58	57.03	221.97	36.97	113.30	184.39	27.16	80.97	29.48	42.65	12.63	
M	29.48	37.86	46.92	201.73	33.67	84.33	193.04	35.26	53.92	23.69	31.18	195.83	
%ch \$US prices	US	Canada	Mexico	China	Japan	Korea	India	France	Germany	UK	RoEU	Saudi Arabia	RoW
GDP	22.24	45.69	36.32	105.24	-5.00	28.50	40.65	22.23	20.75	11.00	28.35	96.04	78.11
C	21.82	35.43	37.51	79.46	-1.16	35.70	38.52	20.89	21.95	11.85	30.62	41.49	80.15
G	34.49	55.75	53.56	324.93	-0.02	37.74	50.86	21.94	21.50	11.36	32.04	68.41	69.35
I	16.18	47.02	26.26	72.76	2.03	37.38	24.27	27.98	24.60	5.40	27.72	47.42	76.05
X	21.86	37.74	32.08	29.08	-0.56	14.17	31.78	18.76	14.68	17.67	25.75	138.62	68.54
M	23.77	26.74	36.83	34.74	37.67	30.58	31.30	20.57	18.13	16.67	29.42	38.46	64.94

Source: Author calculations.

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

Tables A.7 to A.10 give data and projections for real and nominal GDP, population and working-age population (WAP). With one exception, the data were extracted from International Monetary Fund (IMF) (downloaded in July 2023 from <https://www.imf.org/en/Publications/WEO/weo-database/2023/April/>) and International Labour Organization (ILO) (ILOs Labour Force Statistics (LFS) “Working-age population by sex and age”, downloaded from <https://ilostat ilo.org/topics/population-and-labour-force/>) sources.

The exception was real GDP growth for RoW for 2014-19. As explained earlier, this is an estimate based on our 2014-17 validation simulation.

The forecast numbers (beyond 2020) for both population and WAP were taken from SSP2 (Shared Socioeconomic Pathway 2 (middle of the road projections) published by the International Institute for Applied System Analysis (IIASA). We use SSP2_v9 downloaded end-May 2023 from <https://iiasa.ac.at/models-tools-data/ssp>).

Table A.7. Real GDP: IMF data and projections up to 2028, then our projections based on productivity and ILO projections of working-age population.

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

Source: Author calculations.

Table A.8. Nominal GDP: IMF data up to 2019, then our real GDP projections combined with IMF price projections up to 2030.

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

Source: Author calculations.

Table A.9. Population: ILO data and SSP2 projections.

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

Source: Author calculations.

Table A.10. Working age population: ILO data and SSP2 projections.

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

Source: Author calculations.

Real GDP and productivity assumptions for 2029-2050

The data up to 2021 for real and nominal GDP are from the IMF and OECD. These are historical data and the same in both sources. Then from 2021 up to 2028 we use IMF forecasts (International Monetary Fund, World Economic Outlook Database, April 2023).

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

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

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

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

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

Table A.11 shows our productivity growth assumptions for 2029-2050.

Table A.11. Average annual productivity growth (% change in real GDP/WAP).

	assumed for 2029-2050
US	1.6849
Canada	1.4459
Mexico	0.9377
China	4.2821
Japan	1.4101
Korea	3.0295
India	4.7648
France	1.1410
Germany	1.7075
UK	1.3209
RoEU	3.0743
Saudi Arabia	0.3853
RoW	1.8214

Source: Author calculations.

Miscellaneous comments

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

For China there is no working-age population data from ILO before 2020. We deduced growth rates for WAP for 2018, 2019 and 2020 from SSP2 data. For earlier

years we assumed that annual growth in WAP for China is 0.5 percentage points lower than that in population.

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

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

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

The nominal GDP numbers from the IMF in Table A.8 for 2014-19 are in line with those from the OECD in Table A.4 for all regions except RoEU and Saudi Arabia. We have to make a choice. We chose to use the OECD numbers because they have expenditure-side detail.

Energy data and projections from IEA

We extracted the data and projections in Tables A.12 – A.19 from <https://www.iea.org/data-and-statistics/data-product/world-energy-outlook-2022-free-dataset>. The data refers to energy supply. We interpret supply as being what we would call absorption.

Thus, for example, the data show considerable supply of oil in Japan, but production is not given – we suspect it is negligible.

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

We require energy use projections for each of the 13 regions in our model. The free download data from IEA identifies USA, China, Japan, and India as separate regions. Data and projections for these regions are shown in Tables A.12 – A.15.

We deduced Table A.16 (Rest of North America) from data and projections for North America less USA. We use the percentage changes in Table A.16 for both Canada and Mexico.

Table A.17 contains data and projections for the European Union. We use the percentage changes in Table A.17 for France, Germany, U.K, and RoEU.

Table A.18 contains data and projections for the Middle East. We use the percentage changes in Table A.18 for Saudi Arabia.

Table A.19 contains data and projections for the Rest of World. This was calculated by subtracting data for North America, China, Japan, India, European Union, and Middle East, from the data for World.

Features of the data and projections

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

Use of renewables increases in all regions after 2020.

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

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

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

Prices of oil, gas, and coal from 2014 to 2019

For prices of oil, gas and coal see:

...\[ITC\WTO\ CMO-Historical-Data-Annual.xlsx](#) published by the World Bank and

...\[ITC\WTO\WB\ CMO-April-2023-Energy-Fertilizers.xlsx](#)

Table A.12. USA: Energy data and projections from IEA.

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

Source: Author calculations.

Table A.13. China: Energy data and projections from IEA.

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

Source: Author calculations.

Table A.14. Japan: Energy data and projections from IEA.

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

Source: Author calculations.

Table A.15. India: Energy data and projections from IEA.

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

Source: Author calculations.

Table A.16. Rest of North America (Can and Mex): Energy data and projections from IEA.

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

Source: Author calculations.

Table A.17. European Union: Energy data and projections from IEA.

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

Source: Author calculations.

Table A.18. Middle East: Energy data and projections from IEA.

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

Source: Author calculations.

Table A.19. Rest of World: Energy data and projections from IEA.

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

Source: Author calculations.

Oil

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

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

Natural gas

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

Coal

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

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

Index mundi

(<https://www.indexmundi.com/commodities/?commodity=coal-australian&months=240>) shows growth in the price of coal of 20.64 in 2004-14

<https://ourworldindata.org/grapher/coal-prices> has several estimates of growth in prices of coal across the periods 2004-2014 and 2014-19. The Japanese coking coal figures for these two periods are 87.69 and 29.81.

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

Oil -29.86 (Saudi data)

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

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

Net foreign liabilities (NFL)

Table A.20 shows net foreign liabilities at the start of 2014 and the start of 2019. We impose the changes between these two years in the 2014-19 simulation. The data for Net foreign liabilities (NFL) are from the IMF's *World and Regional Tables: Balance of Payments and International Investment Position by Indicator (BPM6)*, available at: <https://data.imf.org/?sk=7a51304b-6426-40c0-83dd-ca473ca1fd52&sid=1542633711584>.

Table A.20. Net foreign liabilities (NFL)

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

Source: Author calculations.

Employment by broad sector in Canada

We downloaded data on jobs by broad sector in Canada for 2014 and 2019 and calculated percentage growth between these two years. The data source was Statistics Canada,

<https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610048901>.¹

However, we have not yet imposed these percentage movements in the 2014-19 simulation.

¹ In our own files, these data are stored at C:\dixon\consult\ITC\2023\WTO\Shenjie\JobsDataCanada171023.xlsx.

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

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

We assume that

$$RW_T = RW_t + \sum_{q=0}^{T-t-1} RS_{t+q} \quad (A.1)$$

where

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

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

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

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

We adopt a smooth growth assumption for real saving:

$$RS_{t+q} = RS_t + (RS_T - RS_t) * \frac{q}{T-t} \quad q = 0, \dots, T-t \quad (A.2)$$

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

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

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

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

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

Including wealth equations in simulations for disjoint years

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

The inclusion of (A.4) in our model for year T destroys the simplicity of equation (1) in section 2 of the main paper. It must now be rewritten for year T as:

$$F(X, RS_t, T - t) = 0 \quad (\text{A.5})$$

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

$$F_T(X) = 0 \quad (\text{A.6})$$

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

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

The inaccuracy of the stylized representation in (1) is not of prime importance. However, the problem of finding an initial solution needs to be solved. As set out in Dixon and Rimmer (2002), this was done via the homotopy approach suggested to us by Mark Horridge.²

The homotopy form

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

$$\begin{aligned} LHS &= RW_t \\ RHS &= RW_t + [RS_t * (T - t)] \end{aligned} \quad (\text{A.7})$$

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

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

$$\begin{aligned} RW_T &= RW_t + \sum_{q=0}^{T-t-1} \left[RS_t + (RS_T - RS_t) * \frac{q}{T-t} \right] \\ &\quad - RS_t * (T - t) * (1 - U) \end{aligned} \quad (\text{A.8})$$

² The homotopy idea was originally developed in the field of numerical analysis, see for example Zangwill and Garcia (1981). The use of homotopy variables in dynamic simulations connecting disjoint years was first worked out by our colleague Mark Horridge about 30 years ago.

In this equation, U is a new exogenous variable. Its value in the initial solution for year T is zero. With this value, the year t solution *does* satisfy (A.8) in the year T model:

$$\begin{aligned} LHS &= RW_t \\ RHS &= RW_t + [RS_t * (T - t)] - RS_t * (T - t) = RW_t = LHS \end{aligned} \quad (A.9)$$

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

Part 3. Giving regional investors forward-looking expectations

Strategy

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

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

$$\frac{KE(r,t(i))}{KB(r,t(i))} = \left(\frac{KB(r,t(i+1))}{KB(r,t(i))} \right)^{\frac{1}{t(i+1)-t(i)}} * FF_KE(t(i)) \quad (\text{A.10})$$

for all r and $i = 1,2,3$

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

As the terminal condition we use

$$\frac{KE(r,t(4))}{KB(r,t(4))} = \left(\frac{KB(r,t(4))}{KB(r,t(3))} \right)^{\frac{1}{t(4)-t(3)}} * FF_KE(t(4)) \quad (\text{A.11})$$

for all r

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

$$\frac{KE(r,t(i))}{KB(r,t(i))} = G(r,t(i)) * FF_KE(t(i)) \quad (\text{A.12})$$

for all r and $i = 1,2,3,4$

In this equation $G(r,t(i))$ is a guess of $\left[\frac{KB(r,t(i+1))}{KB(r,t(i))} \right]^{\frac{1}{t(i+1)-t(i)}}$ for $i=1,2,3$. $G(r,t(4))$ is a guess of $\left[\frac{KB(r,t(4))}{KB(r,t(3))} \right]^{\frac{1}{t(4)-t(3)}}$, with $G(r,t(4)) = G(r,t(3))$. We treat $FF_KE(t(i))$ as endogenous and the guesses, $G(r,t(i))$, as exogenous.

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

First step in the iterative process: static expectations

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

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

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

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

Subsequent steps in the iterative process

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

$$G_q(r, t(i)) = \left(\frac{KB_{q-1}(r, t(i+1))}{KB_{q-1}(r, t(i))} \right)^{\frac{1}{t(i+1)-t(i)}} \quad (\text{A.13})$$

for all r , for $i = 1, 2, 3$ and for $q > 1$

and

$$G_q(r, t(4)) = (G_q(r, t(3))) \quad \text{for all } r \text{ and } q > 1 \quad (\text{A.14})$$

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

GEMPACK implementation

The initial solution for almost all variables in the $t(i)$ simulation is provided by the $t(i-1)$ solution (the database in the case of the $t(1)$ simulation). In equation (A.12), we set the initial solution for $FF_KE(t(i))$ at 1, and the initial solution for $G(r, t(i))$ at $KE(r, t(i-1))/KB(r, t(i-1))$.

The percentage change version of (A.12) that we include in the GEMPACK representation of the model is:

$$ke(r) - kb(r) = g(r) + ff_ke + f_ke(r) \quad \text{for all } r \quad (\text{A.15})$$

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

In the first iteration ($q=1$) we make (A.15) inactive. We do this by endogenizing $f_ke(r)$ and exogenizing ff_ke . Rather than relying on (A.15), we determine investment in each region in year $t(i)$ according to the GTAP mechanism using equalization of risk-adjusted expected rates of return (described above). With (A.15) inactive, the value we choose for $g(r)$ is unimportant: $g(r)$ equals 0 will do.

In subsequent iterations, $q > 1$, (A.15) remains inactive in the 2014-19 simulation, in which regional investment is given by data. However, for the 2019-30, 2030-40 and 2040-50 simulations, (A.15) is activated: $f_{ke}(r)$ is exogenous and ff_{ke} is endogenous. Now the guesses for $g(r)$ play their intended roles of determining growth in capital in the simulation year.

In the $t(i)$ simulation, with $q > 1$, we want to move $G(r, t(i))$ from its initial value to the value given by (A.13) or (A.14). Consequently, the shock we apply to $g(r)$ in the $t(i)$ simulation in the q th iteration is given by:

$$g_q(r, t(i)) = 100 * \left[\frac{\left(\frac{KB_{q-1}(r, t(i+1))}{KB_{q-1}(r, t(i))} \right)^{\frac{1}{t(i+1)-t(i)}} - \left(\frac{KE_{q-1}(r, t(i-1))}{KB_{q-1}(r, t(i-1))} \right)}{\left(\frac{KE_{q-1}(r, t(i-1))}{KB_{q-1}(r, t(i-1))} \right)} \right] \quad (\text{A.16})$$

for all $r, i = 1, 2, 3$

and

$$g_q(r, t(4)) = 100 * \left[\frac{\left(\frac{KB_{q-1}(r, t(4))}{KB_{q-1}(r, t(3))} \right)^{\frac{1}{t(4)-t(3)}} - \left(\frac{KE_{q-1}(r, t(3))}{KB_{q-1}(r, t(3))} \right)}{\left(\frac{KE_{q-1}(r, t(3))}{KB_{q-1}(r, t(3))} \right)} \right] \quad (\text{A.17})$$

for all r

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

Do forward-looking expectations matter?

To answer this question, we prepared Tables A.21 – A.23 which show capital and investment results computed under static expectations ($q=1$) and converged forward-looking expectations ($q=8$).

Table A.21 gives average annual percentage growth rates in capital stocks from the start of 2014 to the start of 2019; from the start of 2019 to the start of 2030, etc. For 2014 to 2019, these growth rates are the same in both panels of the table: they are determined by data. For the other periods, there are differences in growth rates between the two panels, but they are relatively minor.

Table A.22 shows percentage growth in capital stocks *in* 2019, 2030, 2040 and 2050. These compare start-of-year capital stocks with end-of-year capital stocks. The 2019 growth rates are derived from data and consequently are the same in both panels. However, there are considerable differences in the results for the

other years as we move from static expectations to converged forward-looking expectations.

Table A.23 shows average annual percentage growth rates in investment across periods: 2019 compared with 2014; 2030 compared with 2019; etc. The growth rates in the 2014-19 columns are the same in both panels because they are derived from data. The growth rates in the other columns follow in a mechanical way from the results in Tables A.21 and A.22 according to a generalized version of equation (29):

$$i[t(i-1), t(i)] = 100 * \left[\left\{ \left(1 + \frac{kb[t(i-1), t(i)]}{100} \right)^{t(i)-t(i-1)} * \frac{\left[\frac{k[t(i)]}{100} + D \right]}{\left[\frac{k[t(i-1)]}{100} + D \right]} \right\}^{\frac{1}{t(i)-t(i-1)}} - 1 \right] \quad (\text{A.18})$$

where

$i[t(i-1), t(i)]$ is the average annual percentage growth in investment in a region from $t(i-1)$ to $t(i)$, results in Table A.23;

$kb[t(i-1), t(i)]$ is the average annual percentage growth in start-of-year capital for a region, results in Table A.21; and

$k[t(i)]$ is the percentage growth of capital in a region across year $t(i)$, results in Table A.22.

(A.18) means that the investment results in Table A.23 do not need a separate explanation once we have understood the results in Tables A.21 and A.22.

In Table A.21, capital growth over the simulation periods 2019-30, 2030-40 and 2040-50 depends mainly on our assumptions concerning growth in real GDP and employment. These assumptions do not vary as we go from $q=1$ to $q=8$. This is the reason that the differences in the growth rates between the two panels in Table A.21 are relatively minor. Consequently, in explaining the differences in the investment results in left and right panels of Table A.23, we can focus on Table A.22.

Table A.21. Average annual % growth rates in start-of-year capital stocks.

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

Source: Author calculations.

Table A.22. Percentage growth in capital from start to end of year.

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

Source: Author calculations.

Table A.23. Average annual % growth rates in real investment.

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

Source: Author calculations.

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

The results for 2030 in the right panel of Table A.22 are tightly related to those for 2030-40 in the right panel of Table A.21. Under forward-looking expectations, the growth rates *in* 2030 reflect the average annual growth rates for the period 2030 to 2040. The 2030 growth rates in the right panel of Table A.22 are about 0.3 percentage points greater than the 2030-40 growth rates in the right panel of Table A.21. Why the discrepancy? The answer is that global saving as a share of global GDP declines as we go from 2030 to 2040. This means that capital growth *in* 2030 cannot be sustained over the following decade.

Similarly, the growth rates in 2040 in the right panel of Table A.22 are tightly related to those for 2040-50 in the right panel of Table A.21. With our terminal

condition, the growth rates in 2050 in the right panel of Table A.22 are also explained by those for 2040-50 in the right panel of Table A.21.

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

To understand the relationships between the results in the left panels of Tables A.21 and A.22, we need to set out the details of the GTAP specification of capital growth in a year under static expectations. This specification can be expressed as:³

$$RORG = RORC(r, t(i)) * \left(\frac{KE(r, t(i))}{KB(r, t(i))} \right)^{-RORFLEX} * \left(\frac{1}{CGDSLACK(r, t(i))} \right) \quad (A.19)$$

The RHS of (A.19) is the risk-adjusted expected rate of return on investment in region r. It is the product of three factors:

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

The LHS of (A.19) is a scalar. This equalizes risk-adjusted expected rates of return across regions in $t(i)$.

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

In the static-expectations simulations ($q=1$) for later periods, the movements in $RORC(r, t(i))$, $i > 1$, are equated across regions: it is assumed that regional capital flows between $t(i-1)$ and $t(i)$ are determined in a way that equalizes percentage movements in current rates of return. $CGDSLACK(r, t(i))$, $i > 1$, is set exogenously on zero change. Under this setup, (A.19) can be thought of as determining the allocation of global saving to investment in regions by determining $\frac{KE(r, t(i))}{KB(r, t(i))}$.

With no variation in the relative movements across regions in either $RORC$ or $CGDSLACK$, (A.19) does not allow variation across regions in the relative movements in KE/KB . Thus, there is no variation across regions in relative rates of capital growth in years $t(2)$, $t(3)$ and $t(4)$. If region r had high observed capital

³ This specification of expected rates of return and investment comes from Dixon et al. (1982). Readers familiar with GEMPACK representations of the GTAP model will recognize (A.19) 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).

growth in 2019 relative to other regions, then it will have high simulated capital growth relative to other regions in 2030, 2040 and 2050.

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

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

Consider, for example, the results in the left panels of Tables A.21 and A.22 for China. In Table A.21, China's capital growth slows from an average annual rate of 9.61 per cent in 2014-19 to 5.43 per cent in 2019-30 to 4.12 per cent in 2030-40 and to 3.94 per cent in 2040-50. However, in Table A.22 China has strong capital growth *in* 2030, *in* 2040 and *in* 2050. This reflects strong capital growth in 2019. This leaves the simulated capital growth rates in the particular years 2030, 2040 and 2050 too high compared with the growth rates for the relevant decades, making the simulated results for investment levels in these particular years too high. A consequence of the investment levels for the particular years being too high is that the trade balances are too low.

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

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