GTAP-MVH, A Model for Analysing the Worldwide Effects of Trade Policies in the Motor Vehicle Sector: Theory and Data

CoPS Working Paper No. G-290, April 2019

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ISSN 1 031 9034 ISBN 978-1-921654-99-2

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GTAP-MVH, a model for analysing the worldwide effects of trade policies in the motor vehicle sector: theory and data

By

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Abstract: The Office of the Chief Economist in Global Affairs Canada (hereafter, the Office) is seeking to add to its tools for looking at the effects on Canada and other countries of higher U.S. protection. The Office is particularly interested in the motor vehicle sector. To meet the Office's requirements, we created a version of the GTAP model in which the motor vehicle sector is disaggregated. We call this version GTAP-MVH. This paper describes the process and data inputs though which we constructed a disaggregated motor vehicle sector for GTAP-MVH.

The theory in standard GTAP assumes that capital is completely mobile between industries and that labor markets are characterized by either fixed real wages or completely flexible real wages that adjust to eliminate effects on aggregate employment from policy changes. These capital and labor assumptions limit the usefulness of standard GTAP as a tool for analyzing the short-run impacts of policy changes. We describe theoretical innovations to standard GTAP to enhance its depiction of both capital and labor markets. We also describe innovations in other areas, particularly in the treatments of: the accumulation by each region of foreign assets and liabilities; and the determination of savings, investment and rates of return.

JEL codes: C68; F13; F14; F17

Key words: GTAP disaggregation; motor vehicle sector; inter-industry capital mobility; foreign assets and liabilities

Acknowledgements:
We thank Global Affairs Canada for financial support that made it possible for us to undertake this project. Shenjie Chen and Jeff Bennett from Global Affairs provided valuable advice. However, neither they nor their employer is responsible for any part of this paper.

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1. Introduction

The Office of the Chief Economist in Global Affairs Canada (hereafter, the Office) is seeking to add to its tools for looking at the effects on Canada and other countries of higher U.S. protection. The Office is particularly interested in the motor vehicle sector. To meet the Office's requirements, the Centre of Policy Studies (CoPS) has created a version of the GTAP model in which the motor vehicle sector is disaggregated. We call this version GTAP-MVH.

GTAP is the world's best known and most widely used global trade model. Its full database consists of mutually consistent input-output tables, trade flows and protection rates in 140 countries. Documentation of GTAP's theory and data can be found in Hertel (1997), Corong *et al.* (2017) and Aguiar *et al.* (2016). However, the standard GTAP theory and database do not fully meet the Office's requirements.

The theory in standard GTAP assumes that capital is completely mobile between industries and that labor markets are characterized by either fixed real wages or completely flexible real wages that adjust to eliminate effects on aggregate employment from policy changes. These capital and labor assumptions limit the usefulness of standard GTAP as a tool for analyzing the short-run impacts of policy changes. In the short run, policy changes can lead to underutilization of both capital and labor. From a policy perspective, what is needed is a model that can trace out adjustment processes in both capital and labor markets.

The database for the standard GTAP model distinguishes 57 sectors, of which only one sector, denoted by 'mvh', represents motor vehicles industries.[1] For this project, in consultation with the Office, it was decided that the motor vehicle (mvh) industries must be represented in more detail, while non-mvh sectors and the regions could be more aggregated.

Section 2 of this paper describes theoretical innovations that we have made to standard GTAP to enhance its depiction of both capital and labor markets. It also describes innovations that we have made in other areas, particularly in the treatments of: the accumulation by each region of foreign assets and liabilities; and the determination of savings, investment and rates of return. Section 3 describes the process and data inputs though which we constructed a disaggregated motor vehicle sector for GTAP-MVH. Concluding remarks are in section 4.

2. Transforming standard GTAP into GTAP-MVH

This section contains 8 subsections describing the major operations we performed to transform standard GTAP into GTAP-MVH. These operations covered:

(1) aggregation and disaggregation to generate a database highlighting the regions and industries of prime interest in the analysis of motor vehicle trade policies;
(2) reformulation of GTAP's treatment of foreign assets and liabilities to account for net foreign asset accumulation in each region;
(3) development of closures to ensure that accumulated global saving equals accumulated investment over the period from the start of the data year to the start of the simulation year in long-run simulations and that global saving in the simulation year equals global investment in the simulation year in both long-run and year-on-year simulations;
(4) development of new equations and closures for facilitating year-to-year simulations with industry specific capital in each region;

[1] The 57 sectors of the standard GTAP database are listed in the last column of Table 2.2. The table also shows the commodity classification adopted in the new model, GTAP-MVH, described in this paper, including the commodities in the disaggregated motor vehicle sector.

(5) development of a sticky-wage specification that allows for short-run variations in employment; and
(6) introduction of capital-using technical changes and changes in capital-labor substitution elasticities and consumption propensities to obtain credible paths for rates of return on capital in a world in which savings is likely to run ahead of investment;
(7) addition of equations and variables to allow public consumption, private consumption and saving to have fixed shares in regional income in either nominal or real terms ; and
(8) addition of variables to allow the simulation of cost-neutral changes in preferences in any region between imported and domestic products.;.

2.1. Regions and industries in GTAP-MVH

The starting point for the GTAP-MVH database is the GTAP database version 9 for 2011. As explained in Appendix 1, after we created the GTAP-MVH database for 2011 we updated to 2015.

Regions

There are 140 regions in the GTAP v9 database. For this project, they are aggregated to 10 regions of interest listed in 2.1. This regional classification separately identifies all of the major producing and consuming counties for motor vehicles.

Industries

The original GTAP version 9 database distinguishes 57 industries. All motor manufacturing activities are included in just one of the GTAP's 57 industries, namely "mvh". For better analysis of trade policies in the motor vehicle sector, we disaggregate GTAP's mvh industry into 9 more detailed industries. We aggregate other GTAP industries that are of only marginal relevance to trade policy in the motor vehicle sector. For example, in GTAP-MVH the 12 GTAP agricultural industries are aggregated into one. The full list of industries in GTAP-MVH is in Table 2.2, with the disaggregated mvh industries shown shaded and in bold type.

The data and methods used to split the GTAP's mvh industry into 9 industries are described in section 3. We also show the main outcomes from this work. These consist of 10 by 10 matrices for each of the 9 mvh products showing sales between countries.

Table 2.1. Regions in GTAP-MVH model

No.	Regions
1	USA
2	Canada
3	Mexico
4	Japan
5	South Korea
6	China
7	Germany
8	EU26 (= EU-28 less Germany and the UK)
9	United Kingdom
10	Rest of the World

Table 2.2. Sectors in GTAP-MVH model

No.	Sectors	Description	NAICS codes	Original GTAP sectors
1	Agriculture	Agriculture	1111 - 1123	Paddy rice; Wheat; Cereal grains nec; Vegetables, fruits, nuts; Oil seeds; Sugar cane, sugar beet; Plant-based fibres; Crops nec; Bovine cattle, sheep and goats, horses; Animal products nec; Raw milk; Wool, silk-worm cocoons.
2	ForFishMinng	Forestry, fishery and mining	1130-2131	Forestry; Fishing; Coal, oil, gas; Minerals nec.
3	FoodBevTob	Food, beverages and tobacco products	3111 - 3122	Bovine meat products; Meat products nec; Vegetable oils and fats; Dairy products; Processed rice; Sugar; Food products nec; Beverages and tobacco products.
4	TCF	Textile, clothing and footwear	3131 - 3160	Textiles; Wearing apparel; Leather products.
5	WoodProd	Wood products	3211-3219	Wood products.
7	PaperPublish	Paper, printing and publishing	3221 - 3231, 48A000-5111A0	Paper products, publishing.
8	PetrolCoal	Petroleum and coal products	3241	Petroleum, coal products.
9	ChemRubPlast	Chemicals, rubber and plastic products	3251-3262	Chemicals, rubber and plastic products.
6	NMetMinrlPrd	Non-metal mineral materials	3271 - 3279	Mineral products nec.
10	FeMetal	Ferrous metal	3311,3312,331510	Ferrous metals.
11	OthMetals	Non-ferrous metals	3313-3314,331520	Metals nec.
12	MetalProd	Fabricated metal products	3321-3329	Metal products.

Table 2.2 continues …

Table 2.2 continued…

No.	Sectors	Description	NAICS codes	Original GTAP sectors
13	**Autombile**	**Automobile manufacturing**	**336111**	**Motor vehicle and parts**
14	**MVGasEngPrts**	**Motor vehicle gasoline engine and engine parts manufacturing**	**336312**	
15	**MVSteerSuspn**	**Motor vehicle steering, suspension component (except spring) manufacturing**	**336330**	
16	**MVBrakes**	**Motor vehicle brakes and brake systems**	**336340**	
17	**MVPwrTrTrain**	**Motor vehicle transmission and power train parts**	**336350**	
18	**MVSeatInter**	**Motor vehicle interior trim, seats and seat parts**	**336360**	
19	**MVMtlStamp**	**Motor vehicle metal stamping**	**336370**	
20	**OthMVParts**	**Other motor vehicle parts manufacturing**	**336390**	
21	**TruckUteTrlr**	**Manufacturing of trucks, utility vehicles, trailers, motor homes and campers.**	**336112, 336120, 336212, 336213, 336214**	
22	OthTransEq	All other transportation equipment manufacturing	3364-3369	Transport equipment nec.
23	ElectrnicsEq	Electronic equipment	3341-3345	Electronic equipment.
24	OthMachEq	Other machinery and equipment	3331-3339, 3346-3359,3391,	Machinery and equipment nec.
25	OthManuf	Other manufacturing products, *n*.e.c.	3371-3379	Manufactures nec.
26	Services	Services	2211-2334, 4200-8140	Electricity; Gas manufacture, distribution; Water; Construction; Trade; Transport nec; Water transport; Air transport; Communication; Financial services nec; Insurance; Business services nec; Recreational and other services; Public administration, defense, education, health; Dwellings..

2.2. Adding foreign assets and liabilities and associated income flows: calculating net national income

Standard GTAP includes a device known as the Global Bank. Countries whose investment in a given year exceeds their savings borrow from the Global Bank while countries with a surplus of savings over investment lend to the Global Bank. The GTAP code is set up so that aggregate borrowing from the global bank is equal to aggregate lending to the global bank. In this way, the equality between world saving and investment is enforced in each year.

A weakness of standard GTAP is that it does not account for accumulation of foreign assets and liabilities. In effect, the Global Bank throws away its accounts at the end of each period and starts the next period with each country having zero net assets with the Bank. By failing to account for accumulation of foreign assets and liabilities, standard GTAP exaggerates the benefits to countries that stimulate their investment and underestimates the benefits to countries of saving. Extra investment is never paid for and extra saving generates no future income.

Ianchovichina and McDougall (I&M, 2012) overcome this weakness of standard GTAP by creating what they call the Global Trust. The Global Trust introduces the distinction between assets located in a country and the country's wealth. It recognizes that assets in a country depend on investment opportunities while wealth depends on accumulated savings. Through the Global Trust, I&M link the value of assets in a country and the country's wealth by specifying for each country foreign assets and foreign liabilities.

We have adapted I&M's code for the Global Trust and included it in GTAP-MVH. The data for 2015 used in our implementation of the Global Trust is set out in Tables 2.3 and 2.4. Looking at these tables and the identities that they display will be useful in working through the specification of the Global Trust.

Long-run simulations (T > 1)

We start by considering a situation in which the Global Trust is being used in a simulation in which we are moving from a data year, year 0, to a projection year several years into the future, year T, in a single jump. For example, year 0 might be 2015 and year T might be 2020. All coefficient values are known for year 0 from data or perhaps from a simulation for an earlier period in which the projection year was year 0. The only unknowns in the specification of the Global Trust refer to year T. The values of these unknowns are discovered in the simulation from year 0 to year T. We will see that in long-run simulations values for savings and capital for years between 0 and T are avoided by assuming smooth growth between the two years.

Table 2.3. Assets, liabilities and wealth at the start of 2015, $US billion and fractions of GDP*

		Fgn assets	Fgn liabilities	Net fgn assets	Capital	Locally-owned capital	Wealth	Net fgn assets /GDP	Capital /GDP	Wealth /GDP
		(1)	(2)	(3) = (1) – (2)	(4)	(5) =(4) – (2)	(6) = (5) +(1)	(7)	(8)	(9)
	GEMPACK notation	WQHTRUST	WQTFIRM		VKB	WQHFIRM	WQHHLD			
1	USA	25374	31148	-5773	50732	19584	44958	-0.35	3.11	2.76
2	Canada	2976	2847	129	5512	2665	5640	0.07	2.93	3.00
3	Mexico	567	1130	-563	3316	2186	2753	-0.45	2.64	2.20
4	Japan	7982	4699	3283	25901	21202	29185	0.55	4.37	4.92
5	SKorea	1102	974	129	4631	3657	4760	0.10	3.67	3.78
6	China	6579	4734	1844	31774	27040	33619	0.21	3.57	3.77
7	Germany	9506	7690	1817	11264	3575	13081	0.50	3.08	3.58
8	EU26	32003	33619	-1616	41303	7684	39688	-0.14	3.60	3.46
9	UK	968	1553	-585	6350	4797	5766	-0.23	2.48	2.25
10	RoW	24321	22987	1335	68791	45804	70126	0.06	3.00	3.06
	Total	111380	111380	0	249574	138195	249574	0.00	3.28	3.28

[*] Columns (1) and (2) are data for end of 2014 (start of 2015) on International Investment Positions by country published in the IMF's Yearbook for 2018. For EU26 and UK we adjusted down both foreign assets and foreign liabilities by $15,000 billion to avoid a negative entries in column (5). We scaled foreign assets and labilities to eliminate a small mismatch in the totals in the original data. Column (4) contains GTAP data updated from 2011 to 2015 for start-of-year values of capital stocks. All remaining columns were derived by the arithmetic indicated in the column headings.

Table 2.4. Calculation of net saving and net investment in 2015, $US billion*

	GDP	Private consumption	Public consumption	Gross investment	Depreciation	Income from fgn capital	Payments to fgn capital	Net saving	Net investment
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)= (1)-(2) -(3)-(5)+(6)-(7)	(9)= (4) – (5)
GEMPACK notation	GDP	PRIVEXP	GOVEXP	REGINV	VDEP	YQHTRUST	YQTFIRM	SAVE	NETINV
USA	16299	11424	2689	3034	2029	1467	1074	550	1005
Canada	1880	1036	411	433	220	172	160	225	212
Mexico	1254	818	144	261	133	33	179	13	129
Japan	5933	3540	1199	1215	1036	462	192	427	179
SKorea	1261	665	185	391	185	64	71	218	206
China	8911	3235	1239	4122	1271	380	291	3255	2851
Germany	3658	2122	718	670	451	550	532	386	219
EU26	11459	6738	2615	2287	1652	1851	1815	490	635
UK	2566	1743	591	388	254	56	98	-64	134
RoW	22893	13247	3652	5301	2752	1406	2028	2620	2550
Total	76113	44568	13443	18102	9983	6441	6441	8120	8120

* Columns (1) to (5) are GTAP data updated from 2011 to 2015. The calculation of columns (6) and (7) is explained in the text. Columns (8) and (9) were derived by the arithmetic indicated in the column headings.

In our adapted form, the first two equations for I&M's Global Trust are as follows:

$$WQHHLD_T(r) = WQHFIRM_T(r) + WQHTRUST_T(r) \quad (2.2.1)$$

wealth in r = dom. assets, dom. owned + ownership of fgn assets

$$VKB_T(r) = WQHFIRM_T(r) + WQTFIRM_T(r) \quad (2.2.2)$$

assets in r = dom. assets, dom. owned + dom. assets, fgn owned

where

$WQHHLD_T(r)$ is total wealth of country r at the start of year T;
$WQHFIRM_T(r)$ is the value of assets in country r at the start of year T that are owned by the residents of country r;
$WQHTRUST_T(r)$ is the value of foreign assets owned by the residents of country r at the start of year T, that is country r's assets in the Global Trust;
$VKB_T(r)$ is the value of assets in country r at the start of year T, that is, the value of physical capital in country r; and
$WQTFIRM_T(r)$ is the value of assets in country r at the start of year T that are foreign owned, that is, country r's liabilities held by the Global Trust.

The notation in these equations is consistent with I&M's original presentation and with our code for GTAP-MVH. Equation (2.2.1) splits country r's wealth between ownership of domestic and foreign (Trust) assets. Equation (2.2.2) splits the value of assets in country r between domestic and foreign (Trust) ownership.

Next, I&M determine country r's wealth, $WQHHLD_T(r)$, at the start of year T as wealth at the start of the year 0 revalued for changes in prices and incremented by savings from year 0 through year T-1. In GTAP-MVH, we specify the savings/wealth accumulation relationship as[2]:

$$WQHHLD_T(r) = WQHFIRM_0(r) * \left(\frac{PCGDS_T(r)}{PCGDS_0(r)}\right) + WQHTRUST_0(r) * \left(\frac{PTRUST_T}{PTRUST_0}\right) + \sum_{s=0}^{T-1}\left(\frac{SAVE_T(r)}{SAVE_0(r)}\right)^{s/T} * SAVE_0(r) \quad (2.2.3)$$

where

$PCGDS_T(r)$ is the price of capital goods in region r in year T;
$PTRUST_T$ is the price of capital held in the Global Trust in year T; and
$SAVE_T(r)$ is net savings (saving less expenditures required to maintain the capital stock, that is, depreciation) in country r in year T.

In (2.2.3), we assume that savings grow smoothly between year 0 and year T. With (2.2.3) in place, r's wealth at the start of year T is determined largely by its wealth and saving in year 0 and by its saving in year T. Saving in year T is determined largely by r's GDP in T which is determined largely by our assumptions concerning productivity and labor-force growth. Thus, we can think of the simulated value of r's wealth at the start of year T, $WQHHLD_T(r)$, as coming from factors that are exogenous to the Global Trust.

What about the value of r's capital at the start of year T? We can think of the quantity of capital in country r at the start of year T as being determined by our assumptions concerning

[2] Ianchovichina and McDougall (2012) adopt a similar specification, but written directly in changes and percentage changes of variables. However, their specification is slightly illegitimate: it has no valid levels form and is subject to the criticism that it produces results that vary with the path adopted in the multi-step solution methods used in GEMPACK.

rates of return in country r. If we introduce to a simulation assumed reductions in rates of return in country r between year 0 and year T, then on this account the simulated quantity of capital in region r at the start of year T will be high: low rates of return correspond to plentiful capital. The price in country r of capital goods in year T will be determined mainly by our assumptions concerning inflation and technical change. Thus, as with the simulated value of r's wealth, the simulated value of r's capital at the start of year T, VKB(r), comes from factors that are largely exogenous to the Global Trust.

With the values of r's capital and wealth at the start of year T determined as described above, we need one more piece of information (assumption) to tie down movements in all of the three variables on the RHSs of (2.2.1) and (2.2.2). One obvious possibility is to assume a fixed split in the ownership of r's capital between local and foreign, that is, a fixed ratio of $WQHFIRM_T(r)$ to $WQTFIRM_T(r)$. Another possibility is to assume a fixed spread of r's wealth between local and foreign assets, that is, a fixed ratio of $WQHFIRM_T(r)$ to $WQTRUST_T(r)$. Neither of these possibilities is ideal. If we assume a fixed local/foreign ownership split for capital in country r, then in a simulation involving a strong increase in capital located in r (perhaps because of a mining boom in r) we are likely to obtain an unrealistic reduction in the foreign-asset share of r's wealth. Similarly, if we assume a fixed spread of r's wealth between local and foreign assets, then in a simulation involving a strong increase in this wealth (perhaps because of stringent savings-inducing fiscal policy) we are likely to obtain an unrealistic reduction in foreign ownership of r's capital. I&M steer between these two potentially unsatisfactory possibilities by adopting what they refer to as a cross-entropy approach. They assume that

$$WQHFIRM_T(r) = \mu(r) * WQHTRUST_T(r)^{0.5} * WQTFIRM_T(r)^{0.5} \qquad (2.2.4)$$

where $\mu(r)$ is a parameter determined by the data for year zero.
Equation (2.2.4) damps movements in the foreign-asset share of r's wealth and in the foreign-ownership share of capital located in r: it tends to cause WQHTRUST and WQHFIRM to move in the same direction and similarly it tends to cause WQTFIRM and WQHFIRM to move in the same direction.

Year-on-year or short-run simulations (T = 1)

For year-on-year simulations we continue to adopt (2.2.1) through (2.2.4). With T= 1, (2.2.3) simplifies to

$$WQHHLD_1(r) = WQHFIRM_0(r) * \left(\frac{PCGDS_1(r)}{PCGDS_0(r)}\right) + WQHTRUST_0(r) * \left(\frac{PTRUST_1}{PTRUST_0}\right) + SAVE_0(r) \qquad (2.2.5)$$

In the GEMPACK code for GTAP-MVH supplied with this report we include versions of both (2.2.3) and (2.2.5) as separate equations. From a computational point of view we found this more convenient than relying in year-on-year simulations on (2.2.3) with T = 1.

Income flows on foreign assets and liabilities, and net national income

In GTAP-MVH, we calculate for each year:

YQ_FIRM(r) = VOA("Capital",r) - VDEP(r) (2.2.6)

where
YQ_FIRM(r) is income derived from capital in region r net of depreciation;
VOA("Capital",r) is rental income generated by r's capital; and
VDEP(r) is the value of depreciation of r's capital.

VOA("Capital",r) and VDEP(r) are coefficients with associated variables that appear in standard GTAP.

We split YQ_FIRM(r) between payments to domestic owners of capital [YQHFIRM(r)] and payments to the Global Trust [YQTFIRM(r)] according to ownership shares:

$$\text{YQHFIRM(r)} = \text{YQ\_FIRM(r)} * \frac{\text{WQHFIRM(r)}}{\text{VKB(r)}} \qquad (2.2.7)$$

and

$$\text{YQTFIRM(r)} = \text{YQ\_FIRM(r)} * \frac{\text{WQTFIRM(r)}}{\text{VKB(r)}} \qquad (2.2.8)$$

The total income of the Global Trust (YQTRUST) is then given by

$$\text{YQTRUST} = \sum_{r} \text{YQTFIRM(r)} \qquad (2.2.9)$$

The Global Trust distributes its income to the regions according to their ownership shares in the trust. This is represented as:

$$\text{YQHTRUST(r)} = \text{YQTRUST} * \frac{\text{WQHTRUST(r)}}{\text{WQTRUST}} \qquad (2.2.10)$$

where

YQHTRUST(r) is region r's receipts from its ownership of foreign assets.

We can now calculate net national product or income for region r [NNP(r)] as

$$\text{NNP(r)} = \text{GDP(r)} - \text{VDEP(r)} + \text{YQHTRUST(r)} - \text{YQTFIRM(r)} \qquad (2.2.11)$$

NNP(r) corresponds to the GTAP coefficient INCOME(r) with the associated income y(r).

2.3. Saving, investment, capital, rates of return and investment/saving balance in the simulation year

In year-on-year simulations, start-of-year capital stocks for each region are predetermined, reflecting depreciated capital stocks from the start of the previous year plus investment during the previous year. In standard GTAP, these predetermined capital stocks have no industry specificity: start-of-year capital is completely mobile between industries. As we will see shortly, a contribution of this paper is to show how industry specificity can be introduced. However, from the point of view of this subsection it is not misleading to go on thinking in standard GTAP terms in which the start-of-year capital stock for each country is a homogeneous entity inherited form the previous period. In long-run simulations start-of-year capital stock in the simulation year is determined via the mechanisms discussed in the previous subsection: global capital stock at the start of the simulation year is determined primarily by global saving accumulated over the simulation period and regional capital stocks are then determined by distributing the global capital stock to equalize rates of return. So in both year-on-year and long-run simulations we arrive at the start of the simulation year with capital stocks by region essentially in place.

With capital stocks essentially in place, we need to endogenize an overall rate of return on capital in each region. This is required to reconcile the availability of capital with the demand for capital in the simulation year. If the demand for capital in the simulation year is strong, then the use of capital must be chocked off by high rental rates implying high rates of return. [As explained in the next subsection, the introduction of industry-specific capital will require endogenization of industry-specific rates of return in each region.]

GTAP includes equations that relate investment in each region in the simulation year to rates of return on capital in the region (determined as described by the scarcity of start-of-year capital) compared with the rate of return or rate of interest on a risk-free asset. Saving in each region in the simulation year is determined primarily by regional income in the simulation year. With this set up, regions with high rates of return will tend to have positive investment/saving balances resulting in negative trade balances (that is imports greater than exports) while the opposite is true for regions with low rates of return. But how do we ensure that global investment equals global saving, or equivalently, that global trade balances sum to zero? This is done by endogenizing the world-wide safe rate of interest (rorg in GTAP notation).

2.4. Introducing industry-specific capital

Start-of-year industry-specific capital stocks

In equipping GTAP-MVH with the capability for simulations in which capital in each region is industry specific and immobile between industries, we started by adding the equation:

$$\begin{aligned} VKB\_I(j,r)*\left[kb\_i(j,r)+pcgds\_l(r)\right] \\ =\left[VKE\_I\_B(j,r)-VKB\_I\_B(j,r)\right]*deltime+VKB\_I(j,r)*f\_kb\_i(j,r) \end{aligned} \quad (2.4.1)$$

In this equation the variables are:

- kb_i(j,r) which is the percentage change in the quantity of start-of-year capital in industry j in region r. In year-on-year simulations this is the percentage difference between capital available to industry j,r at the beginning of year t (that is capital that j,r can use in production during year t) and capital available to industry j,r at the beginning of the previous year, t-1.
- pcgds_l(r) which is the lagged percentage change in the price of capital goods. This is the percentage change in the price of capital goods calculated by comparing the price in year t-1 with the price in year t-2. We use pcgds_l(r) as the percentage change in the price of units of capital at the start of year t compared with the price at the start of year t-1. To reconcile this use of pcgds_l(r) with the idea that percentage changes in variables are calculated from the centre of one year to the centre of the next, we assume that price changes take place in the first half of each year, see Figure 2.1.
- deltime which is an artificial variable whose value moves from zero to one.
- f_kb_i(j,r) which is a shift variable set exogenously at zero in year-on-year simulations but endogenously in long-run simulations to turn off the equation.

The coefficients are:

- VKB_I(j,r) and VKB_I_B(j,r) which are the values of start-of-year capital stock in industry j,r in the simulation year, year t, and in the previous year, year t-1.
- VKE_I_B(j,r) which is the lagged value of end-of-year capital stock in industry j,r in the simulation year, year t. In year-on-year simulations, this is the value of end-of-year capital stock in industry j,r in year t-1.

The left hand side of (2.4.1) is 100 times the change in the value of start-of-year capital in industry j,r between years t-1 and t. With f_kb_i(j,r) set exogenously on zero, the right hand side of (2.4.1) calculates this same change from coefficient values for year t-1. If t is the first year in a year-on-year simulation, then these coefficients are part of the database. In subsequent years they are part of the solution for year t-1. In year-on-year simulations, equation (2.4.1) ensures that the simulated value of start-of-year capital in industry j,r in year t is equal to the value of end-of-year capital in industry j,r in year t-1.

To connect kb_i(j,r) determined in (2.4.1) with the rest of GTAP-MVH we added the equation:

$$qfe("capital", j, r) = kb\_i(j, r) \qquad (2.4.2)$$

qfe(“capital”,j,r) is GTAP’s variable for the percentage change in industry j,r’s use of capital. In standard GTAP this is determined primarily by the rental price of capital which is undifferentiated by industry in accordance with the assumption that capital is homogeneous and mobile. Standard GTAP also allows for a tax on industry j,r’s use of capital. This can be differentiated by industry. In GTAP-MVH we give this tax two components. The first component we refer to as genuine. This component is collected by government and enters into the calculation of the government’s budget balance and the national accounts. The second component re refer to as phantom. As we will see, this component does not affect the government’s budget or the national accounts. It does however play a key role in our introduction of industry-specific capital.

The genuine and phantom components of the tax on j,r’s use of capital are included in GTAP-MVH through the following new equation:

$$tf(i, j, r) = tfg(i, j, r) + DUMK(i) * tfph(j, r) \qquad (2.4.3)$$

where

tf(i,j,r) in (2.4.3) is the GTAP variable for the percentage change in the power of the tax on industry j,r’s use of primary factor i. Factor i can be skilled labor, unskilled labor, capital, natural resources and land. In applications of standard GTAP, tf(i,j,r) is usually exogenous.

tfg(i,j,r) and tfph(j,r) are percentage changes in genuine and phantom components of the power of the tax on j,r’s use of primary factor i. We make the phantom component apply only to capital through the dummy parameter DUMK(i). This parameter has the value one if i = capital and is zero otherwise.

Standard GTAP allows for price-induced substitution by industry j,r between primary factors. Thus the determination of qfe(“capital”,j,r) is influenced by the cost to industry j,r of using capital relative to the cost of using other primary factors. This allows us to guide industry j,r’s demand for capital to be compatible with predetermined capital availability [(2.4.1) and (2.4.2)] by allowing endogenous movement in the phantom tax on j,r’s capital use. In summary, we introduce equation (2.4.2) and allow it to endogenize tfph(j,r) in (2.4.3).

A question that will occur to readers is: what happens to phantom tax revenue? To answer this question we start by setting out the GTAP-MVH computation of revenue collection from phantom taxes in region r:

$$\begin{aligned} d\_col\_ph(r) = \\ \sum_j VOA\_I("capital", j, r) * TG("capital", j, r) * TPH(j, r) \\ * \left[qfe("capital", j, r) + pm("capital", r) + tf("capital", j, r) \right] \\ - \sum_j VOA\_I("capital", j, r) * TG("capital", j, r) \\ * \left[qfe("capital", j, r) + pm("capital", r) + tfg("capital", j, r) \right] \end{aligned} \qquad (2.4.4)$$

where

d_col_phc(r) is the change in the collection of revenue from the phantom taxes on the use of capital in region r;

VOA_I("capital",j,r) is rental income generated by j,r's capital (this doesn't include payments of taxes by j,r for its use of capital);

TFG("capital",j,r) and TFPH("capital",j,r) are the levels of the genuine and phantom powers of the taxes on j,r's use of capital; and

pm("capital",r) is the GTAP variable for the percentage change in the "market" price for capital use in region r. In standard GTAP, this is the per-unit rental pre income tax.[3] received by the owners of region r's homogeneous capital stock. We can continue with this interpretation in GTAP-MVH even though we are introducing industry-specific capital. We can think of capital as being a homogenous entity that, through the operation of the phantom user taxes, is allocated to industries in a way that is consistent with the assumption of industry specificity and capital immobility.

Equation (2.4.4) is derived from:

$$\begin{aligned} COL\_PH(r) = VOA\_I(\text{"capital"}, j, r) * \left[TFG(\text{"capital"}, j, r) * TFPH(j, r) - 1\right] \\ VOA\_I(\text{"capital"}, j, r) * [TFG(\text{"capital"}, j, r) - 1] \end{aligned} \quad (2.4.5)$$

where

COL_PH(r) is the level of the collection of revenue from the phantom taxes on the use of capital in region r.

In (2.4.5), the collection of revenue from phantom taxes is calculated as total collection of revenue from taxing capital use on by j,r *less* collection of revenue from genuine taxes on capital use by j,r. As can be seen from (2.4.5), we model genuine and phantom taxes a occurring in a sequence: genuine taxes are applied to VOA_I("capital",j,r) and phantom taxes are applied to VOA_I("capital",j,r)*TFG("capital",j,r).

With equation (2.4.4) in place we deal with the problem of phantom tax collections simply by assuming that they sum to zero in each region. We do this by setting them at zero in our initial database and then in each simulation year treating d_col_phc(r) as an exogenous variable set on zero.[4] While these phantom taxes sum to zero in region r, they are not zero for individual industries. For industries in which capital [as determined by (2.4.2)] is scarce, the phantom taxes will be positive, damping these industries' demand for capital. For industries in which capital is abundant, the phantom taxes will be negative, stimulating these industries' demand for capital. Because the collection of phantom taxes in region r sums to zero, this collection does not need to be included in government or national accounts. This treatment also leaves the GTAP interpretation of the GTAP variable pm("capital",r) intact. It is the percentage change in the average pre-income-tax rental received by owners of capital in region r.

The introduction of equation (2.4.4) with the left hand side set exogenously on zero raises a closure issue. The equation introduces R new restrictions where R is the number of regions. What are the R variables in standard GTAP that should now be endogenized?

In standard GTAP, the quantity of the homogeneous capital entity that is available in each region at the start of each year is either exogenous or predetermined. Whatever standard

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[3] GTAP includes an income tax that comes between the market price PM("capital",r) and the supply price PS("capital",r). The supply price is the per-unit rental post income tax received by the owners of region r's homogeneous capital stock. As we will see shortly, the supply price is used in the calculation of rates of return.

[4] In fact we assume for the data year that phantom taxes are zero for every industry in region r [the database value for TFPH(j,r) is one for all j and r].

treatment was chosen, it must now be turned off. This will involve either endogenization of the R aggregate capital stocks themselves or endogenization of an R-dimensional shift variable generating the predetermined values of aggregate capital stocks. With industry specificity of capital stocks in each region, aggregate capital is merely an R-dimensional endogenous variable whose only role is in the analysis and reporting of results. For each region it is calculated as the sum of the region's industry capital stocks.

Investment in a model with industry-specific capital

To implement (2.4.1) we need values for the data year for start and end-of-year capital stocks by industry and region, VKB_I_B(j,r) and VKE_I_B(j,r). For the application of GTAP-MVH reported in section 3 we deduced these values for the data year (2015) from GTAP data updated from 2011 to 2015 on aggregate capital and investment in each region. Within regions we assumed that start-of-year capital was distributed across industries in proportion to input-output values on rental payments to capital by industry. Then we assumed that investment was distributed across industries in proportion to start-of-year capital. Finally we introduced assumptions about depreciation the growth in capital goods prices from 2014 to 2015 allowing us to compute the values of end-of-year capital stocks from the formulas:

$$\mathrm{VKE\_I}_{2015}(j,r) = \mathrm{VKB\_I}_{2015}(j,r) * \frac{\mathrm{LPCGDS}_{2015}(r)}{\mathrm{LPCGDS}_{2014}(r)} + \mathrm{REGINV}_{2015}(j,r) - \mathrm{VDEP}_{2015}(j,r) \tag{2.4.6}$$

and

$$\mathrm{VDEP}_{2015}(j,R) = \mathrm{VKB\_I}_{2015}(j,r) * \frac{\mathrm{LPCGDS}_{2015}(r)}{\mathrm{LPCGDS}_{2014}(r)} * D(j,r) \tag{2.4.7}$$

In these formulas:

$\mathrm{VKB\_I}_{2015}(j,r)$ and $\mathrm{REGINV}_{2015}(j,r)$ are the 2015 values of start-of-year capital and gross investment in industry j,r deduced from updated GTAP data as described above.

$\mathrm{LPCGDS}_{2014}(r)$ and $\mathrm{LPCGDS}_{2015}(r)$ are the 2014 and 2015 levels of capital goods prices in region r. Following the convention described in Figure 2.1, we use $\mathrm{LPCGDS}_{2014}(r)$ to represent capital goods prices at the start of 2015 and $\mathrm{LPCGDS}_{2015}(r)$ to represent capital goods prices at the end of 2015.

$\mathrm{VDEP}_{2015}(j,r)$ is the value in 2015 of depreciation of j,r's capital.

D(j,r) is the rate of depreciation in industry j,r. We have assumed that this is 0.04 for all industries and regions. Ideally, D should be given a genuine industry/region dimension.

To move forward from the data year, we need a theory of investment by industry and region or equivalently a theory to determine the relationship between start-of-year and end-of-year capital stocks by industry and region. We adapt the GTAP theory which itself was originally taken from Australia's ORANI model.[5] In change and percentage change form, similar to that in GTAP-MVH's GEMPACK code, the equations for our adapted theory are as follows[6]:

$$\mathrm{rore\_i}(j,r) = \mathrm{rorc\_i}(j,r) - \mathrm{RORFLEX}(r) * \left(\mathrm{ke\_i}(j,r) - \mathrm{kb\_i}(j,r)\right) \tag{2.4.8}$$

$$\mathrm{rorc\_i}(j,r) = \frac{\mathrm{C\_PTRP}(j,r)}{\mathrm{LPCGDS}(r)} * \left[\mathrm{ptrp}(j,r) - \mathrm{pcgds}(r)\right] \tag{2.4.9}$$

[5] See Dixon *et al* (1982) pages 118-22.

[6] Equations (2.4.8) – (2.4.12) are slightly simplified forms of GTAP-MVH's GEMPACK equations, E_ke_i, E_rorc_i, E_ke, E_qcgdsA and E_f_rore_i & RORGLOBAL.

$$\begin{aligned}&PTRP(j,r)*ptrp(j,r)\\&=\{1+TG("capital",j,r)*TPH(j,r)-TG("capital",j,r)\}*PSK(r)*ps("capital",r)\\&+PSK(r)*\{TG("capital",j,r)*TPH(j,r)*[tfg("capital",j,r)+tfph(j,r)]\\&\qquad-TG("capital",j,r)*tfg("capital",j,r)\}\end{aligned}\tag{2.4.10}$$

$$VKE(r)*ke(r)=\sum_j VKE\_I(j,r)*ke\_i(j,r)\tag{2.4.11}$$

$$\begin{aligned}&VKE(r)*\left[ke(r)+pcgds(r)\right]=VKB(r)*\frac{LPCGDS(r)}{LPCGDS\_L(r)}*\left[kb(r)+pcgds(r)\right]\\&\qquad+REGINV(r)*\left[qcgds(r)+pcgds(r)\right]-VDEP(r)*\left[kb(r)+pcgds(r)\right]\end{aligned}\tag{2.4.12}$$

$$rore\_i(j,r)=rorg+cgdslack(r)+f\_rore\_i(j,r)\tag{2.4.13}$$

Some of the notation in these equations has already been defined. Nevertheless, for reading convenience here we will provide a complete list:

rorc_i(j,r) is the percentage change in the current rate of return on capital in industry j,r. This will be defined more precisely later in this subsection.

rore_i(j,r) and rorg are the percentage change in industry j,r's expected rate of return and the percentage change in a world-wide safe rate of return or interest rate. As we will see at the end of this subsection, these concepts are related by the assumption that industries expand their investment until expected rates of return come into line with interest rates.

ptrp(j,r) is the percentage change in the post-income-tax price of capital used by industry j in region r.

kb_i(j,r) and ke_i(j,r) are percentage changes in j,r's start-of-year and end-of-year capital stocks.

kb(r) and ke(r) are percentage changes in region r's aggregate start-of-year and end-of-year capital stocks.

pcgds(r) and qcgds(r) are the percentage changes in price and quantity of capital goods in region r. The quantity of capital goods is the volume of investment in region r. Thus, pcgds(r) + qcgds(r) is the percentage change in the value of investment in region r.

ps("capital",r) is the GTAP variable for the percentage change in the "supply" price for capital in region r, that is the average post-income-tax rental received by owners of region r's capital.

tfg("capital",j,r) the percentage change in the genuine component of the power of the tax on j,r's use of capital.

tfph(j,r) the percentage change in the phantom component of the power of the tax on j,r's use of capital.

cgdslack(r) and f_rore_i(j,r) are region and industry/region shift variables that can be used exogenously to represent percentage changes in the riskiness of investments differentiated by region or industry/region.

VKB(r) and VKE(r) are levels coefficients for the values of start-of-year and end-of-year aggregate capital stock in region r.

VKE_I(j,r) is the levels coefficients for the value of end-of-year capital stock in industry j,r.

PTRP(j,r) is the levels coefficient for the post-income-tax price of capital used by industry j in region r.

TG("capital",j,r) and TPH(j,r) are the levels coefficients for the genuine and phantom components of the power of the tax on j,r's use of capital.

PSK(r) is the levels coefficient for the "supply" price for capital in region r.

LPCGDS(r) and LPCGDS_L(r) are levels coefficients for capital goods prices in region r in the current year and lagged year (previous year). Following the convention described in 2.1, we use these prices in valuing end-of-year capital stocks and start-of-year capital stocks.

REGINV(r) and VDEP(r) are levels coefficients for the values of gross investment and depreciation in region r.

RORFLEX(r) is a positive parameter. It is the elasticity of the expected rate of return in industry j,r with respect to capital growth (see Figure 2.2). The value used in standard GTAP is 10 for all r. For GTAP-MVH with industry-specific capital we set RORFLEX at 5 for all industries and regions. This value produced more plausible rates of convergence to long-run equilibria than the standard GTAP value. While neither our number nor the standard GTAP number are estimated, the corresponding parameter in the ORANI model was estimated not only for Australia but also for individual industries (see Dixon *et al.* 1982, pp.185-188).

Equation (2.4.8) is the core of GTAP-MVH's industry/region investment theory. This equation is illustrated in its levels form in Figure 2.2. As can be seen from the figure, it is assumed that capital creators expect the rate of return on investment in industry j,r to be the same as the current rate of return if the capital stock at the end of the current year is the same as that at the start of the current year. If it is planned for the capital stock to grow during the current year, then capital creators introduce risk into their calculations by assuming that the rate of return on investment will be less than the current rate of return.

The calculation of the current rate of return is discussed shortly and the determination of the expected rate of return is discussed at the end of this subsection. Here we note that an increase in the current rate of return [RORC_I(j,r)] causes a vertical upward shift in the expected rate of return schedule in Figure 2.2. Consequently, at any given expected rate of return, an increase in the current rate of return causes an increase in the end-of-year/start-of-year capital ratio [KE_I(,r)/KB_I(j,r)] for industry j,r. In this way, good news for industry j,r's current rate of return is translated into increased capital growth requiring increased investment.

The current rate of return is calculated by comparing the post-income-tax rental received by owners of units of capital in industry j,r with the cost of units of capital. A simplifying assumption in GTAP-MVH is that the cost of units of capital is the same for all industries in region r [LPCGDS has an r argument but no j argument]. By contrast, the rental rate per unit of capital varies across industries in region r. As explained earlier, this variation reflects differences across industries in the scarcity of start-of-year capital stocks relative to demand for these stocks. Variation across industries in rental rates on capital is introduced through phantom taxes.

Equation (2.4.9) is a percentage change form for the current rate of return. It can be derived from the following levels equation:

$$\mathrm{RORC\_I}(j,r) = \frac{\mathrm{PTRP}(j,r)}{\mathrm{LPCGDS}(r)} - \mathrm{D}(j,r) \qquad (2.4.14)$$

Equation (2.4.14) specifies the current rate of return as the ratio the post-income-tax rental price of capital in industry j,r to the cost of a unit of capital in region r *less* the rate of depreciation. For example, if the owner of a unit of capital in industry j,r receives a post-tax income of $12 on a unit of capital worth $100 (the asset price) and units of capital depreciate at 5 per cent a year , then we say that the current rate of return in industry j,r is 7 per cent.

Equation (2.4.10) is a percentage change form for the post-tax rental rate on units of capital in industry j,r. It can be derived directly from the levels equation:

$$\mathrm{PTRP(j,r) = \{1 + TG("capital", j,r) * TPH(j,r) - TG("capital", j,r)\} * PS("capital", r)} \quad (2.4.15)$$

To see why (2.4.15) is a legitimate specification of the post-income-tax rental price of units of capital in industry j,r, it is helpful to re-arrange it as:

$$\mathrm{PTRP(j,r) = \{PM("capital",r) + PM("capital",r) * \left[TG("capital", j,r) * TPH(j,r) - 1\right] - PM("capital",r) * \left[TG("capital", j,r) - 1\right] \} * \frac{PS("capital",r)}{PM("capital",r)}} \quad (2.4.16)$$

Equation (2.4.16) calculates the post-income-tax rental price of capital in industry j,r as the product of two terms. The first term in curly brackets is the pre-tax rental received per unit by owners of capital in industry j,r. The second term is the fraction of this income that is retained after payment by capital owners of income tax, that is the ratio of the average supply price in region r [PS(“capital,r)] to the average market price [PM(“capital,r)].

Pre-tax rental received per unit is calculated as the average market price of capital in region r plus the phantom tax revenue per unit of capital in industry j,r. Phantom tax revenue per unit is the difference between total tax revenue per unit charged to users of capital in industry j,r and genuine tax revenue per unit charged to users of capital in industry j,r. Why do we add phantom-tax-revenue per unit to the average market price to arrive at the pre-income-tax rental price?

We can think of users of capital in industry j,r as making two separate payments to owners. First, they pay the average market price for capital in region r [PM(“capital”,r)]. The second payment by users to owners is the phantom tax. If capital in industry j,r is scarce, then this tax will be positive giving owners of j,r’s capital a rental receipt that is above the average for region r. This high rental will produce a high current rate of return which, as we will see shortly, will stimulate investment in industry j,r relative to that in other industries. If capital in industry j,r is abundant, then the phantom tax will be negative. The rental receipt for owners of j,r’s capital will be below the average for region r. This low rental will produce a low current rate of return which will damp investment in industry j,r. Another way of understanding (2.4.16) is to derive it by subtracting genuine taxes (both income taxes and user taxes) from the price paid by industry j,r to use a unit of capital.

Equation (2.4.11) defines the percentage change in aggregate end-of-year capital stock in region r [ke(r)] as a weighted average of the percentage changes in the end-of-year capital stocks of the industries in region r [ke_i(j,r)].

Equation (2.4.12) is a percentage change version of the accounting identity that determines the aggregate value of end-of-year capital stocks in region r as the aggregate value in end-of-year prices of the start-of-year capital stocks in region r *plus* gross investment *less* depreciation. In equations that we retain in GTAP-MVH, standard GTAP ensures that the percentage change in aggregate start-of-year capital stock in region r is a weighted average of the percentage changes in the start-of-year capital stocks of the industries in region r [kb_i(j,r)].[7] This ties down kb(r) via the predetermination in (2.4.1) of start-of-year industry capital stocks. Given that we have determined ke(r) in (2.4.11) and that movements in capital goods prices [pcgds(r)] are determined elsewhere in our model via wage rates and other input prices, we can think of (2.4.12) as determining the percentage change in aggregate investment in region r [qcgds(r)].

Figure 2.1. Price paths

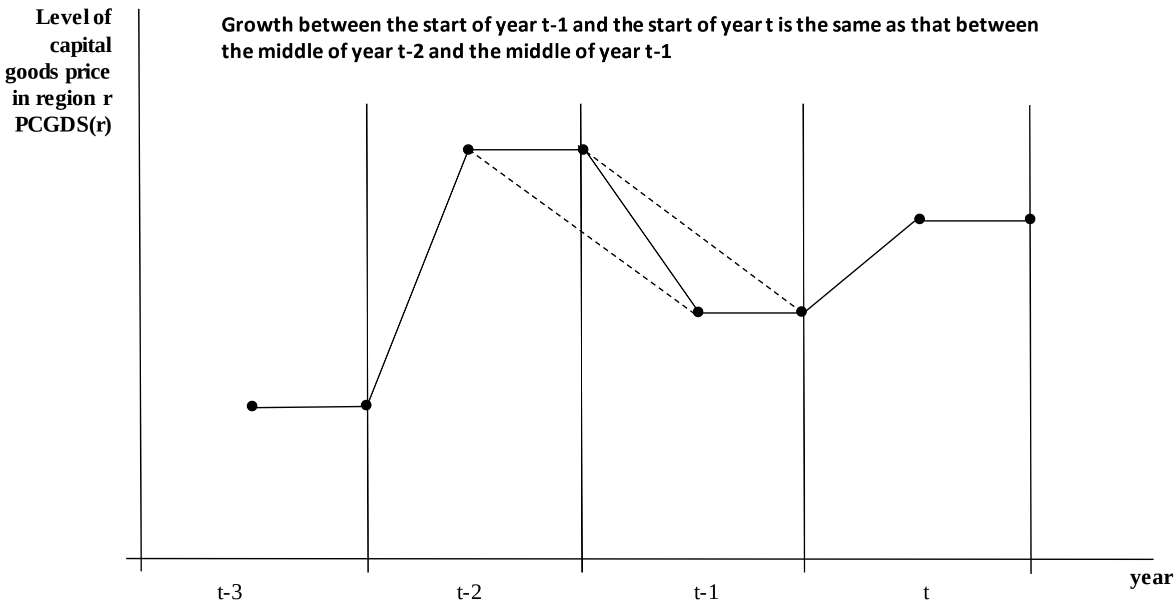
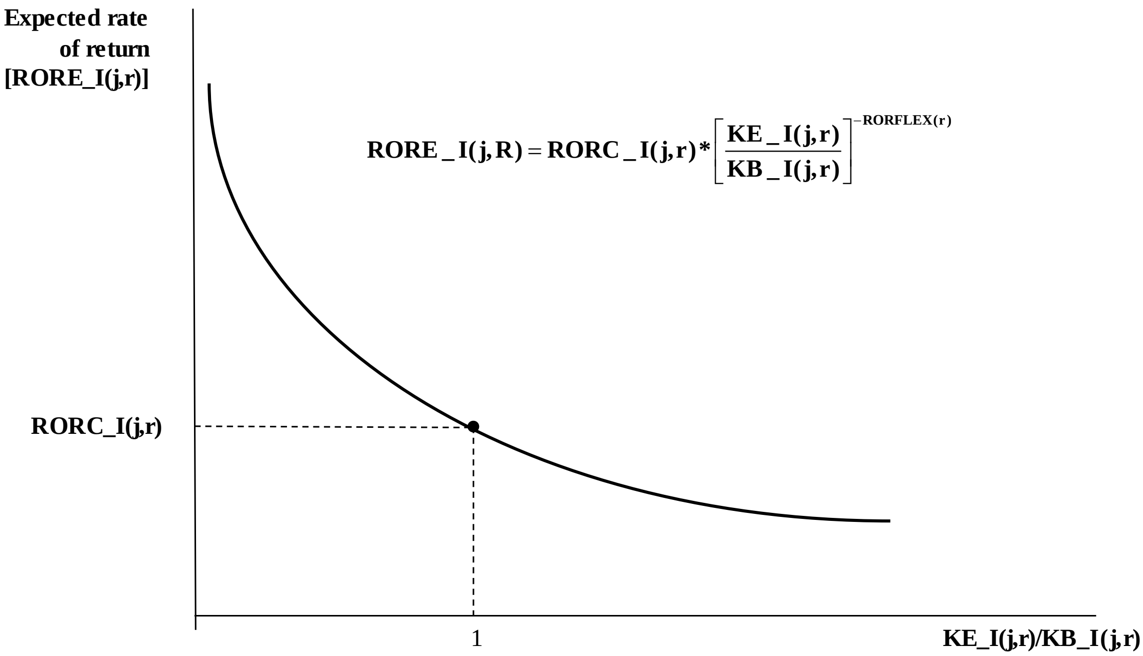


Figure 2.2. Expected rate of return schedule for industry j,r



7 See equations KAPSVCES, KBEGINNING, MKTCLENDWM and E_qfe_capital in the GEMPACK code for GTAP-MVH.

While (2.4.12) determines aggregate investment in region r, it raises the question of whether we should be concerned with investment by industry in region r. The percentage change in investment in industry j,r could be deduced from results for the percentage changes in start- and end-of-year capital in industry j,r [kb_i(j,r) and ke_i(j,r)]. However this is not necessary even though we are developing a model with industry-specific capital. We can avoid explicitly modelling investment at the industry level because we assume that the input composition of capital creation is the same for every industry in region r. Thus the industry composition of aggregate investment in a simulation year has no effect on results for GDP, employment, industry output or any other variable of policy interest.

Equation (2.4.13) gives us the expected rate of return on investment in industry j,r. We should think of this equation as determining the rate of interest at which industry j,r can obtain finance for investment. With this interpretation of rore_i(j,r) in mind, we return to equation (2.4.8). In (2.4.8), kb_i(j,r) is predetermined and we can think of rorc_i(j,r) as being determined, largely independently of finance costs, by the current scarcity of capital in industry j,r relative to demand. With rore_i(j,r) being set by equation (2.4.13), we now see that (2.4.8) determines the percentage change in the end-of-year capital stock [ke_i(j,r)] in industry j,r. Between the start and end of a simulation year capital creators expand or contract the capital stock in industry j,r so that the expected rate of return on capital in the industry is equal to the cost of finance given by forces external to the industry's capital creators. These forces include changes in region and industry-specific risks that can introduced by shocks to the exogenous shift variables in (2.4.13), cgdsack(r) and f_rore_i(j,r). In terms of Figure 2.2, a positive shock to cgdsack(r) causes a north-west movement along the expected rates of return schedules for all industries in region r with consequent reductions in end-of-year capital stocks and investment for these industries. A positive shock to f_rore_i(j,r) restricts the direct investment contraction to industry j in region r.

In addition to exogenous region and industry/region shift variables, the right-hand side of (2.4.13) contains a scalar variable, rorg. This variable is almost always endogenous. Its role in both year-on-year and long-run simulations is to ensure that global investment in any simulation year equals global saving. A region's saving in a simulation year is normally determined primarily by its income, largely independently of its investment. Through rorg, expected rates of return (cost of finance) in industries world-wide are adjusted positively or negatively. Via (2.4.8) this causes negative or positive adjustments in end-of-year capital stocks by industry and region with consequent negative or positive adjustments in global investment. In this way, rorg brings global investment into line with income-determined global saving.

2.5. Introducing sticky real wages

In most general equilibrium analyses of the effects of changes in policy instruments and other changes in the economic environment (e.g. changes in MVH tariffs), one of the following two assumptions is made:

a. real wages adjust so there is no effect on employment; or
b. real wages remain unaffected and employment adjusts.

Models built by the Centre of Policy studies (CoPS) over the last 20 years allow for intermediate positions between a and b.[8] In these models it can be assumed that real wages are sticky in the short run and flexible in the long run. Then favourable shocks generate short-run gains in aggregate employment and long-run gains in real wages.

8 See for example Industry Commission (1997, chapter O) and Dixon and Rimmer (2002, section 24).

In the simplest CoPS models, labor supply in each occupation is fixed on its basecase forecast path. In these models we usually assume in policy simulations that the deviation in the real wage rate for an occupation from its basecase forecast level increases at a rate which is proportional to the deviation in employment from its basecase forecast level. The coefficient of proportionality is chosen so that the employment effects of a shock to the economy are largely eliminated after 5 years. In other words, after about 5 years, the benefits of favourable shocks, such as technological improvements, are realized almost entirely as increases in real wage rates. This labor market assumption is consistent with conventional macro-economic modelling in which the NAIRU is either exogenous or only weakly dependent on real wage rates.

In more elaborate CoPS models, the wage specification takes account not only of deviations in demand for labor but also deviations in supply. In building GTAP-MVH we adopted a CoPS demand/supply approach. The labor-market specification that we included in GTAP-MVH for use in policy simulations has the form:

$$\left\{\frac{W(a,r)}{W\_F(a,r)}-1\right\}=\left\{\frac{W\_L(a,r)}{W\_L\_F(a,r)}-1\right\}+\alpha*\left\{\frac{E(a,r)}{E\_F(a,r)}-\frac{L(a,r)}{L\_F(a,r)}\right\}+SHIFT(a,r) \quad (2.5.1)$$

In this equation:

- underscore F (_F) indicates a basecase forecast value, that is, a value in the simulation without the policy or other shock under consideration.
- underscore L (_L) denotes lagged value.
- W_F(a,r), E_F(a,r) and L_F(a,r) are the real post-tax wage rate, employment and labor supply in occupation a in region r in the basecase forecast.
- W(a,r), E(a,r) and L(a,r) are the real post-tax wage rate, employment and labor supply in (a,r) in the policy simulation, that is the simulation with the shock.
- α is a positive parameter, set (as mentioned earlier) so that employment and labor-supply deviations from basecase induced by the policy shock are approximately equal after about 5 years.
- SHIFT(a,r) is a shift variable set exogenously on zero in policy simulations and left endogenous in forecast simulations.

With SHIFT(a,r) set on zero, (2.5.1) means that in a policy simulation with a favourable shock, (a,r)'s post-tax real wage rate continues to move further above its basecase path in every year in which the deviation in employment from its basecase path exceeds the deviation in labor supply from its basecase path. In a well-behaved simulation, the increases in (a,r)'s wage will eventually close the gap between the deviations in employment and labor supply, stabilizing the wage rate. Similarly, in a policy simulation with an unfavourable shock, (a,r)'s post-tax real wage rate moves below its basecase path in every year in which the employment deviation is below the labor supply deviation.

In GTAP-MVH we follow standard GTAP in assuming that employment in (a,r) is determined by demand for (a,r) and that demand reflects industry outputs, technologies and (a,r)'s pre-tax wage rate relative to the costs to industries of using other primary factors. On the supply side we assume in policy simulations without a labor-supply policy shock that aggregate labor supply for region r follows its basecase forecast path. However, we allow a policy shock to generate movements in labor supply between occupations. If a policy induces an increase in the wage rate of skilled labor relative to unskilled (the only 2 occupations in standard GTAP and GTAP-MVH) then we allow for an increase in skilled labor supply with a corresponding reduction in unskilled supply. In the tariff experiment described in section 3, these labor-supply movements are extremely small for two reasons.

First, the shocks do not have strong effects on relative wages and second we assume a low value for the transformation elasticity between skilled and unskilled.

2.6. Rates of return in the baseline forecast and capital-labor substitution

As explained in Appendix 1, our baseline forecasts for GDP and employment were derived from the IMF and World Bank publications. Initially we assumed that each country's propensity to save out of net national product (NNP) remained constant between 2015 and 2023. This produced results showing a strong increase over the period in global capital relative to global GDP. The increase in the K/GDP ratio arose from a combination of two factors: (a) the high savings propensity of China; and (b) the rapid increase in China's share of global NNP. With a large increase in K/GDP, our model projected large decreases in rates of return on capital. This effect was exacerbated by a decision we took to revise the GTAP capital-labor substitution elasticities from their standard values, which for many industries are as high as 1.26, to more normal values in CGE models of 0.5. With the increase in the global K/GDP ratio and reduced capital-labor substitution elasticities, our simulations initially showed reductions in rates of return of the order of 30 per cent, say from 10 per cent to 7 per cent. While we think that an increase in the global K/GDP ratio is realistic, we were worried about projecting such dramatic effects on rates of return. To damp the implied reduction in rates of return, we introduced two assumptions. First we assumed that there would be capital-using technical change at two per cent per annum throughout the world economy, and second that the savings to NNP ratio would fall by two per cent per annum in all countries. With these assumptions, the projected reductions in global rates of return between 2015 and 2023 were about 14 per cent, say from 10 to 8.6 per cent.

2.7. Private consumption, public consumption and net savings

Standard GTAP contains an elaborate treatment of the split of regional income (net national product, NNP) between private consumption, public consumption and net savings (see for example, Corong *et al.*, section 3.4, 2017). Under this treatment, regions are viewed as maximizing a welfare function in which the arguments are utility from private consumption, utility from public consumption and utility from net savings. We don't find this treatment helpful. The welfare function is essentially arbitrary, reflecting the arbitrary units in which the three component utility functions are measured. Consequently, we have slightly modified the GTAP theory by adding a critical shift variable and worked out a closure in which the values of private consumption, public consumption and net savings in region r can maintain constant shares in the region's NNP. The GTAP approach and our modification can be explained via the following GTAP equations:

$$\mathrm{dpav(r) = SP(r) * dppriv(r) + SG(r) * dpgov(r) + SS(r) * dpsave(r)} \tag{2.7.1}$$

$$\mathrm{uelas(r) = SP(r) * uepriv(r) - dpav(r)} \tag{2.7.2}$$

$$\mathrm{yp(r) = y(r) + uelas(r) - uepriv(r) + dppriv(r)} \tag{2.7.3}$$

$$\mathrm{yg(r) = y(r) + uelas(r) + dpgov(r)} \tag{2.7.4}$$

$$\mathrm{vsave(r) = y(r) + uelas(r) + dpsave(r)} \tag{2.7.5}$$

$$\mathrm{uepriv(r) = \sum_i XWCONSHR(i,r) * \left[pp(i,r) + qp(i,r) - yp(r)\right] + f\_uepriv(r)} \tag{2.7.6}$$

plus a new equation that we added:

$$\mathrm{cr(r) = gr(r) + f\_crgr(r)} \tag{2.7.7}$$

In these equations

SP(r), SG(r) and SS(r) are the shares of private consumption, public consumption and net savings in net national product (NNP) for region r;
dppriv(r), dpgov(r) and dpsave(r) are percentage changes in variables that govern region r's preferences between private consumption, public consumption and net savings;
dpav(r) is the average of the percentage changes in the preference variables;
uelas(r) is the percentage change in NNP in region r required to generate a one per cent increase in r's utility;
uepriv(r) is the percentage change in private consumption expenditure in region r required to generate a one per cent increase in r's utility derived from private consumption;
yp(r), yg(r) and vsave(r) are the percentage changes in the values of private consumption, public consumption and net savings in region r;
cr(r) and gr(r) are the percentage changes in real private and public consumption while f_crgr(r) is the percentage change in the ratio of real private to real public consumption;
y(r) is the percentage change in r's NNP;
pp(i,r) and qp(i,r) are percentage changes in the price and quantity of private consumption of commodity i in region r;
f_uepriv(r) is the critical shift variable mentioned above that allows exogenization of uepriv(r), that is allows (2.7.6) to be turned off; and
XWCONSHR(i,r) is a modified share of r's private consumption accounted for by commodity i. If a Cobb Douglas utility function is assumed for r's private consumption, then this is simply the unmodified share of commodity i in r's consumption. In standard GTAP, modifications are made in accordance with a CDE specification of preferences (see for example, Corong *et al.*, section 3.5, 2017). However, the nature of these modifications is of no importance here. As explained below, we exogenize uepriv(r) so that XWCONSHR(i,r) has no role in our simulation results.

It is reassuring to note that despite the complications of uepriv(r), uelas(r) etc, equations (2.7.1) to (2.7.5) imply that

$$y(r) = SP(r) * yp(r) + SG(r) * yg(r) + SS(r) * vsave(r) \qquad (2.7.8)$$

Equation (2.7.8) can be derived by: multiplying (2.7.3), (2.7.4) and (2.7.5) through by SP(r), SG(r) and SS(r); adding the three equations; and then using (2.7.1) and (2.7.2).

To eliminate the effects of uepriv(r), uelas(r) etc, and to conduct simulations in which NNP for region r is split in exogenous shares between saving and consumption while the ratio of real private and public consumption is also exogenous, we:

- endogenize f_uepriv(r) allowing us to fix uepriv(r) exogenously on zero; and
- exogenize dpsave(r), f_crgr(r) and dpav(r).

To see how this works we can consider the special case in which dpsave(r), f_crgr(r) and dpav(r) are set on zero. With uepriv(r) also set on zero, (2.7.2) implies that uelas(r) equals zero. Then (2.7.5) ensures that the savings share in NNP is fixed. Equations (2.7.3), (2.7.4) and (2.7.1) reduce to

$$yp(r) = y(r) + dppriv(r) \qquad (2.7.9)$$

$$yg(r) = y(r) + dpgov(r) \qquad (2.7.10)$$

$$0 = SP(r) * dppriv(r) + SG(r) * dpgov(r) \qquad (2.7.11)$$

With f_crgr(r) exogenous on zero, the difference between yp(r) and yg(r) is determined by

$$yp(r) - yg(r) = ppriv(r) - pgov(r) \qquad (2.7.12)$$

where ppriv(r) and pgov(r) are percentage changes in the price indexes for private and government consumption in region r which are determined elsewhere in the GTAP model. Equations (2.7.9) to (2.7.12) give enough structure to determine movements in dppriv(r) and dpgov(r) compatible with the fixity of the ratio of real private to real government consumption in region r.

2.8. Adding the capability to simulate import/domestic preference twists

Standard GTAP includes variables for import-saving technical change by source, ams(i,s,r). If this variable is set at 10, then we are introducing a technology or preference change that allows all agents in region r to satisfy their input requirements or achieve any given level of utility with 10 per cent less imported good i from source region s while holding constant their purchases of all other inputs. For GTAP-MV we want a facility to simulate the effects of import-saving technical change for commodity i in region r, not differentiated by source. Similarly we want a facility to simulate the effects of domestic-saving technical change for commodity i in region r. These facilities can be useful in simulations concerned with preference shifts between imported and domestic motor vehicle products, for example, induced by non-price mechanisms such as presidential exhortations to source locally.

Consequently, we amended standard GTAP by adding the variables ams2(i,r) and ads(i,r). Positive shocks to the first of these variables introduces technology or preference changes that allow all agents in country r to satisfy their input requirements or achieve any given level of utility with less *imported* good i from all foreign-source countries while holding constant their purchases of all other inputs. Positive shocks to the second of these variables introduces technology or preference changes that allow all agents in country r to satisfy their input requirements or achieve any given level of utility with less *domestic* good i while holding constant their purchases of all other inputs.

In adding ams2(i,r) and ads(i,r) we made necessary changes to input-demand equations in standard GTAP and also to equations for aggregate variables such as real GDP from the income side (see E_qgdpinc). Finally, we added an equation (E_f_twist) that allows for cost-neutral twists in preferences in country r between imported and domestic units of commodity i. Cost-neutral twists are introduced by movements in ads(i,r) offset by movements of opposite sign in ams2(i,r).

3. GTAP-MVH database compilation

The aim of this section is to describe how we disaggregated the data for the mvh sector in our 18 industry, 10 region GTAP database (described in sub-section 2.1) to include 9 mvh commodities/industries, that is how we moved from a database with the 18 com/ind categories to a database with the 26 com/ind categories as indicated in Table 2.2.

In performing the disaggregation we drew on a wide range of data sources. These are listed in subsection 3.1. The method we used to achieve the disaggregation is set out in subsection 3.2. This method makes maximum use of trade data which, as describe in subsection 3.3, are available for the mvh sector at a highly disaggregated level. We also used Canadian and U.S. input-output data which disaggregate the mvh sector into the categories required for this project.[9] Another set of inputs to the disaggregation method are initial guesses for 8 of the 10 regions (data for Canada and the U.S. are known from the input-output tables) of: outputs of each of the 9 mvh products; the use of each of the 9 mvh products in each of the 9 mvh

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9 The Canadian data has all 9 disaggregated mvh com/ind categories. The U.S. data has 8 disaggregated categories, 7 coinciding with 7 of the required nine. The 8^{th} U.S. category is an aggregate of 2 or our required categories: Motor vehicle steering, suspension component manufacturing and Motor vehicle brakes and brake systems. As a preliminary maneuver we split the U.S. input-output data for his 8^{th} category into the 2 required categories using Canadian shares.

industries; and the use of each of the 9 mvh products outside the mvh sector. The derivation of these initial guesses is described in subsection 3.4.

Subsection 3.5 displays selected outcomes from the disaggregation process.

3.1. Data sources

The sources used in creating the database for GTAP-MVH are:

The GTAP database

1. We use the latest GTAP database (version 9), which represents the year 2011, and contains 57 sectors and 140 countries and/or regions (hereafter referred to simply as regions) (Aguiar *et al*. 2016).

Additional global data for disaggregating the MVH sector

2. Bilateral trade data for motor vehicle sectors for all regions in the United Nations Commodity Trade Statistics Database in 2015 (UN Comtrade 2018).
3. Data on production, exports, imports and apparent consumption for manufacturing industries at the 4-digit level of ISIC Rev.4 for about 100 countries, 2010-2015 (UNIDO 2018).
4. Market reports on output values of automobiles, automobile gas engine and engine parts, and heavy truck manufacturing in 2017 for 61 major countries (Barnes reports 2017a-c).

Selected individual country data for disaggregating the MVH sector

5. For the USA: The USAGE model database for the year 2015, with 392 commodities and 392 industries (Dixon *et al*. 2017). This database contains 8 MV industries, which cover 7 of the required 9 MV industries, the two exceptions being *Motor vehicle steering, suspension component manufacturing* and *Motor vehicle brakes and brake systems*, which are aggregated into 1 industry.
6. For Canada: Supply and Use tables for 2014 (Statistics Canada 2017). This database contains all 9 of the required MV industries.
7. For China: The database for the year 2012 from CHINAGEM (a CGE model of the Chinese economy) with 142 commodities and 142 industries (Wittwer 2018). This database contains 2 aggregated MV industries (namely *Motor vehicles* and *MV parts*).
8. For Japan: 2011 Input-output (IO) tables for 2011, with 518 commodities and 397 industries (Ministry of Internal Affairs and Communications 2016). This database contains 3 aggregated MV industries (namely *Automobile*; *Trucks, utility vehicles and trailers*; and *MV gas engines*).
9. For South Korea: Input-output tables for 2010, with 384 commodities and 394 industries (Bank of Korea 2014). This database contains 3 aggregated MV industries (namely *Motor vehicles*; *MV gas engines*; and *MV parts*).
10. For the remaining regions, there are no IO data, or only quite aggregated IO data that are not suitable for use in this project. As will be discussed later, GTAP-MVH data for these regions is compiled from GTAP data and other data sources listed in this section.

Note that the various data sources can span a range of years. Our principle is to use the GTAP data for 2011 as the starting point, and use other data to inform the cost, sales and output shares of the detailed motor vehicle industries when disaggregating them from

GTAP's single 'mvh' sector. Where possible, we use the most recent data for the various shares in order to best reflect the current structures of the industries of interest. The 2011 database is updated to 2015 using available data on macroeconomic outcomes (see Appendix 1).

3.2. Theoretical structure for the disaggregation of the mvh sector into 9 mvh industries

The theory of our disaggregation method has 2 parts. First, we specify an equation system in which the inputs are: data on trade flows for disaggregated mvh products; U.S. and Canadian input-output data for these products; and initial guesses for outputs of and demands for mvh products for regions other than the U.S. and Canada. The equation system produces revised estimates of inputs to and outputs from disaggregated mvh industries for all regions, apart from the U.S. and Canada, for 2015. In the second part of our methodology the results from the equation system are used to compute splitting shares that are fed into a program that automatically disaggregates our GTAP database for 2011 and rebalances it. At first glance it may seem incongruous to use 2015 shares to disaggregate a 2011 database. However, we use only marco data to update form 2011 to 2015. So embedding 2015 mvh structures in the 2011 data has the advantage that the eventual 2015 database for GTAP-MVH reflects 2015 mvh structures.

In formal terms we estimate for 2015 the U.S. dollar values of:

- VQ(n,s) for $n \in$MVH, $s \in$OTHREG
  where MVH is the set of 9 mvh coms/inds; OTHREG is the set of 8 regions (excludes Canada and the U.S.); and VQ(n,s) is the value of output of commodity n in region s.
- Z(n,j,s) for $n \in$INPUT, $j \in$MVM, $s \in$OTHREG
  where INPUT is the set of all commodities and primary factor inputs to production and Z(n,j,s) is the value of input n (domestic plus imported in the case of commodity flows) to industry j in region s.
- Zimp(n,j,s) for $n \in$ COM, $j \in$MVH, $s \in$OTHREG
  where COM is the set of all commodities and
  Zimp(n,j,s) is the value of the flow of imported intermediate commodity n to industry j in region s.
- ODD(n,f,s) for $n \in$ MVH, $f \in$NonMVH, $s \in$OTHREG
  where ODD (n,f,s) is the value of commodity n (domestic plus imported) used in region s by purchaser f outside the mvh sector. NonMVH is the set of purchasers outside the mvh sector. These are non-mvh industries and final demanders (households, capital creators and government but not exports).
- DDUSE(n,s) for $n \in$ MVH, $s \in$OTHREG
  where DDUSE(n,s) is the value of domestically produced commodity n absorbed in region s.
- DABS(n,d) for $n \in$ MVH, $d \in$OTHREG
  where DABS(n,d) is the value of total absorption (domestic plus imported) of commodity n in region d.

  We also estimate

- ADJ(n,d) for $n \in$ MVH, $d \in$OTHREG
  where ADJ(n,d) is an adjustment factor on demand and supply of commodity n in region d. As we will see shortly, this factor is used to adjust our initial guesses of

demand and supply variables to align estimates of absorption in each region based on supply (output plus imports less exports) and demand (intermediate and final use excluding exports). A value of ADJ(n,d) of greater than one adjusts demand variables up and supply variables down.

- $A_{USCAN}(n,j)$ for $n \in INPUT$, $j \in MVH$
  where $A_{USCAN}(n,j)$ is the average input-output coefficient for Canada and the U.S. for the use of n in industry j.
- MSH(n,s,d) for $n \in MVH$, s, $d \in OTHREG$
  where MSH(n,s,d) is the share of the absorption of n in region d accounted for by supplies from region s.

We base the estimates of these coefficients on values given by data or initial guesses of:

- TR(n,s,d) for $n \in MVH$, s, $d \in REG$,
  where TR(n,s,d) is the value of commodity n exported from region s to region d.
- $VQ_{USCAN}(n)$ for $n \in MVH$,
  where $VQ_{USCAN}(n)$ is the aggregate value, calculated from U.S. and Canadian input-output data updated to 2015, of input n produced in the two countries.
- $Z_{USCAN}(n,j)$ for $n \in INPUT$, $j \in MVH$
  where $Z_{USCAN}(n,j)$ is the aggregate value, calculated from U.S. and Canadian input-output data updated to 2015, of input n (domestic plus imported if n is a commodity) used in the production of j in the two countries.
- $ODD_{USCAN}(n,f)$ for $n \in MVH$, $f \in NonMVH$
  where $ODD_{USCAN}(n,f)$ is the aggregate value, calculated from U.S. and Canadian input-output data updated to 2015, of commodity n (domestic plus imported) used by purchaser f in the two countries.
- VQ1(n,s) for $n \in MVH$, $s \in OTHREG$
  where VQ1(n,s) is our initial guess of the value of commodity n produced region s.
- Z1(n,j,s) for n, $j \in MVH$, $s \in OTHREG$
  where Z1(n,j,s) is our initial guess of the value of commodity n (domestic plus imported) used in the production of j in region s.
- ODD1(n,f,s) for $n \in MVH$, $f \in NonMVH$, $s \in OTHREG$
  where ODD1(n,f,s) is our initial guess of the value of commodity n (domestic plus imported) used by purchaser f in region s.

We make the estimates using the equation system listed below. In this system the variables to be estimated are in black normal type. The variables we take as given in red italics.

Estimating equation system

Absorption of n in region d calculated as imports +output – exports

$$DABS(n,d) = \sum_{\substack{s \in Reg \\ s \neq d}} \mathit{TR}(n,s,d) + VQ(n,d) - \sum_{\substack{s \in Reg \\ s \neq d}} \mathit{TR}(n,d,s) \quad \text{for all } n \in MVH,\ d \in OTHREG \tag{3.1}$$

Absorption of n in region d calculated as intermediate demands in the mvh sector and demand outside the mvh sector

$$DABS(n,d) = \sum_{j \in MVH} Z(n,j,d) + \sum_{f \in NonMVH} ODD(n,f,d) \quad \text{for all } n \in MVH,\ d \in OTHREG \tag{3.2}$$

Calculation of mvh-mvh input-output coefficients from U.S. and Canadian input-output data.

$$A_{USCAN}(n,j) = \frac{Z_{USCAN}(n,j)}{VQ_{USCAN}(j)} \quad \text{for all } n, j \in MVH \tag{3.3}$$

Intermediate use of n in industry j, region d estimated by applying US/Canada input-output coefficients and adjusting to reconcile absorption of n in d calculated by (3.1) and (3.2):

$$Z(n,j,d) = A_{USCAN}(n,j) * VQ(j,d) * ADJ(n,d) \quad \text{for all } n, j \in MVH,\ d \in OTHREG \tag{3.4}$$

Other (NonMVH) demands for n in region d after adjustment

$$ODD(n,f,d) = ODD1(n,f,d) * ADJ(n,d) \quad \text{for all } n \in MVH,\ f \in NonMVH,\ d \in OTHREG \tag{3.5}$$

Output of n in d after adjustment

$$VQ(n,d) = \frac{VQ1(n,d)}{ADJ(n,d)} \quad \text{for all } n \in MVH,\ d \in OTHREG \tag{3.6}$$

Calculation of the source shares (imports by region and domestic) in d's absorption of n:

$$MSH(n,s,d) = \begin{cases} \dfrac{TR(n,s,d)}{DABS(n,d)} & \text{for all } n \in MVH,\ s,d \in REG,\ s \neq d \\ 1 - \sum\limits_{s \neq d} \dfrac{TR(n,s,d)}{DABS(n,d)} & \text{for all } n \in MVH,\ d \in REG,\ s = d \end{cases} \tag{3.7}$$

Solving the equation system

Substituting from (3.3), (3.4), (3.5) and (3.6) into (3.1) and (3.2) gives

$$\sum_{\substack{s \in Reg \\ s \neq d}} TR(n,s,d) + \frac{VQ1(n,d)}{ADJ(n,d)} - \sum_{\substack{s \in Reg \\ s \neq d}} TR(n,d,s)$$

$$= \sum_{j \in MVH} \frac{Z_{USCAN}(n,j)}{VQ_{USCAN}(j)} * \frac{VQ1(j,d)}{ADJ(j,d)} * ADJ(n,d) + \sum_{f \in NonMVH} ODD1(n,f,d) * ADJ(n,d) \tag{3.8}$$

for all $n \in MVH$ and $d \in OTHREG$

The values of the adjustment factors, ADJ(n,d) can be computed from (3.8). Once they have been computed the values of all the other unknowns in (3.1) – (3.7) can be determined recursively.

Deriving the GTAP-MVH database by applying SplitCom

The GTAP database on commodity and factor flows can be organised into a NATIONAL matrix and a TRADE matrix. The NATIONAL matrix shows for each region the flows of commodities (undifferentiated by source) to industries and domestic final uses (households, capital creators and government, but not exports). The NATIONAL matrix also shows primary factor inputs to each industry. The TRADE matrix shows flows of each commodity from each region to each other region. To disaggregate the mvh sector into our required 9 mvh coms/inds we must perform the following operations:

(a) split the original mvh-to-mvh flow in the NATIONAL matrix for each region in to 81 flows (9 by 9);
(b) split each other original mvh flow in the NATIONAL matrix for each region into 9 flows;
(c) split each original input flow into the original mvh sector in the NATIONAL matrix for each region into 9 flows.

(d) split each of the new 9-order mvh commodity flows into values supplied from 10 sources (domestic plus 9 import sources).
(e) split each mvh flow in the original TRADE matrix into 9 flows.

Horridge (2008) provides a convenient GEMPACK program, titled SplitCom, to perform these operations. Users of the program must input to SplitCom initial shares to guide the splits. We obtained these initial shares from data for Canada and the U.S. and the solution of the 7 equation system set out in (3.1) – (3.7) for the other 8 regions. For the five operations (a) – (e) we used:

split (a): $Z(n,j,s)/\sum_{m\in MVH}\sum_{k\in MVH} Z(m,k,s)$ for all n, j∈MVH and s∈REG

split (b): $ODD(n,f,s)/\sum_{m\in MVH} ODD(m,f,s)$ for all n ∈MVH, f ∈NonMVH and s∈REG

split (c): $Z(n,j,s)/\sum_{k\in MVH} ODD(n,k,s)$ for all n ∈NonMVH_INPUT, j ∈MVH and s∈REG

where NonMVH_INPUT is the set of primary factors and commodities excluding MVH commodities

split (d): $MSH(n,s,d)$ for all n ∈MVH, s∈REG

split (e): $TR(n,s,d)/\sum_{m\in MVH} TR(m,s,d)$ for all n ∈MVH and s,d∈REG, s ≠ d

Given these initial shares, SplitCom divides all of the original mvh-related flows into flows for our 9 disaggregated mvh coms/inds in a way that: (i) preserves the values of the initial mvh-sector flows; (ii) reinstates necessary GTAP balance conditions; and (iii) implies shares that deviate from the initial split shares (a) to (e) as little as possible.

3.3. Compilation of trade data [TR(n,s,d)]

We downloaded data on import and export values for mvh products at the 6-digit HS (Harmonised code) level for the year 2015 from the COMTRADE database (UN Comtrade 2018, Chapters 84 and 87).

The data were then mapped and aggregated to the 9 new mvh commodities for the 10 GTAP-MVH regions. The concordance between 6-digit HS codes and the 9 mvh commodities in GTAP-MVH is reported in Table 3.1. The concordance is based on Aguiar (2016) and a careful examination of HS codes and their descriptions, as well as the descriptions of the 9 mvh commodities in NAICS (United States Census Bureau 2017).

The COMTRADE data come in the form EXPORTS(c,s,d), i.e. exports of commodity *c* from reporting region *s* to partner region *d*, and IMPORTS(c,d,s), i.e. imports of *c* to reporting region *d* from partner region *s*. In principle, these two types of data must match, i.e. for the same commodity *c* and the same country pair *s*,*d*, we expect EXPORTS(c,s,d) = IMPORTS (c,d,s). However, it is well-known that there are discrepancies in these data (see, for example, Gelhar 1996, Ferrantino et al. 2012, Shaar 2017). Reconciling them is a complex process. Within the scope of this project, the following procedure was used:

Step 1. According to UN guidelines (UN 2013), exports should be reported at FOB prices, and imports should be reported at CIF prices. Most countries follow this recommendation, but some do not (see UN 2008). Specifically, among the 10 regions in GTAP-MVH, the USA and Canada report imports at FOB, not CIF prices. Hence, the first step was to convert all COMTRADE import values (except those reported by the US and Canada) to FOB prices, using the FOB/CIF ratio for the motor vehicle sector in the original GTAP database.

Table 3.1. Concordance between mvh commodities in GTAP-MVH and 6-digit HS codes

	mvh commodities in GTAP-MVH	HS code
13	Automobile manufacturing	8702 (Motor vehicles for the transport of ten or more persons, including the driver.) 8703 - (Motor cars and other motor vehicles principally designed for the transport of persons, including station wagons and racing cars.) 8706 (chassis fitted with engines, for motor vehicles)
14	Motor vehicle gasoline engine and engine parts manufacturing	840731 – 840734, 840820, 840891, 840899 (Spark ignition reciprocating piston engines and parts)
15	Motor vehicle steering, suspension component (except spring) manufacturing	870880 (Suspension systems and parts thereof) 870894 (Steering wheels, columns, boxes)
16	Motor vehicle brakes and brake systems	870830 (Brakes and servo-brakes of motor vehicle)
17	Motor vehicle transmission and power train parts	870840 (Gear boxes and parts thereof) 870850 (Drive-axles with differential, whether/not provided with other transmission components, & non-driving axles; parts thereof of the motor vehicles of headings 87.01 to 87.05.)
18	Motor vehicle interior trim, seats and seat parts	870821 (Safety seat belts for motor vehicles) 870870 (Road wheels and parts and accessories thereof)[10]
19	Motor vehicle metal stamping (fenders, tops, body parts, trim, and molding)	8707 (Bodies (including cabs), for the motor vehicles of headings 87.01 to 87.05) 870810 (Bumpers and parts) 870829 (Parts & accessories of bodies (incl. cabs) of the motor vehicles of 87.01-87.05, *n*.e.*s*. in 87.08)
20	Other motor vehicle parts manufacturing	870891 (Radiators and parts) 870892 (Silencers and exhaust pipes) 870893 (Clutches and parts thereof, for tractors) 870895 (Safety airbags with inflator system) 870899 (Other parts & accessories for motor vehicle)
21	Truck, utility vehicle, trailer, motor home, travel trailer and camper manufacturing	870120 (Road tractors for semitrailers) 8704 (Motor vehicles for the transport of goods.) 8705 (Special purpose motor vehicles, other than those principally designed for the transport of persons or goods (for example, breakdown lorries, crane lorries, fire fighting vehicles, concrete-mixer lorries, road sweeper lorries, spraying lorries, mobile work) 8709 (Works trucks, self-propelled, not fitted with lifting or handling equipment, of the type used in factories, warehouses, dock areas or airports for short distance transport of goods; tractors of the type used on railway station platforms; parts of the fore) 8710 (Tanks and other armoured fighting vehicles, motorised, whether or not fitted with weapons, and parts of such vehicles.) 8716 (Trailers and semi-trailers; other vehicles, not mechanically propelled; parts thereof.) excl. 871680 (Other vehicles, not mechanically propelled, nes)

[10] This concordance is set by The Office in email communication, 13 August 2018.

Step 2. Next, we explored the discrepancies between export and import values of the same commodity flows between the same country pairs, now all at FOB prices. The discrepancies can be quite large. The ratios of export values to import values ranged from 0.3 to 23. There are several approaches to reconciling these discrepancies. For example, Gelhar (1996) and Shaar (2017) compile reliability and data quality indices for all countries, and then accept the reported trade flows of the more reliable partner in each country pair. Calderon et al. (2007) give primacy to the data reported by the country with the higher income in each country pair. The first approach requires significant resources and was beyond the scope of the current project. Hence, we adopted the second approach. Specifically:

- Among GTAP-MVH's 10 regions, we consider USA, Canada, Japan, South Korea, Germany, EU26 and the UK as higher income countries, and the remaining regions (Mexico, China and RoW) as lower income countries.
- For trade flows from higher income countries to lower income countries, we adopted export values reported by the higher income countries.
- For trade flows from lower income countries to higher income countries, we adopted import values reported by higher income countries.
- For trade flows amongst similar income level country pairs, we adopted the average values of imports and exports.

3.4. Setting the initial guesses for use in equation system (3.1) – (3.7)

(a) Outputs of new mvh industries in output: VQ1(n,s) for $n \in MVH$, $s \in OTHREG$

1. For Canada: IO data identifies all of the required 9 new mvh industries, hence the outputs can be calculated directly from the IO data.
2. For the USA: IO data identifies 7 of the required new mvh industries. Only 2 of the required mvh industries are aggregated into one sector. We use Canadian shares for these 2 industries to split the aggregated sector in the US data.
3. For other individual countries for which there are detailed input-output data, namely China, Japan, and South Korea, the outputs were calculated directly from their official input-output data as listed in subsection 3.1. The mvh industries in these data are usually somewhat more aggregated than the required industries. In these cases, we use the shares of the more detailed industries in the aggregate industries in the USA and Canada (i.e. USCAN data) to undertake the splits. For example, the Japanese input-output data distinguishes 4 mvh industries, namely (i) *Automobiles*; (ii) *Trucks, utility vehicles, and trailers*; (iii) *mvh gas engines and parts*; and (iv) *Other motor vehicle parts*. The first 3 industries are the same as those required for GTAP-MVH. The last industry is an aggregation of the 6 remaining required mvh industries. We used the shares of these 6 industries in their aggregate sector from the USCAN database to split the corresponding aggregate sector in the Japanese data into the 6 required mvh industries.
4. For the remaining countries/regions (Mexico, Germany, EU26, the UK and RoW) the outputs were calculated from data published by the United Nations Industrial Development Organization (UNIDO 2018). UNIDO data are at a 4-digit level of disaggregation, and hence do not provide information for all 9 new mvh industries (some of which are at 6-digit level). They provide information on 2 aggregated mvh sectors: (i) *Cars, trucks and trailers*, and (ii) *Parts and accessories for motor vehicles*. The aggregate '*Parts and accessories for motor vehicles*' industry in the UNIDO data were then

disaggregated into 2 aggregate industries '*mvh gas engines*' and '*Other mvh parts*', using data from Barnes reports (Barnes reports 2017a-c). At this stage, we have 3 mvh aggregate industries, namely: (1) *Cars, trucks and trailers*; (2) *mvh gas engines*; and (3) *other mvh parts*. These 3 aggregate industries were then disaggregated to the required 9 mvh industries, using the average shares of the 9 mvh industries in the corresponding 3 aggregated industries as calculated from the USCAN matrix.

(b) Production technologies of new mvh industries and demands for new mvh products outside the mvh sector: Z1(n,j,s) for n, j $\in$ *MVH, s* $\in$ *OTHREG and ODD1(n,f,s) for n* $\in$ *MVH, f* $\in$ *NonMVH, s* $\in$ *OTHREG*

An industry's production technology is described by the composition of intermediate and factor inputs required to produce a given level of the industry's output. We need information on the composition of the inputs to each of the new mvh industries in each region. To create the initial disaggregated database, we began by using production technologies (i.e. input cost shares) of each of the new mvh industries as described in the USCAN matrix. That is, we assumed that the production technologies for each of the new mvh industries in every region are the same as those of the U.S and Canada. We think this assumption is acceptable because the new mvh industries are sophisticated manufacturing industries, often representing subsidiaries of multi-national firms, and are thus likely to have similar production technologies. An alternative approach would have been to use the input structures from the input-output tables for the individual countries. We judged that this was problematic because of uncertainties concerning the comparability across countries of industrial classifications.

For our initial guesses of flows of mvh products to users outside the mvh sector our approach was to use mvh data at the most detailed level available in national input-output tables and then fill in what was not readily available by relying on shares from the USCAN data.

It should be emphasized that the procedures outlined in this subsection are used merely to provide initial guesses. We can be confident that the initial guesses are significantly improved by the use of detailed trade data as described in subsection 3.2. For example, if initially the procedure in this subsection give country s a low value for output of mvh gasoline engines but the trade data show a large quantity of exports, then the equation system in 3.2 leads to a significant upward revision of the value of s's output of this product.

3.5. Sales matrices for disaggregated mvh products: outcomes of the disaggregation procedures

Tables 3.2a - 3.2i contain sales matrices for the 9 mvh commodities in GTAP-MVH. These were generated by disaggregating GTAP-2011 data using the disaggregation procedures described in subsections 3.1 to 3.4. For each commodity, the rows in these tables show sales from source regions where the commodity is produced, and the columns show the destination regions where the commodity is used. The row totals show output values of the commodity in the source regions. The column totals show absorption values of the commodity in the destination regions. The diagonal elements of the tables show the commodity's use in the region where it is produced.

Table 3.2a. Automobiles: flows from source to destination (US$million, 2011)

Destination Source	1 USA	2 Canada	3 Mexico	4 Japan	5 SKorea	6 China	7 Germany	8 EU26	9 UK	10 RoW	Total
1 USA	103,206	4,589	2,025	252	93	883	667	447	189	3,712	116,063
2 Canada	11,034	7,871	410	26	18	182	33	127	23	614	20,336
3 Mexico	13,543	1,684	8,305	137	42	428	1,227	369	120	3,594	29,451
4 Japan	26,005	3,052	2,324	30,110	1,251	12,028	2,244	7,119	3,461	48,435	136,031
5 South Korea	6,463	1,030	462	491	6,599	3,038	577	3,623	410	20,929	43,622
6 China	860	92	62	495	155	123,170	171	413	195	4,006	129,620
7 Germany	11,478	1,575	952	3,469	1,318	11,675	17,805	60,119	16,890	32,784	158,067
8 EU26	3,168	354	470	1,322	488	3,502	27,292	114,147	17,512	27,869	196,123
9 UK	2,243	238	72	448	107	1,865	3,371	10,185	8,161	7,620	34,310
10 RoW	2,275	257	718	1,399	230	542	2,632	6,446	1,655	145,578	161,731
Total	180,276	20,741	15,799	38,150	10,301	157,313	56,020	202,997	48,616	295,140	1,025,355

Table 3.2b. Motor vehicle gasoline engine and engine parts: flows from source to destination (US$million, 2011)

Destination Source	1 USA	2 Canada	3 Mexico	4 Japan	5 SKorea	6 China	7 Germany	8 EU26	9 UK	10 RoW	Total
1 USA	22,916	2,937	2,307	141	143	698	578	240	39	1,411	31,411
2 Canada	2,184	3,298	187	5.8	11	57	11	27	1.9	93	5,877
3 Mexico	2,415	390	2,295	27	23	122	382	71	8.9	493	6,227
4 Japan	1,766	270	364	40,367	262	1,300	266	524	98	2,531	47,748
5 South Korea	499	103	82	43	8,609	374	78	304	13	1,244	11,350
6 China	577	80	95	372	322	51,596	200	300	54	2,066	55,663
7 Germany	1,647	293	315	562	589	2,677	13,871	9,371	1,006	3,617	33,948
8 EU26	646	93	220	303	311	1,145	9,775	29,282	1,481	4,375	47,633
9 UK	396	54	29	89	59	528	1,047	1,953	1,101	1,033	6,289
10 RoW	522	76	378	360	165	200	1,060	1,606	157	29,900	34,425
Total	33,568	7,594	6,273	42,271	10,493	58,697	27,269	43,680	3,959	46,764	280,570

Table 3.2c. Motor vehicle steering and suspension components: flows from source to destination (US$million, 2011)

Destination Source	1 USA	2 Canada	3 Mexico	4 Japan	5 SKorea	6 China	7 Germany	8 EU26	9 UK	10 RoW	Total
1 USA	11,493	687	450	22	16	140	86	39	7	213	13,152
2 Canada	396	1,703	32	0.8	1.1	10	1.5	3.9	0.3	13	2,162
3 Mexico	597	111	780	5.1	3.2	30	69	14	2.0	91	1,703
4 Japan	238	42	47	14,596	20	173	26	56	12	255	15,464
5 South Korea	118	28	19	8	2,748	88	14	57	2.9	220	3,302
6 China	182	29	29	88	57	16,871	46	76	16	490	17,885
7 Germany	299	61	55	77	60	480	4,885	1,349	168	489	7,922
8 EU26	124	21	40	44	33	217	1,374	9,151	262	625	11,890
9 UK	38	5.9	2.7	6.4	3.2	50	73	148	815	73	1,216
10 RoW	114	19	79	60	20	43	171	281	32	10,732	11,552
Total	13,599	2,707	1,533	14,906	2,962	18,102	6,747	11,175	1,317	13,202	86,248

Table 3.2d. Motor vehicle brakes and brake systems: flows from source to destination (US$million, 2011)

Destination Source	1 USA	2 Canada	3 Mexico	4 Japan	5 SKorea	6 China	7 Germany	8 EU26	9 UK	10 RoW	Total
1 USA	6,462	272	161	8	6	38	39	16	3	85	7,089
2 Canada	121	730	9.2	0.2	0.3	2.2	0.5	1.3	0.1	4.0	868
3 Mexico	223	43	456	1.8	1.2	7.8	30	5.8	0.8	35	805
4 Japan	106	19	19	7,686	9.1	54	14	28	5	118	8,059
5 South Korea	60	15	8.8	4	1,459	31	8.0	32	1.4	115	1,733
6 China	186	31	27	85	60	8,223	55	85	16	516	9,283
7 Germany	159	34	27	39	33	179	2,614	790	89	270	4,233
8 EU26	80	14	24	27	22	98	1,031	4,805	167	417	6,684
9 UK	40	6.5	2.6	6.4	3.4	37	90	171	308	80	745
10 RoW	45	7.8	29	22	8.2	12	78	121	12	5,882	6,217
Total	7,480	1,171	764	7,879	1,602	8,681	3,959	6,055	602	7,522	45,717

Table 3.2e. Motor vehicle transmission and power train parts: flows from source to destination (US$million, 2011)

Destination Source	1 USA	2 Canada	3 Mexico	4 Japan	5 SKorea	6 China	7 Germany	8 EU26	9 UK	10 RoW	Total
1 USA	28,958	2,400	1,997	95	108	1,017	389	191	32	1,007	36,194
2 Canada	908	3,354	73	1.8	3.7	38	3.5	10	0.7	30	4,423
3 Mexico	1,960	282	2,550	16	15	157	227	50	6.5	311	5,575
4 Japan	2,915	397	567	34,982	355	3,414	322	751	146	3,246	47,094
5 South Korea	565	104	88	36	7,702	674	65	298	13	1,094	10,639
6 China	236	29	36	112	107	52,690	60	107	20	656	54,053
7 Germany	1,309	207	237	330	385	3,394	13,438	6,461	722	2,233	28,716
8 EU26	333	43	108	116	132	939	3,700	24,977	689	1,748	32,784
9 UK	134	16	9.5	22	17	287	261	575	1,961	272	3,555
10 RoW	279	36	191	143	73	169	417	746	76	27,582	29,712
Total	37,596	6,868	5,857	35,854	8,896	62,778	18,882	34,166	3,666	38,179	252,743

Table 3.2f. Motor vehicle interior trim, seats and seat parts: flows from source to destination (US$million, 2011)

Destination Source	1 USA	2 Canada	3 Mexico	4 Japan	5 SKorea	6 China	7 Germany	8 EU26	9 UK	10 RoW	Total
1 USA	19,209	999	374	57	18	108	154	52	8	213	21,193
2 Canada	277	3,162	11	0.9	0.5	3.4	1.2	2.2	0.1	5.3	3,464
3 Mexico	414	68	1,797	5.7	1.5	10	52	8	0.9	38	2,394
4 Japan	53	8.1	5.2	34,602	3.0	18	6	10	1.7	34	34,741
5 South Korea	83	17	6.6	8.4	5,899	29	10	32	1.3	93	6,180
6 China	404	56	32	310	85	32,201	111	135	22	650	34,006
7 Germany	192	35	18	79	26	144	11,814	701	69	190	13,266
8 EU26	112	16	18	64	20	91	1,349	12,708	151	341	14,870
9 UK	25	3.5	0.9	6.9	1.4	15	53	79	829	29	1,044
10 RoW	134	20	47	112	16	24	217	266	24	12,142	13,001
Total	20,903	4,385	2,311	35,244	6,072	32,642	13,769	13,994	1,106	13,735	144,160

Table 3.2g. Motor vehicle metal stamping: flows from source to destination (US$million, 2011)

Destination Source	1 USA	2 Canada	3 Mexico	4 Japan	5 SKorea	6 China	7 Germany	8 EU26	9 UK	10 RoW	Total
1 USA	18,640	1,113	703	36	26	263	166	65	8.7	304	21,325
2 Canada	429	4,398	205	5.3	7.2	78	12	27	1.5	73	5,234
3 Mexico	326	364	2,010	17	11	113	270	47	4.9	262	3,425
4 Japan	96	101	108	39,240	48	482	75	139	22	538	40,847
5 South Korea	71	101	64	28	6,538	363	58	211	7.6	692	8,133
6 China	60	57	54	175	112	44,086	107	151	23	835	45,660
7 Germany	165	203	174	259	200	1,843	12,370	4,618	414	1,428	21,675
8 EU26	67	66	124	143	108	803	5,221	19,236	623	1,761	28,152
9 UK	22	21	9.1	23	11	203	306	537	984	227	2,343
10 RoW	63	63	253	201	68	165	669	953	78	18,505	21,018
Total	19,939	6,487	3,705	40,126	7,128	48,398	19,254	25,984	2,166	24,625	197,812

Table 3.2h. Other motor vehicle parts: flows from source to destination (US$million, 2011)

Destination Source	1 USA	2 Canada	3 Mexico	4 Japan	5 SKorea	6 China	7 Germany	8 EU26	9 UK	10 RoW	Total
1 USA	44,231	9,352	7,528	488	411	2,711	2,047	1,107	169	5,757	73,800
2 Canada	3,805	4,985	157	5.2	8.1	58	10	32	2.1	99	9,162
3 Mexico	5,062	389	5,410	30	21	147	420	102	12	624	12,216
4 Japan	2,255	164	226	69,008	143	954	178	456	80	1,951	75,416
5 South Korea	2,996	295	240	133	10,871	1,292	246	1,243	51	4,506	21,872
6 China	1,479	97	119	495	353	88,363	270	527	90	3,202	94,995
7 Germany	3,086	261	288	545	471	2,881	30,405	11,954	1,208	4,088	55,188
8 EU26	1,753	120	292	427	361	1,785	13,939	65,245	2,583	7,155	93,659
9 UK	631	41	23	74	41	484	878	2,122	4,855	993	10,141
10 RoW	1,170	81	414	419	158	257	1,251	2,458	227	59,739	66,175
Total	66,469	15,785	14,697	71,624	12,837	98,930	49,644	85,246	9,278	88,113	512,623

Table 3.2i. Trucks, utility vehicles, trailers, motor homes and campers: flows from source to destination (US$million, 2011

Source \ Destination	1 USA	2 Canada	3 Mexico	4 Japan	5 SKorea	6 China	7 Germany	8 EU26	9 UK	10 RoW	Total
1 USA	247,786	22,722	5,542	547	326	1,138	2,526	1,809	590	15,112	298,097
2 Canada	33,052	14,030	357	18	20	75	40	164	23	797	48,576
3 Mexico	26,417	1,734	14,627	62	30	114	960	309	78	3,035	47,366
4 Japan	8,591	536	223	103,299	151	534	294	1,002	376	6,906	121,911
5 South Korea	1,950	165	40	34	29,221	123	69	466	41	2,723	34,832
6 China	3,915	221	82	516	261	198,825	312	805	292	7,875	213,104
7 Germany	8,126	591	196	555	343	1,106	79,089	18,102	3,907	9,992	122,005
8 EU26	3,932	232	169	371	223	583	13,500	151,699	7,094	14,881	192,684
9 UK	832	47	7.8	37	15	91	495	1,597	25,029	1,212	29,363
10 RoW	4,009	238	368	564	151	130	1,863	4,860	959	209,908	223,050
Total	338,611	40,515	21,612	106,001	30,741	202,719	99,148	180,814	38,387	272,440	1,330,989

Table 3.3. Regional allocation of sales of Canadian-produced motor vehicle commodities (%)

mvh commodity \ Region	1 USA	2 Canada	3 Mexico	4 Japan	5 SKorea	6 China	7 Germany	8 EU26	9 UK	10 RoW	Total
1 Automobile	54.3	38.7	2.0	0.1	0.1	0.9	0.2	0.6	0.1	3.0	100.0
2 MVGasEngPrts	37.2	56.1	3.2	0.1	0.2	1.0	0.2	0.5	0.0	1.6	100.0
3 MVSteerSuspn	18.3	78.8	1.5	0.0	0.1	0.5	0.1	0.2	0.0	0.6	100.0
4 MVBrakes	13.9	84.0	1.1	0.0	0.0	0.3	0.1	0.2	0.0	0.5	100.0
5 MVPwrTrTrain	20.5	75.8	1.7	0.0	0.1	0.9	0.1	0.2	0.0	0.7	100.0
6 MVSeatInter	8.0	91.3	0.3	0.0	0.0	0.1	0.0	0.1	0.0	0.2	100.0
7 MVMtlStamp	8.2	84.0	3.9	0.1	0.1	1.5	0.2	0.5	0.0	1.4	100.0
8 OthMVParts	41.5	54.4	1.7	0.1	0.1	0.6	0.1	0.4	0.0	1.1	100.0
9 TruckUteTrlr	68.0	28.9	0.7	0.0	0.0	0.2	0.1	0.3	0.0	1.6	100.0
All mvh commodities	52.2	43.5	1.4	0.1	0.1	0.5	0.1	0.4	0.1	1.7	100.0

The tables shows that:

- Except for automobiles, most motor vehicle commodities are used mainly in the countries where they are produced. Exceptions include the production of Gasoline engines by Mexico and the UK. This production is mainly exported, to the USA in the case of Mexico, and to Germany and EU26 in the case of the UK. Another exception is the production Trucks etc by Canada and Mexico, which is absorbed mainly by the USA.
- Automobiles, as a finished product, are mainly used outside of their source regions. For example, the USA is the main user of automobiles produced by Canada and Mexico. Rest of World is the main user of automobiles produced by Japan and South Korea. EU26 is the main user of automobiles produced by Germany and the UK.
- With regard to finished products, EU26 and Germany are the biggest producers of Automobiles, while the USA and China are the biggest producers of Trucks, utility vehicles, trailers, motor homes and campers. Japan and China are the biggest producers of nearly all mvh components.

The tables can be converted to percentages in either the row direction or the column direction to highlight sales and demand patterns. We can also create new tables to highlight the data for all products for a particular country. This is done in Table 3.3 which shows destination percentages in the sales of Canadian mvh products. The table shows that the USA is by far the biggest export market for Canadian mvh products. Exports to the USA comprise more than half of Canadian Automobiles and Trucks etc, and over a third of Canadian Gasoline engines and Other motor vehicle parts. In total, exports to the USA comprise 52.2 per cent of Canada's mvh output and about 90 per cent of Canada's mvh exports. RoW and Mexico rank second and third among export markets for Canada's mvh products. But exports to these markets account for only small shares of Canadian output (1.7 and 1.4 per cent).

4. Concluding remarks

In this paper we have described modifications to the theory and database of the GTAP model to enhance its value as a tool for analysing the effects on Canada and other countries of changes in U.S. protection, particularly in the motor vehicle sector.

The most important theoretical innovation was the introduction to GTAP of industry-specific capital. This innovation was achieved quite simply mainly by a closure swap with little disruption to the standard model: the key idea was to endogenize a phantom tax on the use of capital by each industry in each region while exogenizing or pre-determining start-of-year capital availability in each industry and each region. A simplifying assumption that we retained from standard GTAP is that the commodity composition of investment is the same across industries in any given region.

With regard to the GTAP database, we specified a new method for disaggregating industries. The method makes maximum use of trade data that are readily available at a highly disaggregated level. It also uses detailed input-output data that are available for a few countries including Canada and the U.S. We demonstrated the new method by disaggregating the single mvh industry in standard GTAP into 9 industries. These 9 industries are part of the newly created GTAP-MVH model which has 26 industries in total and 10 regions.

The work reported in the paper can be deepened and improved in two directions. First, the new model, GTAP-MVH, needs to be applied in real-world policy situations. Only then will its strengths and weaknesses be revealed. Application is the main avenue through which areas for improvement in both theory and data are pinpointed. Second, detailed analysis is needed on the outcomes from our data disaggregation procedures. We need to analyse the results for the adjustment factors, ADJ(n,s), used to reconcile disparate information on demand for and supply of disaggregated commodities. We need to understand in greater depth the sensitivity of our final disaggregated database to the initial values for outputs by region and other variables that we feed into our disaggregation equation system. Analysis of these sensitivities will guide future research on the determination of these settings and the search for additional data sources to improve their accuracy.

Appendix 1. Inputs to baseline forecast for GTAP-MVH

Inputs into the update and baseline forecasts for the 10 regions in GTAP-MVH for the period 2011-2023 include: (i) changes in real GDP; (ii) changes in population; and (iii) changes in labor supply. In this section we discuss the data sources and our calculations for these inputs.

A1.1. Changes in regional real GDP

Table A1.1 reports GDP growth rates over the forecast periods, which are used as shocks in the baseline forecasts.

Table A1.1: Baseline growth rates in real GDP (%)

Years	USA	Canada	Mexico	Japan	S. Korea	China	Germany	EU-26	UK	RoW
2011	1.60	3.14	3.66	-0.12	3.68	9.50	3.72	1.22	1.45	7.57
2012	2.22	1.75	3.64	1.50	2.29	7.90	0.69	-1.13	1.48	3.73
2013	1.68	2.48	1.35	2.00	2.90	7.80	0.60	-0.24	2.05	3.66
2014	2.57	2.86	2.85	0.38	3.34	7.30	1.93	1.36	3.05	2.84
2015	2.86	1.00	3.27	1.35	2.79	6.90	1.50	2.42	2.35	1.77
2016	1.49	1.41	2.91	0.94	2.83	6.72	1.86	1.92	1.94	1.83
2017	2.27	3.00	2.04	1.71	3.09	6.86	2.51	2.58	1.79	2.69
2018	2.93	2.08	2.29	1.21	3.04	6.56	2.54	2.49	1.62	3.09
2019	2.66	2.04	3.04	0.92	2.92	6.41	2.01	2.10	1.52	3.41
2020	1.85	1.82	2.96	0.32	2.85	6.25	1.53	1.80	1.54	3.40
2021	1.70	1.79	2.93	0.67	2.78	6.00	1.36	1.69	1.55	3.39
2022	1.48	1.64	2.94	0.52	2.69	5.70	1.29	1.63	1.63	3.39
2023	1.39	1.60	2.86	0.52	2.62	5.53	1.21	1.63	1.64	3.39

Source: IMF World Economic Outlook database (IMF 2018a).

Changes in regional real GDP for the forecast periods were calculated from the World Economic Outlook database (IMF 2018a). The database contains GDP actual data for the period 1980-2016 and GDP projections to 2023 for 194 countries. The data are at current and constant prices, in national currency and in US dollars. Ideally, real GDP growth rates should be calculated from GDP at constant prices in national currencies, because GDP in U.S. dollars would be contaminated by movements in the exchange rates of the national currencies relative to the USD. However, this raises problems for regions in the model that are groups of countries, because each group's GDP could not be simply a sum of GDP values at different national currencies of countries within the group. Therefore, the following procedure was used to calculate movements in real GDP:

1. For individual countries among the 10 regions (namely, the USA, Canada, Mexico, Japan, South Korea, China, Germany and the UK), we calculated the percentage changes in GDP at constant prices in their national currencies.
2. For groups among the 10 regions (namely, EU-26 and Rest of the World), we calculated real GDP growth rates measured in national currencies of individual countries within each group. The group's real GDP growth rate was then calculated as the weighted average of the individual countries' growth rates, using their GDP in USD in 2011 as weights.[11]

Over the forecast period, China is by far the fastest growing region. Other regions grow more or less at similar rates, although Japan is projected to grow the slowest. For the factors underlying these forecasts, see IMF (2018b).

[11] 2011 is the year of the starting database of GTAP-MVH.

A1.2. Changes in labor supply and population

Changes in labor supply and population for the forecast period were calculated from population estimates and projections for 259 countries and country groups, and by age groups (World Bank 2018).[12]

The growth rates of labor supply for the ten regions in GTAP-MVH were calculated from World Bank (2018) projections for population aged 15 - 64, i.e. the working age population (WAP). We assumed that, for all regions in the model, labor force participation rates would remain unchanged over the forecast periods, and hence percentage changes in WAP were adopted as percentage changes in labor supply.

Population growth rates were calculated from World Bank (2018) projections for the number of total population of the regions.

Tables A1.2 and A1.3 report the projected baseline growth rates in population and labor supply for the ten regions.

Table A1.2. Baseline growth rates in population (%)

Years	USA	Canada	Mexico	Japan	S. Korea	China	Germany	EU-26	UK	RoW
2011	0.74	0.99	1.51	-0.19	0.77	0.48	-1.84	0.17	0.78	1.61
2012	0.75	1.19	1.46	-0.16	0.53	0.49	0.19	0.14	0.70	1.50
2013	0.71	1.16	1.41	-0.14	0.46	0.49	0.27	0.24	0.67	1.59
2014	0.75	1.09	1.38	-0.13	0.63	0.51	0.42	0.21	0.76	1.57
2015	0.76	0.84	1.34	-0.11	0.53	0.51	0.87	0.08	0.80	1.55
2016	0.74	1.21	1.31	-0.12	0.45	0.54	0.81	0.10	0.72	1.52
2017	0.71	1.22	1.27	-0.16	0.43	0.56	0.42	0.13	0.65	1.50
2018	0.74	0.88	1.24	-0.30	0.35	0.34	-0.11	0.05	0.56	1.45
2019	0.74	0.85	1.20	-0.31	0.33	0.30	-0.12	0.04	0.56	1.43
2020	0.73	0.82	1.17	-0.33	0.32	0.26	-0.12	0.03	0.55	1.41
2021	0.73	0.79	1.13	-0.34	0.30	0.22	-0.12	0.02	0.53	1.38
2022	0.72	0.77	1.10	-0.37	0.28	0.18	-0.11	0.01	0.51	1.36
2023	0.71	0.75	1.06	-0.39	0.27	0.15	-0.11	0.00	0.49	1.34

Source: World Bank population estimates and projections (World Bank 2018).

Table A1.3. Baseline growth rates in labor supply (%)

Years	USA	Canada	Mexico	Japan	S. Korea	China	Germany	EU-26	UK	RoW
2011	0.61	0.65	2.12	-1.13	0.88	0.42	-1.89	-0.27	0.30	1.87
2012	0.59	0.82	2.05	-1.18	0.62	0.29	0.20	-0.36	0.21	1.77
2013	0.51	0.74	1.97	-1.20	0.48	0.17	0.29	-0.32	0.18	1.83
2014	0.50	0.60	1.89	-1.16	0.54	0.08	0.37	-0.37	0.26	1.79
2015	0.44	0.28	1.80	-1.06	0.31	0.00	0.74	-0.48	0.31	1.75
2016	0.42	0.58	1.64	-0.92	0.15	-0.10	0.62	-0.36	0.30	1.65
2017	0.31	0.52	1.60	-0.88	0.02	-0.13	0.16	-0.36	0.24	1.62
2018	0.27	0.14	1.53	-0.93	-0.20	-0.35	-0.44	-0.43	0.17	1.58
2019	0.26	0.12	1.45	-0.87	-0.36	-0.33	-0.51	-0.41	0.20	1.56
2020	0.27	0.11	1.37	-0.82	-0.53	-0.28	-0.56	-0.40	0.22	1.54
2021	0.15	0.03	1.34	-0.69	-0.65	-0.20	-0.70	-0.43	0.19	1.48
2022	0.21	0.06	1.25	-0.63	-0.81	-0.15	-0.75	-0.38	0.23	1.47
2023	0.22	0.08	1.18	-0.60	-0.93	-0.14	-0.80	-0.36	0.23	1.46

[12] IMF (2018a) also contains data and projections for population, employment and unemployment to 2023. However, the data for employment and unemployment are missing for many countries. Hence we used the World Bank (2018) data.

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