Updates to disaggregating the refined oil sector in EPPA: EPPA6-ROIL

David Ramberg and Y.H. Henry Chen

MIT JOINT PROGRAM ON THE SCIENCE AND POLICY of GLOBAL CHANGE

Technical Note No. 15
December 2015

The MIT Joint Program on the Science and Policy of Global Change combines cutting-edge scientific research with independent policy analysis to provide a solid foundation for the public and private decisions needed to mitigate and adapt to unavoidable global environmental changes. Being data-driven, the Program uses extensive Earth system and economic data and models to produce quantitative analysis and predictions of the risks of climate change and the challenges of limiting human influence on the environment—essential knowledge for the international dialogue toward a global response to climate change.

To this end, the Program brings together an interdisciplinary group from two established MIT research centers: the Center for Global Change Science (CGCS) and the Center for Energy and Environmental Policy Research (CEEPR). These two centers—along with collaborators from the Marine Biology Laboratory (MBL) at Woods Hole and short- and long-term visitors—provide the united vision needed to solve global challenges.

At the heart of much of the Program's work lies MIT's Integrated Global System Model. Through this integrated model, the Program seeks to: discover new interactions among natural and human climate system components; objectively assess uncertainty in economic and climate projections; critically and quantitatively analyze environmental management and policy proposals; understand complex connections among the many forces that will shape our future; and improve methods to model, monitor and verify greenhouse gas emissions and climatic impacts.

This reprint is one of a series intended to communicate research results and improve public understanding of global environment and energy challenges, thereby contributing to informed debate about climate change and the economic and social implications of policy alternatives.

Ronald G. Prinn and John M. Reilly,
Program Co-Directors

For more information, contact the Program office:
MIT Joint Program on the Science and Policy of Global Change

Postal Address:
Massachusetts Institute of Technology
77 Massachusetts Avenue, E19-411
Cambridge, MA 02139 (USA)

Location:
Building E19, Room 411
400 Main Street, Cambridge

Access:
Tel: (617) 253-7492
Fax: (617) 253-9845
Email: ***globalchange@mit.edu***
Website: ***http://globalchange.mit.edu/***

Updates to disaggregating the refined oil sector in EPPA: EPPA6-ROIL

David Ramberg* and Y.H. Henry Chen†

Abstract

This note describes how to disaggregate the standard version of EPPA's refined oil (ROIL) commodity into specific refined petroleum products. EPPA's treatment of all refined products as a single commodity implies that all refined fuels are fungible, that the ease of international trade in each fuel is equal, and that all refined fuels face the same drivers of demand. This treatment precludes examination of competition between specific refined fuels (e.g., gasoline cars vs. diesel cars), modeling the impacts of low-sulfur fuel requirements (which would prohibit usage of residual fuel oils in maritime shipping, for example), or the examination of technologies that could compete with oil refining in specific fuels (e.g., gas-to-liquids (GTL), coal-to-liquids (CTL), or even a rigorous treatment of biofuel production. The methodology described here disaggregates the refined oil product imported from Global Trade Analysis Project (GTAP) by calculating the volume and value flow shares of six refined fuel categories. Data from the International Energy Agency (IEA), the U.S. Energy Information Administration (EIA), and the International Council on Clean Transportation (ICCT) are utilized to calculate these shares.

Contents

*Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology, Cambridge, MA. (Email: dramberg@alum.mit.edu)

†Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology, Cambridge, MA. (Email: chenyh@mit.edu)

1. INTRODUCTION

MIT's Economic Projection and Policy Analysis (EPPA) model at the Joint Program on the Science and Policy of Global Change is a computable general equilibrium (CGE) model that simulates microeconomic processes over long time scales. EPPA models production as a choice between inputs of varying levels of substitutability. The current version, EPPA6, is described in Chen *et al.* (2015). An earlier version is detailed in Paltsev *et al.* (2005). The global economy is broken into 18 regions and 14 sectors of production, with 2 sectors for consumption: final demand and household transportation. In each region is a single producer for each sector that operates under the principle of perfect competition (price equals cost). Each sector produces a single commodity. That commodity is traded under an Armington specification[1] in every case except crude oil (Armington, 1969). Crude oil is traded under the Heckscher-Ohlin assumption of perfect substitutability across regions (Hecksher and Ohlin, 1933). Production is modeled using nested constant elasticity of substitution (CES) functions. This is useful for examining how one fuel input can be substituted for another. The data in the model are from the Global Trade Analysis Project (GTAP) (Narayanan *et al.*, 2012a). EPPA6 is calibrated to a 2007 base year. It solves for 2010, then solves through 2100 in five-year intervals thereafter.

This note describes two modifications that can be made for analyses that require more detail in the refined oil commodities. EPPA uses a single sector and commodity for refined oil, called ROIL. Treating all refined fuels as a single aggregated commodity assumes that demand growth, usage, and tradeability of each refined fuel is uniform, and that each is perfectly interchangeable. This precludes analyses of technologies that produce fuels that are only perfectly substitutable with some, but not all, petroleum products. It would also preclude examination of competition *between* key refined fuels in the transport sector. A single commodity is too aggregated for this purpose. In 2006, Choumert *et al.* (2006) developed a version of EPPA that disaggregated the ROIL commodity into six products: refinery gases (RGAS), distillate fuels (DISL), gasolines (GSLN), heavy fuel oils (HFOL), petroleum coke (COKE), and other products (OTHP). He also added technologies that were relevant only if the ROIL product were separated into distinct fuels. The modified model was EPPA-ROIL.

[1] The Armington model of trade assumes that internationally-traded products are not uniform in quality or other characteristics, so are not perfectly substitutable. Each commodity has an elasticity of substitution that measures the degree to which imported goods are substitutable with domestically-produced ones.

The ROIL commodity in EPPA is traded as an Armington good. This makes sense under an aggregated petroleum product, since many refined fuels are of limited international substitutability. However, for transportation fuels, the Heckscher-Ohlin paradigm of perfect international substitutability is more appropriate for modeling inter-regional trade. This paper describes Choumert's methodology (with some modifications) to break out the individual fuels from the aggregated refined oil (ROIL) product, add GTL technology, and modify trade specifications for transport fuels. It does not provide detail on the workings of the EPPA model itself except where it pertains to the disaggregation of the ROIL commodity.

2. DATA

Five databases were utilized in the disaggregation of the aggregated refined oil commodity (ROIL) into sub-products that allow for inter-fuel competition to be modeled. The initial data are from the GTAP8 database described in Narayanan *et al.* (2012b). GTAP8 contains the volumes and values consumed in each region and sector for the aggregated refined oil product. Volumes were disaggregated using the International Energy Agency (IEA) Energy Statistics and Balances Database (International Energy Agency, 2010).[2] Value flows were re-constructed by referring to the IEA Energy Prices and Taxes database (International Energy Agency, 2008) for principal fuels in major regions. Then the relative prices between the principal fuels and the products that were not included in Energy Prices and Taxes were estimated using the State Energy Data System (SEDS) database (U.S. Energy Information Administration, 2014). Data from the International Council on Clean Transportation (ICCT) Global Transportation Roadmap model (International Council on Clean Transportation, 2012) were used to disaggregate the household transportation fuel usage. The refined oil commodity is disaggregated into six sub-commodities: RGAS, DISL, GSLN, HFOL, OTHP, and COKE.

2.1 The Global Trade Analysis Project (GTAP) 8 database

The GTAP database, version 8 ("GTAP8") provides the aggregated refined oil product data. It covers 244 countries aggregated into 129 regions and 57 sectors. Each sector produces a single commodity, and the commodity inputs to support activity in each sector are recorded. All production, trade flows and consumption are balanced so that the entire data base is an input-output table for the global economy. The commodities are aggregated from Central Product Classification (CPC) codes for food processing and agriculture (21 sectors) and the International Standard Industry Classification (ISIC) codes for the remaining 36 sectors (Narayanan *et al.*, 2012a). The GTAP8 sector that corresponds to the ROIL sector in the model is called the *p_c* sector. It includes ISIC codes 231 (Manufacture of coke oven products), 232 (Manufacture of refined petroleum products), and 233 (Processing of nuclear fuel) (Narayanan *et al.*, 2012b).

The *p_c* sector in GTAP8 appears in many data sets that are relevant to the structure of the CGE model. **Table 1** presents a list of the components of GTAP8 referenced in the data preparation for EPPA that contain the *p_c* commodity. Agent prices are prices including taxes. Market prices are ex-tax. The indices on each data set are as follows: i denotes sectors, j is an alias for

[2] http://www.oecd-ilibrary.org/energy/data/iea-world-energy-statistics-and-balances_enestats-data-en

Table 1. GTAP8 data sets containing the *p_c* product for disaggregation

GTAP8 data set	Description
vdga(i,r)	Government - domestic purchases at agents' prices
viga(i,r)	Government - imports at agents' prices
vdgm(i,r)	Government - domestic purchases at market prices
vigm(i,r)	Government - imports at market prices
vdpa(i,r)	Private households - domestic purchases at agents' prices
vipa(i,r)	Private households - imports at agents' prices
vdpm(i,r)	Private households - domestic purchases at market prices
vipm(i,r)	Private households - imports at market prices
evoa(f,r)	Endowments - output at agents' prices
evfa(f,x,r)	Endowments - firms' purchases at agents' prices
vfm(f,x,r)	Endowments - firms' purchases at market prices
vdfa(i,x,r)	Intermediates - firms' domestic purchases at agents' prices
vifa(i,x,r)	Intermediates - firms' imports at agents' prices
vdfm(i,x,r)	Intermediates - firms' domestic purchases at market prices
vifm(i,x,r)	Intermediates - firms' imports at market prices
vxmd(i,r,s)	Trade - bilateral exports at market prices
vxwd(i,r,s)	Trade - bilateral exports at world prices
vst(i,r)	Trade - exports for international transportation
vtwr(i,j,r,s)	Trade - margins for international transportation at world prices
ftrv(f,j,r)	Taxes - factor employment tax revenue
fbep(f,j,r)	Protection - factor-based subsidies
isep(i,j,r,src)	Protection - intermediate input subsidies
osep(i,r)	Protection - ordinary output subsidies
adrv(i,r,s)	Protection - anti-dumping duty
tfrv(i,r,s)	Protection - ordinary import duty
purv(i,r,s)	Protection - price undertaking export tax equivalent
vrrv(i,r,s)	Protection - VER export tax equivalent
mfrv(i,r,s)	Protection - MFA export tax equivalent
xtrv(i,r,s)	Protection - ordinary export tax
edf(i,j,r)	Usage of domestic product by firms (mtoe)
eif(i,j,r)	Usage of imported product by firms (mtoe)
edp(i,j,r)	Private consumption of domestic product by firms (mtoe)
eip(i,j,r)	Private consumption of imported product by firms (mtoe)
edg(i,j,r)	Government consumption of domestic product by firms (mtoe)
eig(i,j,r)	Government consumption of imported product by firms (mtoe)
exidag(i,r,s)	Volume of trade (mtoe)

Source: Narayanan *et al.* (2012b).

sectors to distinguish inter-sectoral transactions, r denotes regions, s is an alias for regions to distinguish region-to-region trade flows, f denotes factors of production, src denotes the source (domestic or imported), and x denotes all goods including final consumption, government consumption, and investment.[3] The *p_c* sector is disaggregated into the six sub-products wherever it

[3] Initial data preparation integrates *vdpm* and *vdgm* into *vdfm*, *vipm* and *vigm* into *vifm*, *vdpa* and *vdga* into *vdfa*, and *vipa* and *viga* into *vifa*. Private households are designated as sector "c" and government is designated sector "g" in *vdfm*, *vifm*, *vdfa*, and *vifa*.

appears in the data sets shown in Table 1. The *p_c* product only needs to be disaggregated when it is used as an input to other activities and in production. The *p_c* commodity need not be aggregated when it is listed as a consumer of inputs, since the *p_c* sector maps directly into ROIL as a production sector. Unlike every other sector in EPPA6-ROIL, the ROIL sector is a multi-output sector, producing six commodities: 13 sectors each produce a single commodity, but the ROIL sector produces six commodities.

2.2 The International Energy Agency (IEA) Energy Statistics and Balances Database

Volume data in the IEA Energy Statistics and Balances Database are used to break the GTAP8 *p_c* commodity volumes into the six ROIL sub-products. The website for the Organization for Economic Cooperation and Development (OECD) hosts the Energy Statistics and Balances Database.[4] The Energy Statistics database contains data for 102 "FLOWS" – a combination of sectoral consumption, production, imports, and exports – and 143 countries. 57 of the FLOWS represent consumption by economic sectors. Energy Statistics and Balances also traces the volumetric flows of 68 energy products in tons of oil equivalent (TOE) (International Energy Agency, 2010). 24 of these energy products are sourced from petroleum. The IEA regions, sectors, and fuels are di-rectly mapped to the EPPA regions, sectors and fuels. **Table 2** illustrates the IEA-GTAP8-EPPA regional mapping relationships.

Table 2. IEA-GTAP8-EPPA6 regional mapping with description

IEA "COUNTRY"	GTAP8 Region	EPPA6 Region	Description
Albania	ALB	roe	Non-EU Europe/FSU
Algeria	XNF	afr	Africa
Angola	XAC	afr	Africa
Argentina	ARG	lam	Latin America
Armenia	ARM	roe	Non-EU Europe/FSU
Australia	AUS	anz	Australia/New Zealand and Pacific Islands
Austria	AUT	eur	European Union
Azerbaijan	AZE	roe	Non-EU Europe/FSU
Bahrain	BHR	mes	Middle East
Bangladesh	BGD	rea	Rest of Asia
Belarus	BLR	roe	Non-EU Europe/FSU
Belgium	BEL	eur	European Union
Benin	XWF	afr	Africa
Bolivia	BOL	lam	Latin America
Bosnia and Herzegovina	XER	roe	Non-EU Europe/FSU
Botswana	BWA	afr	Africa
Brazil	BRA	bra	Brazil
Brunei Darussalam	XSE	rea	Rest of Asia
Bulgaria	BGR	eur	European Union
Cambodia	KHM	rea	Rest of Asia
Cameroon	CMR	afr	Africa
Canada	CAN	can	Canada
Chile	CHL	lam	Latin America
Chinese Taipei	TWN	asi	Asia Pacific
Colombia	COL	lam	Latin America
Congo	XCF	afr	Africa
Costa Rica	CRI	lam	Latin America
Cote d'Ivoire	CIV	afr	Africa

Continued on next page

[4] http://www.oecd-ilibrary.org/energy/data/iea-world-energy-statistics-and-balances_enestats-data-en

Table 2 – *Continued from previous page*

IEA "COUNTRY"	GTAP8 Region	EPPA6 Region	Description
Croatia	HRV	roe	Non-EU Europe/FSU
Cuba	XCB	lam	Latin America
Cyprus	CYP	eur	European Union
Czech Republic	CZE	eur	European Union
Dem. People's Rep. of Korea	XEA	rea	Rest of Asia
Democratic Republic of Congo	XAC	afr	Africa
Denmark	DNK	eur	European Union
Dominican Republic	XCB	lam	Latin America
Ecuador	ECU	lam	Latin America
Egypt	EGY	afr	Africa
El Salvador	SLV	lam	Latin America
Eritrea	XEC	afr	Africa
Estonia	EST	eur	European Union
Ethiopia	ETH	afr	Africa
Finland	FIN	eur	European Union
Former Yugoslav Republic of Macedonia	XER	roe	Non-EU Europe/FSU
France	FRA	eur	European Union
Gabon	XCF	afr	Africa
Georgia	GEO	roe	Non-EU Europe/FSU
Germany	DEU	eur	European Union
Ghana	GHA	afr	Africa
Gibraltar	XER	roe	Non-EU Europe/FSU
Greece	GRC	eur	European Union
Guatemala	GTM	lam	Latin America
Haiti	XCB	lam	Latin America
Honduras	HND	lam	Latin America
Hong Kong, China	HKG	chn	China
Hungary	HUN	eur	European Union
Iceland	XEF	eur	European Union
India	IND	ind	India
Indonesia	IDN	idz	Indonesia
Iraq	XWS	mes	Middle East
Ireland	IRL	eur	European Union
Islamic Republic of Iran	IRN	mes	Middle East
Israel	isr	mes	Middle East
Italy	ITA	eur	European Union
Jamaica	XCB	lam	Latin America
Japan	JPN	jpn	Japan
Jordan	XWS	mes	Middle East
Kazakhstan	KAZ	roe	Non-EU Europe/FSU
Kenya	KEN	afr	Africa
Korea	KOR	kor	South Korea
Kosovo	XEE	roe	Non-EU Europe/FSU
Kuwait	KWT	mes	Middle East
Kyrgyzstan	KGZ	roe	Non-EU Europe/FSU
Latvia	LVA	eur	European Union
Lebanon	XWS	mes	Middle East
Libya	XNF	afr	Africa
Lithuania	LTU	eur	European Union
Luxembourg	LUX	eur	European Union
Malaysia	MYS	asi	Asia Pacific
Malta	MLT	eur	European Union
Mexico	MEX	mex	Mexico
Mongolia	MNG	rea	Rest of Asia
Montenegro	XER	roe	Non-EU Europe/FSU
Morocco	MAR	afr	Africa
Mozambique	MOZ	afr	Africa
Myanmar	XSE	rea	Rest of Asia
Namibia	NAM	afr	Africa

Continued on next page

Table 2 – *Continued from previous page*

IEA "COUNTRY"	GTAP8 Region	EPPA6 Region	Description
Nepal	NPL	rea	Rest of Asia
Netherlands	NLD	eur	European Union
Netherlands Antilles	XCB	lam	Latin America
New Zealand	NZL	anz	Australia/New Zealand and Pacific Islands
Nicaragua	NIC	lam	Latin America
Nigeria	NGA	afr	Africa
Norway	NOR	eur	European Union
Oman	omn	mes	Middle East
Other Africa	MDG	afr	Africa
Other Africa	MUS	afr	Africa
Other Africa	MWI	afr	Africa
Other Africa	UGA	afr	Africa
Other Africa	XCF	afr	Africa
Other Africa	XEC	afr	Africa
Other Africa	XSC	afr	Africa
Other Africa	XWF	afr	Africa
Other Asia	LAO	rea	Rest of Asia
Other Asia	XOC	anz	Australia/New Zealand and Pacific Islands
Other Asia	XSA	rea	Rest of Asia
Other Asia	XTW	anz	Australia/New Zealand and Pacific Islands
Other Non-OECD Americas	XCA	lam	Latin America
Other Non-OECD Americas	XNA	lam	Latin America
Other Non-OECD Americas	XSM	lam	Latin America
Pakistan	PAK	rea	Rest of Asia
Panama	PAN	lam	Latin America
Paraguay	PRY	lam	Latin America
People's Republic of China	CHN	chn	China
Peru	PER	lam	Latin America
Philippines	PHL	asi	Asia Pacific
Poland	POL	eur	European Union
Portugal	PRT	eur	European Union
Qatar	QAT	mes	Middle East
Republic of Moldova	XEE	roe	Non-EU Europe/FSU
Romania	ROU	eur	European Union
Russian Federation	RUS	rus	Russia
Saudi Arabia	SAU	mes	Middle East
Senegal	SEN	afr	Africa
Serbia	XER	roe	Non-EU Europe/FSU
Singapore	SGP	asi	Asia Pacific
Slovak Republic	SVK	eur	European Union
Slovenia	SVN	eur	European Union
South Africa	ZAF	afr	Africa
Spain	ESP	eur	European Union
Sri Lanka	LKA	rea	Rest of Asia
Sudan	XEC	afr	Africa
Sweden	SWE	eur	European Union
Switzerland	CHE	eur	European Union
Syrian Arab Republic	XWS	mes	Middle East
Tajikistan	XSU	roe	Non-EU Europe/FSU
Thailand	THA	asi	Asia Pacific
Togo	XWF	afr	Africa
Trinidad and Tobago	XCB	lam	Latin America
Tunisia	TUN	afr	Africa
Turkey	TUR	roe	Non-EU Europe/FSU
Turkmenistan	XSU	roe	Non-EU Europe/FSU
Ukraine	UKR	roe	Non-EU Europe/FSU

Continued on next page

IEA "COUNTRY"	GTAP8 Region	EPPA6 Region	Description
Table 2 – *Continued from previous page*			
United Arab Emirates	ARE	mes	Middle East
United Kingdom	GBR	eur	European Union
United Republic of Tanzania	TZA	afr	Africa
United States	USA	usa	United States
Uruguay	URY	lam	Latin America
Uzbekistan	XSU	roe	Non-EU Europe/FSU
Venezuela	VEN	lam	Latin America
Vietnam	VNM	rea	Rest of Asia
Yemen	XWS	mes	Middle East
Zambia	ZMB	afr	Africa
Zimbabwe	ZWE	afr	Africa

Table 3 details the sectoral mapping between data from the IEA, GTAP8, and EPPA.

Table 3. IEA-GTAP8-EPPA6 sector mapping

IEA FLOW	GTAP8 Sector	EPPA6 Sector
Agriculture/forestry	c_b	crop
Agriculture/forestry	gro	crop
Agriculture/forestry	ocr	crop
Agriculture/forestry	osd	crop
Agriculture/forestry	pdr	crop
Agriculture/forestry	pfb	crop
Agriculture/forestry	v_f	crop
Agriculture/forestry	wht	crop
Agriculture/forestry	frs	fors
Agriculture/forestry	ctl	live
Agriculture/forestry	oap	live
Autoproducer CHP plants	ely	elec
Autoproducer electricity plants	ely	elec
Autoproducer heat plants	gdt	gas
BKB plants	i_s	eint
Blast furnaces	i_s	eint
Charcoal production plants	lum	othr
Chemical and petrochemical	crp	eint
Chemical heat for electricity production	ely	elec
Coal liquefaction plants	p_c	roil
Coal mines	coa	coal
Coke ovens	p_c	roil
Commercial and public services	g	serv
Commercial and public services	isr	serv
Commercial and public services	obs	serv
Commercial and public services	ofi	serv
Commercial and public services	osg	serv
Commercial and public services	ros	serv
Commercial and public services	trd	serv
Construction	cns	othr
Domestic aviation	atp	tran
Domestic navigation	wtp	tran
Electric boilers	gdt	gas
Fishing	fsh	live
Food and tobacco	b_t	food
Food and tobacco	cmt	food
Food and tobacco	mil	food
		Continued on next page

Table 3 – *Continued from previous page*

IEA FLOW	GTAP8 Sector	EPPA6 Sector
Food and tobacco	ofd	food
Food and tobacco	omt	food
Food and tobacco	pcr	food
Food and tobacco	sgr	food
Food and tobacco	vol	food
Food and tobacco	rmk	live
For blended natural gas	gdt	gas
Gas works	gdt	gas
Gasification plants for biogases	gdt	gas
Heat pumps	gdt	gas
Industry	fmp	eint
International aviation bunkers	atp	vtwr.atp
International marine bunkers	wtp	vtwr.wtp
Iron and steel	i_s	eint
Liquefaction (LNG)/regasification plants	gdt	gas
Machinery	ele	othr
Machinery	ome	othr
Main activity producer CHP plants	ely	elec
Main activity producer electricity plants	ely	elec
Main activity producer heat plants	gdt	gas
Mining and quarrying	omn	othr
Non-energy use in other	lum	othr
Non-energy use in other	cns	othr
Non-energy use in other	ele	othr
Non-energy use in other	ome	othr
Non-energy use in other	omn	othr
Non-energy use in other	omf	othr
Non-energy use in other	wtr	othr
Non-energy use in other	otn	othr
Non-energy use in other	lea	othr
Non-energy use in other	tex	othr
Non-energy use in other	wap	othr
Non-energy use in other	mvh	othr
Non-energy use in other	otn	othr
Non-energy use in other	lum	othr
Non-energy use in transport	atp	tran
Non-energy use in transport	wtp	tran
Non-energy use in transport	otp	tran
Non-energy use industry/transformation/energy	i_s	eint
Non-energy use industry/transformation/energy	crp	eint
Non-energy use industry/transformation/energy	fmp	eint
Non-energy use industry/transformation/energy	nfm	eint
Non-energy use industry/transformation/energy	nmm	eint
Non-energy use industry/transformation/energy	ppp	eint
Non-ferrous metals	nfm	eint
Non-metallic minerals	nmm	eint
Non-specified (energy)	lum	othr
Non-specified (energy)	cns	othr
Non-specified (energy)	ele	othr
Non-specified (energy)	ome	othr
Non-specified (energy)	omn	othr
Non-specified (energy)	omf	othr
Non-specified (energy)	wtr	othr
Non-specified (energy)	otn	othr
Non-specified (energy)	lea	othr
Non-specified (energy)	tex	othr
Non-specified (energy)	wap	othr
Non-specified (energy)	mvh	othr
Non-specified (energy)	otn	othr

Continued on next page

Table 3 – *Continued from previous page*

IEA FLOW	GTAP8 Sector	EPPA6 Sector
Non-specified (energy)	lum	othr
Non-specified (industry)	omf	othr
Non-specified (industry)	wtr	othr
Non-specified (other)	cmn	serv
Non-specified (transformation)	i_s	eint
Non-specified (transformation)	crp	eint
Non-specified (transformation)	fmp	eint
Non-specified (transformation)	nfm	eint
Non-specified (transformation)	nmm	eint
Non-specified (transformation)	ppp	eint
Non-specified (transport)	otn	othr
Nuclear industry	p_c	roil
Oil and gas extraction	gas	gas
Oil and gas extraction	oil	oil
Oil refineries	p_c	roil
Own use in electricity, CHP and heat plants	ely	elec
Paper, pulp and print	ppp	eint
Petrochemical plants	crp	eint
Pipeline transport	otp	tran
Pumped storage plants	ely	elec
Rail	otp	tran
Residential	c	dwe
Residential	dwe	dwe
Road	otp	tran
Textile and leather	wol	live
Textile and leather	lea	othr
Textile and leather	tex	othr
Textile and leather	wap	othr
Transport equipment	mvh	othr
Transport equipment	otn	othr
Wood and wood products	lum	othr

2.3 The International Council on Clean Transportation (ICCT) Global Transportation Roadmap model

The ground transport sector *otp* in GTAP8 must be disaggregated to separate household transportation from commercial transportation. The non-household portion is added to GTAP8's air transport (*atp*) and water transport (*wtp*) values to become the TRAN sector in EPPA. Data from the ICCT Global Transportation Roadmap model (International Council on Clean Transportation, 2012) is used to break the fuel usage in the IEA's single transport sector into the ROIL subproducts. The Roadmap model is calibrated on data detailing transportation fuel usage by power train, fuel, and size, and whether the transport mode was road, rail, water, or air. The regional detail closely matches the regional aggregation in EPPA6. The only differences were that EPPA has two regions related to Asia – ASI and REA – while the ICCT data only has one. The other region not explicitly represented in the ICCT model was Indonesia (IDZ). In both cases, the data from ICCT's Asia-Pacific-40 regional category were used as a proxy for ASI and REA.

2.4 The IEA Energy Prices and Taxes database

The IEA's Energy Prices and Taxes database was used to get a baseline for prices and taxes of petroleum products in 29 OECD and 17 non-OECD countries in 2007 (International Energy Agency, 2008). Sectors include Industry, Electricity generation, and Households. Prices are reported for the following petroleum products: low-sulfur fuel oil, heavy fuel oil, light fuel oil, diesel (high- and/or low-sulfur), and gasoline (leaded and/or unleaded, premium and/or regular). Natural gas prices are also included. The prices for transportation fuels (diesels and gasolines) are in units of the local currency per litre. Fuel oils are in units of local currency per 1,000 litres, and natural gas is priced in units of local currency per 10^7 kilocalories gross calorific value (GCV). All were converted to US dollars per metric ton of oil equivalent ($/TOE). These were mapped to the IEA Energy Statistics countries and products. Energy Prices and Taxes reports prices on fewer products than Energy Statistics requires, so the prices of the fuels reported by the IEA are augmented using price ratios between fuels from the EIA's State Energy Data System (SEDS) database.

2.5 The State Energy Data System (SEDS) database

The State Energy Data System (SEDS) database is curated by the U.S. Energy Information Administration (EIA) (U.S. Energy Information Administration, 2014). It tracks the annual consumption, price, expenditure and production of up to 253 energy products nationally and by state for each year. Price data are ex-tax. SEDS was used to generalize price ratios across multiple products that were benchmarked to prices in the IEA Energy Prices and Taxes database. This generated proxy prices for the IEA Energy Statistics volume data. Value flows based on IEA volume and proxy price data were developed for each petroleum product. **Table 4** illustrates the mapping between the IEA Energy Statistics' petroleum "Product", the six sub-product categories, the IEA Prices and Taxes "Fuel", and the SEDS database "Source" products.

Table 4. IEA-EPPA6-SEDS product mapping for commodity price tracking

IEA Product	EPPA6 Commodity	IEA Fuel	SEDS Source
Coke.oven.coke..kt.	COKE		CC
Gas.coke..kt.	COKE		CC
Petroleum.coke..kt.	COKE		PC
Gas.diesel.oil..kt.	DISL	Automotive.diesel	DF
Kerosene.type.jet.fuel..kt.	DISL		JF
Other.Kerosene..kt.	DISL	Light.fuel.oil	KS
Natural.gas..TJ.gross.	gas	Natural.gas	
Aviation.gasoline..kt.	GSLN		AV
Gasoline.type.jet.fuel..kt.	GSLN	Regular.unleaded.gasoline	MG
Motor.gasoline..kt.	GSLN	Regular.unleaded.gasoline	MG
Bitumen..kt.	HFOL		AR
Fuel.oil..kt.	HFOL	High.sulphur.fuel.oil	RF
Refinery.feedstocks..kt.	HFOL		UO
Additives.blending.components..kt.	OTHP		AB

Continued on next page

IEA Product	EPPA6 Commodity	IEA Fuel	SEDS Source
Lubricants..kt.	OTHP		LU
Naphtha..kt.	OTHP		FN
Non.specified.oil.products..kt.	OTHP		MS
Other.hydrocarbons..kt.	OTHP		FO
Paraffin.waxes..kt.	OTHP		WX
White.spirit...SBP..kt.	OTHP		SN
Coke.oven.gas..TJ.gross.	RGAS		CG
Ethane..kt.	RGAS	Liquefied.petroleum.gas	LG
Gas.works.gas..TJ.gross.	RGAS	Liquefied.petroleum.gas	GW
Liquefied.petroleum.gases..LPG...kt.	RGAS	Liquefied.petroleum.gas	LG
Natural.gas.liquids..kt.	RGAS		LG
Refinery.gas..kt.	RGAS		LG
	RGAS		SF

This mapping allows for detailed prices (and volumes) of individual products to be aggregated into value flows for RGAS, DISL, GSLN, HFOL, OTHP, and COKE. Like the IEA Prices and Taxes, SEDS divides product prices into Households, Electric Generation, and Industry.

3. DISAGGREGATING DOMESTIC VS. IMPORTED VOLUMES: GTAP8 AND IEA ENERGY STATISTICS

GTAP8 datasets *edf*, *eif*, *edp*, *eip*, *edg*, and *eig* contain imported and domestic volumes of refined oil consumed in each sector. Refined oil (*p_c*) is a single commodity. The IEA's Energy Statistics database tracks sectoral usage for 24 petroleum products. However, the IEA data do not distinguish domestic from imported volumes consumed within each sector. Volumes for overall production, exports, and imports of each of the 24 petroleum products *are* reported in the IEA data. IEA data are used to calculate each petroleum product's portion of the imported and domestic *p_c* commodity volumes from GTAP. **Table 5** is the map between the IEA's FLOW and production (PROD), imports (IMP), exports (EXP), or consumption (CONS).

Table 5. IEA "FLOW"-to-EPPA "Activity" map

FLOW	Activity
Memo: Feedstock use in petrochemical industry	CONS
Agriculture/forestry	CONS
Autoproducer CHP plants	CONS
Autoproducer electricity plants	CONS
Autoproducer heat plants	CONS
BKB plants	CONS
Blast furnaces	CONS
Charcoal production plants	CONS
Chemical and petrochemical	CONS

Continued on next page

Table 5 – *Continued from previous page*

FLOW	Activity
Chemical heat for electricity production	CONS
Coal liquefaction plants	CONS
Coal mines	CONS
Coke ovens	CONS
Commercial and public services	CONS
Construction	CONS
Domestic aviation	CONS
Domestic navigation	CONS
Domestic supply	SUPPLY
Electric boilers	CONS
Exports	EXP
Fishing	CONS
Food and tobacco	CONS
For blended natural gas	CONS
From other sources - coal	PROD
From other sources - natural gas	PROD
From other sources - non-specified	PROD
From other sources - oil products	PROD
From other sources - renewables	PROD
Gas works	CONS
Gas-to-liquids (GTL) plants	CONS
Gasification plants for biogases	CONS
Heat pumps	CONS
Imports	IMP
Industry	CONS
International aviation bunkers	EXP
International marine bunkers	EXP
Iron and steel	CONS
Liquefaction (LNG)/regasification plants	CONS
Machinery	CONS
Main activity producer CHP plants	CONS
Main activity producer electricity plants	CONS
Main activity producer heat plants	CONS
Mining and quarrying	CONS
Non-energy use in other	CONS
Non-energy use in transport	CONS
Non-energy use industry/transformation/energy	CONS
Non-ferrous metals	CONS
Non-metallic minerals	CONS
Non-specified (energy)	CONS
Non-specified (industry)	CONS
Non-specified (other)	CONS
Non-specified (transformation)	CONS
Non-specified (transport)	CONS
Nuclear industry	CONS
Oil and gas extraction	CONS
Oil refineries	CONS

Continued on next page

Table 5 – *Continued from previous page*	
FLOW	**Activity**
Own use in electricity, CHP and heat plants	CONS
Paper, pulp and print	CONS
Patent fuel plants	CONS
Petrochemical plants	CONS
Pipeline transport	CONS
Production	PROD
Pumped storage plants	CONS
Rail	CONS
Residential	CONS
Road	CONS
Textile and leather	CONS
Transport equipment	CONS
Wood and wood products	CONS

Breaking out domestic and imported volume shares of GTAP's p_c commodity involved two steps: (1) calculating domestic and imported volume shares of each fuel at a regional level, and (2) calculating each petroleum product's share of total domestic and total imported volumes of refined fuel usage. Domestic and imported shares for each IEA product are calculated using the data on production (PROD), exports (EXP), and imports (IMP). International Marine Bunker entries were excluded. Exports (EXP) were subtracted from production (PROD) volumes to calculate domestic consumption. Negative results implied the re-export of imported goods. Import volumes were adjusted downwards in these cases to set exports to zero. Negative net imports were set to zero. Net Import volumes were divided each product's total supply (SUPPLY).[5] The result was import share of each product's total consumption. The domestic share of each product's consumption is 1 minus the imported share $(1 - impshare)$. The same domestic and imported shares were applied to the consumption of each fuel in each sector under the assumption that all sectors drew from the same national pool of fuels. Total sectoral fuel consumption was thus disaggregated into imported and domestic volumes for each of the IEA's 24 petroleum products.

4. BREAKING OUT HOUSEHOLD TRANSPORTATION FROM FINAL CONSUMPTION

GTAP8 records the final consumption volumes of the p_c refined fuel in *edp* (domestic) and *eip* (imports). IEA Energy Statistics reports consumption of specific products by type of use. Residences and a portion of Road volumes correspond to the p_c final consumption data. The calibration data in the ICCT's Roadmap model is utilized to estimate the portion of each product that is consumed for household transport. The ICCT Roadmap model is calibrated using data from 2005 and 2010. The GTAP8 base year is 2007. 2005 and 2010 data were averaged to provide a mid-2007 estimate.

The ICCT data are segmented by drivetrain. Three petroleum-based drivetrains – gasolines, diesels, and LPGs – are used by households, and correspond to the consumption of GSLN, DISL,

[5] "SUPPLY" is the total amount of each product consumed in each country, including stock changes and statistical differences.

and RGAS. Drivetrains are divided by vehicle types: light duty vehicles (LDV), Bus, 2-wheelers, 3-wheelers, truck, passenger rail, freight rail, aviation, and marine. Total fuel usage for each fuel in Road transport is the sum of LDV, 2-wheeler, 3-wheeler, Bus, and truck fuel volumes. The ICCT categories "Conventional and hybrid gasoline" and "Plug-in hybrid gasoline" correspond to GSLN, "Conventional and hybrid diesel" and "Plug-in hybrid diesel" correspond to DISL, and "LPG" corresponds to RGAS. The sum of LDV and 2-wheeler data for each fuel represents the household transportation portion of the total.[6] The household transportation totals within each fuel and within each region are divided by the total road transport for each fuel and each region. This provides the share of on-road fuel consumption of diesel (DISL), gasoline (GSLN), and LPGs (RGAS) that is consumed by households.

Household fuel consumption shares are multiplied by the corresponding fuel volume in the IEA Road data to estimate household transportation consumption of each fuel. These volumes are added to the Residential consumption category, since they are fuels consumed by households in transportation. The same volume is subtracted from the Road data. Commercial Road transport is the remainder. Each fuel's household Road volume is divided by the augmented Residential volumes to estimate the *share* of household fuel consumption used for transportation. This share is the "*os*" parameter in EPPA6. It is indexed by fuel (GSLN, DISL, or RGAS) and region. *os* is multiplied by the GTAP household fuel consumption in each region to break out the household transportation volumes in the CGE model.

5. DETERMINING PRICES OF PETROLEUM PRODUCTS IN IEA ENERGY STATISTICS

The IEA's Energy Prices and Taxes reports prices for up to six key products in all OECD countries and 17 non-OECD countries. Not every region reports ex-tax and post-tax prices for every product. Both the GTAP8 database and the SEDS database are used to estimate pre- and post-tax prices for all 24 petroleum products in IEA Energy Statistics.

IEA prices are based on end use, including taxes (International Energy Agency, 2008, p. 46 of 2nd quarter 2008). These correspond to GTAP's agent prices. Taxes were reported separately. The share of the total price due to taxes was calculated. Subtracting the tax share from 1 creates a multiplier for the market (ex-tax) prices (the "market price multiplier") in each country for each fuel and in each of the three consumption categories (households, electric generation, and industry).

Each post-tax ("agent") price was multiplied by the market price multiplier to estimate market prices for each of the six products in each country in the Energy Prices and Taxes database. Where multiple prices were listed for a fuel type, the minimum value set the single market price. The IEA Prices and Taxes data thus provided an agent and market price in 29 OECD and 17 non-OECD countries for up to six petroleum products in up to three sectors (households, electricity generation, and industry).

The IEA Prices and Taxes sectors match the EIA SEDS sectors: households, electric generation, and industry. SEDS contains 22 petroleum products that were mapped to the IEA's 24

[6] In making this assumption, taxis are included in this total, but the aggregation cannot be avoided. Taxi data are not available for enough regions to be able to break them out.

petroleum products. Six of the SEDS fuels were mapped to the six fuels in the IEA Prices and Taxes data. **Table 6** contains the map.

Table 6. IEA Prices and Taxes "Fuel"-to-EIA SEDS "Source" mapping for product pricing

IEA Fuel	EIA SEDS Source
Automotive.diesel	DF
Light.fuel.oil	KS
Liquefied.petroleum.gas	LG
Premium.unleaded.95.RON	MG
Premium.unleaded.98.RON	MG
Premium.leaded.gasoline	MG
Regular.unleaded.gasoline	MG
Regular.leaded.gasoline	MG
Low.sulphur.fuel.oil	RF
High.sulphur.fuel.oil	RF
Natural.gas	SF

The price of each petroleum product in the SEDS database was divided by the price of each of the six products that matched the IEA to generate a set of price ratios. Market prices for the 18 products *not* reported in the IEA's Energy Prices and Taxes were estimated by multiplying each ratio by its corresponding IEA benchmark price. Each price estimate was weighted by the volume of its reference fuel to get a volume-weighted market price estimate for each of the 18 additional petroleum products in each sector and region.

Next, prices in the countries that were not included in IEA's Prices and Taxes were estimated. Using GTAP data, domestic market value flows (*vdfm*) were divided by domestic volumes consumed (*ed*) to estimate an average market price for petroleum products by region. Price ratios between the regions were calculated. The GTAP ratios were mapped to the 18 EPPA regions. Brazil (BRA) was counted as LAM (Latin America). The missing country's market price ratio was multiplied by the reference country market price, and a volume-weighted average was used in cases where there were more than one reference price per EPPA region.This step produced a full set of domestic market price estimates for 24 petroleum products in 142 IEA countries.

Three price series were left to complete: domestic agent (post-tax) prices, imported market (ex-tax) prices, and imported agent prices. Some of the domestic agent prices were already reported in IEA Prices and Taxes. For the rest, the GTAP8 volumes and value flows were aggregated to match the IEA country and sector according to the maps in Tables 2 and 3. This produced total *p_c* volumes, market-priced values, and agent-priced values for imported and domestically-sourced products by IEA country and sector. The average tax rate on domestic petroleum products was calculated by dividing the agent value flow (*vdfa*) of the *p_c* commodity by its market value flow (*vdfm*) in each country and sector. This created a "domestic agent price multiplier" for cases in which the IEA price data did not report taxes. The agent price multiplier for imported products was calculated by dividing GTAP8's *vifa* data by the *vifm* data. Total values were divided by total volumes to estimate the volume-weighted average price of petroleum products, both domestic and imported, and both market and agent. Dividing the imported price by the domestic price in each sector created an imported/domestic price ratio for both market and agent prices. These price ratios were used to translate domestic market prices into the other three price series.

The country-specific imported market price was estimated by multiplying the domestic market price by the GTAP8 imported/domestic *p_c* price ratio in each country. Domestic agent prices were estimated by multiplying the estimated market price in each country by a sector-specific GTAP8 agent/market *p_c* price ratio for each country and sector. Two methods were employed to estimate the imported agent price: one was to divide the GTAP imported agent price by the imported market price for each sector and region. Multiplying this ratio by the imported market price gives one estimate of the imported agent price. Another method is to divide the GTAP8 imported agent price by the domestic agent price. Multiplying this ratio by the domestic agent price produces an alternative estimate of the imported agent price. The estimates are not identical; a simple average of the two methods is taken to estimate the imported agent price.

This procedure created a set of domestic and imported market prices and domestic and imported agent prices for all 142 countries and all 57 sectors for all 24 petroleum products in IEA Energy Statistics. Many assumptions were made that would undermine the utility of this set as a true price reference. However, it is suitable for creating proxy value flows to determine the relative values of the fuels by sector and region.

6. CALCULATING VOLUME- AND VALUE-FLOW SHARES OF OIL PRODUCTS

Value flows are created by multiplying the price estimates by the volumes. There were four price estimates for each sector and country in IEA Energy Statistics: domestic market prices, domestic agent prices, imported market prices, and imported agent prices. Multiplying the two domestic price estimates by the domestic volumes in IEA Energy Statistics creates the market and agent-priced value flows for domestically-produced volumes. The exercise is repeated for the imported volumes. This creates a set of value flows, both ex-tax and including tax, for both domestic and imported products, in each sector in each country in IEA Energy Statistics.

The IEA volume and value data were then aggregated. IEA's 24 petroleum products were summed into RGAS, DISL, GSLN, OTHP, HFOL, and COKE. The mapping for the petroleum products is covered in Table 4. IEA's 57 sectors were summed into the 14 sectors (plus final consumption) to be used in the CGE model. The sector mapping is detailed in Table 3. IEA's 142 countries were summed into EPPA's 18 regions. Regional mapping is reported in Table 2.

Once the data were aggregated, the volume and value flow shares were calculated according to the following equations:

$$S_{vol_{p,sec,di}} = \frac{Vol_{p,sec,di}}{\sum_p Vol_{p,sec,di}} \quad (1)$$

$$S_{val_{p,sec,di,type}} = \frac{Pr_{p,sec,di,type} Vol_{p,sec,di}}{\sum_p Pr_{p,sec,di,type} Vol_{p,sec,di}} \quad (2)$$

$S_{vol_{p,sec,di}}$ is the share of total petroleum product volume represented by each product p in each sector sec for imports or domestic goods (di). p is the set of ROIL sector commodities – RGAS, DISL, GSLN, OTHP, HFOL, or COKE. sec is the set of sectors – CROP, LIVE, FORS, FOOD, COAL, OIL, ROIL, GAS, ELEC, EINT, OTHR, SERV, TRAN, DWE, or final consumption. di denotes whether the share is for domestic or imported goods. $S_{val_{p,sec,di,type}}$ is the share of total expenditures on petroleum products represented by each product p in each sector sec for imports or domestic products (di) by the price $type$. $type$ is either agent or market. Vol refers to volumes, and Pr refers to prices. Within each $sec/di/type$ combination, the sum of S over all p equals 1.

GTAP8 data were aggregated to 15 sectors (including final consumption) and 18 regions. The ROIL entry in each sector/region combination was multiplied by each of the six petroleum product shares to calculate the value (or volume) represented by each petroleum product. The sum of each of these products equals the original value of ROIL, so the original dataset remained balanced for every activity except trade flows.

The volumes calculated for the household Road transportation and Residential fuel consumption were multiplied by market prices to determine values spent on fuel for (1) transport and (2) other household uses. The value share of household transportation fuel use was calculated by dividing the transport value of each fuel by the total household expenditure for each fuel. This is the *es* parameter that breaks out the expenditure share of final consumption for household transportation.

7. PREPARING PRODUCTS FOR INTERNATIONAL TRADE

International trade flows of *p_c* were disaggregated into the six refined products. GTAP8 trade data for volumes and value flows track country-to-country trade of the *p_c* product. The pricing data from IEA Energy Prices and Taxes in conjunction with IEA Energy Statistics identified the shares of each product in total imports, but not the individual exporters. The same problem existed for exports. The goal is to provide the product-specific trade between regions but ensure that volumes and values still sum to the total export and total import proportions already calculated from GTAP.

In each sector zero-profit conditions must be maintained, and the domestic and imported markets must “clear”. Zero-profit conditions mean that the total domestic inputs plus imports (net of tariffs) in each sector must exactly equal post-tax expenditures on domestic and imported goods plus factors of production. Domestic market clearing means that the total amount spent on a good in a region must equal the sum of expenditures on that good in each sector of that region. Imported market clearing means that the total value imported (after accounting for transport costs, export subsidies, and import tariffs) must equal the market value of imported goods in each sector of each region.

Trade flows were optimized while enforcing zero-profit conditions and domestic and imported market clearing. An optimization algorithm was utilized to ensure that country-to-country imports from each exporter sum across all exporters to the total imported volume or value flow shares calculated in IEA Energy Statistics. The same constraint was used for exports aggregated across all importers, for each region and petroleum sub-product.

The objective function minimizes the sum of squared differences between the calculated variable value and its estimated value after disaggregation. Squared deviations from the initial volumes are given 100 times more weight than other parameters because of the greater confidence in the accuracy of estimated volumes than in estimated prices. The following constraints were imposed: the sum of all six petroleum products must equal the original value for ROIL for every volume and value flow; tax revenue/subsidy expenditures for each product must sum to the ROIL tax revenue/subsidy expenditures; agent-priced value flows for each commodity must equal the market-priced value flows plus tax revenue or minus subsidy expenditure. The maximum or minimum price (or tax/subsidy) allowed is based on the maximum and minimum values in GTAP8.

The final data set is the basis for the disaggregated model. It is complete and balanced for international trade flows and domestic and imported value flows (both ex-tax and post-tax). Tax revenues/subsidy expenditures for each product sum to the original GTAP8 value. Data preparation scripts in GAMS translate these to individual tax and subsidy rates.

The last modification related to international trade was to set distillates (DISL), gasolines (GSLN), and heavy fuel oils (HFOL) as tradable goods under the Heckscher-Ohlin model (Heckser and Ohlin, 1933). This implies perfect substitutability between domestic and imported products. Transportation fuels are widely traded internationally. In reality there are various grades and quality levels that preclude true perfect substitutability, but the three fuels are much closer to perfect substitutes than to region-specific fuels. Only regions that exported the fuel in the base year are able to export it going forward, and the same rule applies for imports. This prevents massive trade distortions in the model as trading restrictions are lifted. This feature provides an opportunity. In order to ensure that the goods can be traded unhindered across borders, each country that will trade the good as an importer or exporter must be initialized with a nominal value flow. Trade can be prevented by initializing the value as zero. This allows modelers to permit or restrict international trade in these fuels, and control which regions are trading – a useful tool in examining the impacts of international trade.

8. DISAGGREGATING REFINED FUEL EMISSIONS

EPPA6 tracks ROIL emissions of three greenhouse gases (carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)) and seven urban pollutants (ammonia (AMO), black carbon (BC), carbon monoxide (CO), nitrogen oxides (NOx), organic carbon (OC), sulfur dioxide (SO_2), and volatile organic compounds (VOC)). The emissions of each of the individual refined oil products were disaggregated from the ROIL commodity emissions. In order to do so, both volumetric consumption data and the relative emissions of each fuel were used to weight the aggregated emissions.

The emissions factors for residual fuel oils, LPGs, propane, gasolines, and petroleum coke were found on the EPA's website (EPA, 2014). Emission factors were converted into pounds per million Btu (LB/mmBtu) using measurements from the EIA (EIA, 2011). Missing emissions factors were gathered for methane and nitrous oxide, and for nitrous oxide emissions from refinery gases (EIA, 2008; EPA, 1993). Emissions factors were gathered for petroleum product usage and combustion in a variety of sectors, each of which mapped to one of the sectors in the CGE model. Adjustments were made to the EPA's emissions factors for three sets of regions. The OECD countries (the U.S., Canada, the European Union, Japan, Australia/New Zealand, and South Korea) used the weighted average emissions factors including both controlled and uncontrolled emission technologies. The countries less concerned with environmental degradation in 2007 (Africa, India, the rest of East Asia, the Middle East, Russia, and China) used weighted average emissions factors from uncontrolled sources only. The remaining regions (Mexico, Eastern Europe, Brazil, East Asia, Latin America, and Indonesia) used the OECD emissions factors for the electricity and energy-intensive industries, but the uncontrolled emissions factors for other sectors.

All emissions factors were divided by the DISL emissions factor in each region and sector. The result was an emissions weight-per-unit-combusted relative to the distillate fuel emissions-per-unit-combusted. These weights were then multiplied by the refined fuel volumes consumed in each sector and each region to get emissions-weighted volumes. Each refined product's *share* of total emissions was calculated by dividing the emissions-weighted volumes by all emissions-weighted volumes as in equation 1. This preserved the total emissions inventories but apportioned out the total to each fuel according to its proportional share of the ROIL emissions of each pollutant.

9. INTEGRATING THE DISAGGREGATED PRODUCTS INTO THE CGE MODEL

Each sector that originally used the ROIL commodity was modified so that the various individual sub-products were the inputs. In sectors where multiple refined products were used as inputs, they were placed into a "refined products" nest. An elasticity of substitution was added to the nest so that the sector could adjust its use of inputs based on changes in the relative prices of the products. The nesting structure is described in greater detail in Babiker *et al.* (2001); Paltsev (2004); Paltsev *et al.* (2004); Sue Wing (2004); Paltsev *et al.* (2005); Choumert *et al.* (2006); Waugh *et al.* (2011); Chen *et al.* (2015) and others.

The portion of final demand for refined fuels used in household transportation (*os*, calculated above) was multiplied by the final consumption of each product to break out the volumes pertaining to household transport. The *es* expenditure shares were applied to the market value flows to break out the refined fuel expenditures for household transportation. These were included in an additional final demand category called "htrn".

10. TECHNOLOGIES ADAPTED TO MULTIPLE REFINED PRODUCTS

A number of technologies in addition to GTL were also added to the model. **Table 7** provides a list of these technologies and the years in which they become available. All of these are treated

Table 7. Technologies included and dates of availability

Backstop technology	EPPA Code	Yr. available
Wind	WIND	2010
Bioelectricity	BIOELEC	2015
Biofuels	BIO-OIL	2015
1^{st} gen. biofuels	BIO-FG	2007
Solar	SOLAR	2010
Synthetic oil	SYNF-OIL	2015
Syngas – coal	SYNF-GAS	2015
Syngas – heavy fuel oil	SYNF-GASh	2010
Syngas – pet. coke	SYNF-GASk	2010
Wind/biofuel backup	WINDBIO	2010
Wind/nat. gas backup	WINDGAS	2010
Nat. gas combined cycle	NGCC	2015
NGCC w/ CCS	NGCAP	2020
IGCC w/ CCS – coal	IGCAP	2020
IGCC w/ CCS – heavy fuel oil	IGCAPh	2020
IGCC w/ CCS – pet. coke	IGCAPk	2020
Advanced nuclear	ADV-NUCL	2020
Non-conventional crudes	NC	2010
NC upgrading	NCUP	2010
NC upgrading w/ CCS	CAPNCUP	2020
NC w/ CCS	CAPNC	2020
Heavy fuel oil upgrading	UPGRAD	2010
Gas-to-liquids	GTL	2020

as backstop technologies in EPPA: they are not initially economic and are not in use in the initial year, but can be selected for deployment at some future date if the economics become favorable. Though many are technologies that are deployed within the operations of existing sectors, they are tracked separately. Among these were versions of technologies that existed in the base model that needed to be differentiated to account for specific outputs or inputs that relate to a disaggregated refined fuels commodity. Others were directly related to oilsands production and upgrading. One technology represented the heavy fuel oil upgrading sections of modern oil refineries. This upgrading technology provided more flexibility for existing oil refineries to increase output of high-value products by upgrading the residuum. Details on all of these additional technologies are available in Choumert *et al.* (2006). They were updated to reflect 2007 prices and costs.

10.1 Representing GTL in EPPA6-ROIL

GTL technology was added to the newest version of EPPA-ROIL. Like other backstop technologies, the initial levelized costs are translated from a discounted cash flow (DCF) model to a constant elasticity of substitution (CES) nesting structure. The natural gas input cost is the Armington price.[7] Distillate and petrochemical feedstock output is based on the domestic production cost of each fuel. Table 8 reports the base case GTL cost in 2007 U.S. prices. The DCF analysis

Table 8. Base case input variables to GTL for DCF analysis: USA

Parameter and units	Value
Capital Cost, $/bpd capacity:	68,000
Gas Input, mmBtu/bbl output:	9.85
Variable O&M, $/bbl:	5.00
Fixed O&M, % of Capital Cost/yr:	4.00
Capacity, bbl/d:	120,000
Capacity, bbl/d ULS Diesel (DISL):	84,000
Capacity, bbl/d Petrochemical feedstocks (OTHP):	36,000
Percent Financed, %:	0.00
Capacity utilization, %:	93.00
Number of years for project (after 3 year construction):	25
Tax Rate, %:	35.00
Interest Rate, %:	10.00
Discount Rate, %:	10.00
Diesel (DISL) Price, $/bbl:	49.83
Petrochemical Feedstock (OTHP) Price, $/bbl:	102.60
Natural Gas Price, $/mmBtu:	6.79

was repeated for each region so GTL could be modeled anywhere. The only differences across regions were the values of diesel, petrochemical feedstocks, and natural gas. The DCF model was run and the LCOE per barrel was calculated. The LCOE was compared to the weighted output value in each region (70% diesel and 30% petrochemical feedstocks by volume). The LCOE divided by the weighted output value is the markup. The markup is the cost of GTL relative to an oil refinery in the base year.

The cost data were adapted to a nested CES production block. Each input bundle is related through an elasticity of substitution σ. Whenever substitutability is identical across multiple inputs, more than two inputs can be included in a single nest. The elasticity of substitution measures the ease with which one input can be substituted for another. It is the slope of the relative amounts of two inputs in the graph of a production function at the calibration point. It must be positive. When σ is equal to zero, there is no substitutability. This is called a Leontief input structure. Outputs are related by an elasticity of transformation, τ, and function in the same manner. Figure 1 depicts the GTL CES nesting structure. The Labor (L) inputs are the Fixed and Variable O&M cost *share* of the total LCOE per barrel over the project's 25-year lifetime. Capital (K) inputs are the capital expenditure share of total LCOE per barrel. The GAS input is the natural gas cost share of total LCOE costs per barrel. FF is the fixed factor input cost share.[8] The fixed factor was set at 1% of total input costs. There are three additional inputs: FCARB, PCARB, and PT-

[7] The Armington price is the weighted average price of a product accounting for both imports and domestic supplies.
[8] The fixed factor serves to limit the rate of penetration of a new technology in its early phases of deployment.

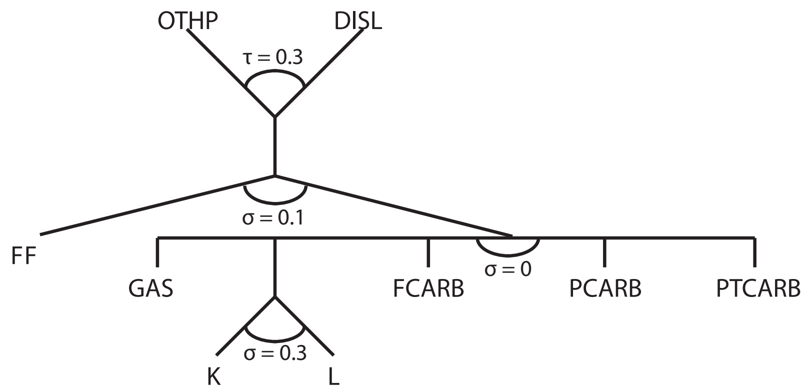

Figure 1. CES nesting structure for GTL

CARB. FCARB is the non-tradable CO_2 permit price on final demand emissions. PCARB is the non-tradable CO_2 permit price on all emissions, and PTCARB is the tradable CO_2 permit price on all emissions.

GTL technology inputs are inflexible. Capital and labor are of limited substitutability, with a σ of 0.3. The K-L bundle, the GAS inputs, and the carbon permits are all in a Leontief nest, so are not substitutable. The elasticity of substitution between the fixed factor (FF) and all other inputs is 0.1, making the fixed factor a difficult input to substitute. The τ elasticity of transformation between DISL and OTHP outputs is 0.3. The 70/30 DISL/OTHP output ratio is thus costly to alter.

Table 9 details the initial estimates, by region, of the input shares for GTL technology and its markup in the Base case capital cost scenario. All inputs are calibrated to 2007 prices. These figures reflect a mechanical calculation of markups and cost shares based on the reported prices of natural gas, distillate fuels (DISL), and other petroleum products (OTHP) in each region. It is not realistic to assume that many of these countries will be viable candidates for GTL production. Only regions with significant resources or that exported natural gas in the base year should be considered candidates unless modeling a scenario in which natural gas hydrates from the ocean or some as-yet untapped shale gas resources are being exploited. The column "Gas Resource?" reports whether GTL is likely to be deployable in each region given its natural gas resources and its natural gas trade patterns in the 2007 base year.

Acknowledgements

This work has been funded in part by BP, the MITEI ENI Energy Fellowship, the MITEI Martin Family Fellowship, and sponsors of MIT's Joint Program on the Science and Policy of Global Change. The Joint Program on the Science and Policy of Global Change is funded by the U.S. Department of Energy, Office of Science under grants DE-FG02-94ER61937, DE-FG02-08ER64597, DE-FG02-93ER61677, DE-SC0003906, DE- SC0007114, XEU-0-9920-01; the U.S. Department of Energy, Oak Ridge National Laboratory under Subcontract 4000109855; the U.S. Environmental Protection Agency under grants XA-83240101, PI-83412601-0, RD-83427901-0, XA-83505101-0, XA-83600001-1, and subcontract UTA12-000624; the U.S. National Science

Table 9. Base case input shares to GTL backstop technology by region

Region	GAS	K	L	FF	Markup	Gas Resource?
USA	60.6%	26.6%	11.8%	1.0%	1.675	YES
CAN	54.7%	30.7%	13.6%	1.0%	1.298	YES
MEX	59.9%	27.1%	12.0%	1.0%	2.026	YES
JPN	61.2%	26.2%	11.6%	1.0%	0.870	NO
ANZ	55.5%	30.1%	13.4%	1.0%	1.038	YES
EUR	62.7%	25.1%	11.1%	1.0%	1.115	YES
ROE	59.6%	27.3%	12.1%	1.0%	0.845	YES
RUS	42.7%	39.0%	17.3%	1.0%	0.667	YES
ASI	60.5%	26.7%	11.8%	1.0%	1.115	NO
CHN	53.2%	31.7%	14.1%	1.0%	0.913	YES
IND	60.2%	26.9%	11.9%	1.0%	1.258	NO
BRA	50.8%	33.4%	14.8%	1.0%	1.459	YES
AFR	54.1%	31.1%	13.8%	1.0%	1.136	YES
MES	44.4%	37.8%	16.8%	1.0%	1.625	YES
LAM	32.5%	46.1%	20.4%	1.0%	1.212	YES
REA	60.5%	26.7%	11.8%	1.0%	0.945	YES
KOR	61.8%	25.8%	11.4%	1.0%	0.889	NO
IDZ	51.7%	32.8%	14.5%	1.0%	0.933	NO

Foundation under grants AGS-0944121, EFRI-0835414, IIS-1028163, ECCS-1128147, ARC-1203526, EF-1137306, AGS-1216707, and SES-0825915; the U.S. National Aeronautics and Space Administration (NASA) under grants NNX06AC30A, NNX07AI49G, NNX11AN72G and Sub Agreement No. 08-SFWS-209365.MIT; the U.S. Federal Aviation Administration under grants 06-C-NE-MIT, 09-C-NE-MIT, Agmt. No. 4103-30368; the U.S. Department of Transportation under grant DTRT57-10-C-10015; the Electric Power Research Institute under grant EP-P32616/C15124, EP-P8154/C4106; the U.S. Department of Agriculture under grant 58-6000-2-0099, 58-0111-9-001; and a consortium of 35 industrial and foundation sponsors (for the complete list see: http://globalchange.mit.edu/sponsors/all).

11. REFERENCES

Armington, P. S., 1969: A Theory of Demand for Products Distinguished by Place of Production. *Staff Papers-International Monetary Fund*, pp. 159–178.

Babiker, M. H., J. M. Reilly, M. Mayer, R. S. Eckaus, I. Sue Wing and R. C. Hyman, 2001: The MIT emissions prediction and policy analysis (EPPA) model: revisions, sensitivities, and comparisons of results. Joint Program on the Science and Technology of Global Change, MIT *Joint Program Report Series*. (http://18.7.29.232/handle/1721.1/3574).

Chen, Y.-H. H., S. Paltsev, J. M. Reilly, J. F. Morris and M. H. Babiker, 2015: The MIT EPPA6 Model: Economic Growth, Energy Use, and Food Consumption. Joint Program on the Science and Technology of Global Change, MIT *Joint Program Report Series*, Mar., 43 p. (http://globalchange.mit.edu/research/publications/2892).

Choumert, F., S. Paltsev and J. Reilly, 2006: Technical Note 9: Improving the Refining Sector in EPPA. Joint Program on the Science and Policy of Global Change, MIT *Joint Program Technical Note*. (http://globalchange.mit.edu/research/publications/527).

EIA, U., 2008: Direct Emissions from Mobile Combustion Sources. Climate Leaders Greenhouse Gas Inventory Protocol Core Module Guidance. EPA430-K-08-004. United States Environmental Protection Agency May. (http://www.epa.gov/climateleadership/documents/resources/mobilesource_guidance.pdf).

EIA, U., 2011: EIA Appendix A of the Annual Energy Review 2011 (http://www.eia.gov/totalenergy/data/annual/pdf/sec12.pdf).

EPA, U., 1993: Emission Factor Documentation for AP-42 Section 1.5 Liquefied Petroleum Gas Combustion EPA430-K-08-004. United States Environmental Protection Agency. Office of Air Quality Planning and Standards, Office of Air and Radiation Apr. (http://www.epa.gov/ttnchie1/ap42/ch01/bgdocs/b01s05.pdf).

EPA, U., 2014: Search and Retrieval of EPA Emissions Factors (WebFIRE) (http://cfpub.epa.gov/webfire/index.cfm?action=fire.SearchEmissionFactors).

Hecksher, E. and B. Ohlin, 1933: *Interregional and international trade*. Harvard University Press, Cambridge, MA.

International Council on Clean Transportation, I., 2012: Global Transportation Roadmap Dec.

International Energy Agency, I., 2008: *IEA Energy Prices and Taxes*. Organisation for Economic Co-operation and Development (OECD): Paris; Washington, D.C., database edition. (http: //dx.doi.org/10.1787/eneprice-data-en).

International Energy Agency, I., 2010: *IEA World Energy Statistics and Balances*. International Energy Agency: Paris, France, electronic resource edition. (http://www.oecd-ilibrary.org/energy/data/iea-world-energy-statistics-and-balances_enestats-data-en).

Narayanan, B., A. Aguiar and R. McDougall, 2012a: *Global Trade, Assistance, and Production: The GTAP 8 Data Base*. Center for Global Trade Analysis: Purdue University, electronic resource edition. (http://www.gtap.agecon.purdue.edu/databases/v8/v8_doco.asp).

Narayanan, B., B. Dimaranan and R. McDougall, 2012b: *GTAP 8 Data Base Documentation - Chapter 2: Guide to the GTAP Data Base*. Electronic resource edition. (http://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=3777).

Paltsev, S., 2004: Moving from Static to Dynamic General Equilibrium Economic Models (Notes for a beginner in MPSGE). Joint Program on the Science and Policy of Global Change, MIT *Joint Program Technical Note*, 49 p. (http://globalchange.mit.edu/research/publications/523).

Paltsev, S., S. Viguier, M. H. Babiker, J. M. Reilly and K. Tay, 2004: Disaggregating Household Transport in the MIT-EPPA Model. Joint Program on the Science and Policy of Global Change, MIT *Joint Program Technical Note*, 32 p. (http://globalchange.mit.edu/research/publications/522).

Paltsev, S., J. M. Reilly, H. D. Jacoby, R. S. Eckaus, J. R. McFarland, M. C. Sarofim, M. O. Asadoorian and M. H. Babiker, 2005: The MIT emissions prediction and policy analysis (EPPA) model: version 4. Joint Program on the Science and Policy of Global Change, MIT *Joint Program Report Series*, Aug. (http://dspace.mit.edu/handle/1721.1/29790).

Sue Wing, I., 2004: Computable General Equilibrium Models and Their Use in Economy-Wide Policy Analysis. Joint Program on the Science and Policy of Global Change, MIT *Joint Program Technical Note*, 50 p. (http://globalchange.mit.edu/research/publications/524).

U.S. Energy Information Administration, E., 2014: *State Energy Data System (SEDS)*. United States Department of Energy, Energy Information Administration, electronic database edition. (http://www.eia.gov/state/seds/).

Waugh, C., S. Paltsev, N. Selin, J. M. Reilly, J. Morris and M. Sarofim, 2011: Emission Inventory for Non-CO2 Greenhouse Gases and Air Pollutants in EPPA 5. Joint Program on the Science and Policy of Global Change, MIT *Joint Program Technical Note*, 51 p. (http://globalchange.mit.edu/research/publications/2153).

APPENDIX A: Methodological appendix for Joint Program Researchers

This appendix is designed for researchers at the Joint Program with access to the GitHub repository. It describes specific files and scripts that must be run. First, a few caveats:

1. These scripts were put together over the course of many months. Some pieces turn out to be redundant or unnecessary. A careful reader could remove the redundant portions of code.

2. The coding in these files – especially the R scripts – is not very streamlined or elegant. A lot of learning occurred during the scripting process. Part of the format leaves the opportunity to create output files to examine intermediate sections. This was necessary for the development of the disaggregation methodology, but is not necessary now. Many of the scripts would benefit from some revision to shorten and clean up the code.

3. The algorithm for optimizing trade flows was not published in the main text of this technical note. The GAMS script in which it appears might also benefit from some alternative formulation or even more parsimony.

4. Some more careful research into relative tax rates between the six main petroleum products could improve some of the price estimates in many regions.

5. Very little background information is provided here. This is mostly a checklist for mechanically reproducing the input data that goes into EPPA6-ROIL. The idea is to make it much easier for the next researcher to create a ROIL version based on the next release(s) of GTAP.

In order to follow these instructions, one needs access to the ∼/GTAP8inGAMS folders and the ∼/ROILDataPrep folders on GitHub. These instructions are based on the assumption that a Mac or UNIX-based operating system is running the scripts directly from the command line. The main difference is that the UNIX-based systems use a forward slash "/" in directory paths while the Windows-based systems use a backslash "\" in directory paths.

1.1 Extracting GTAP8 data for disaggregation

Get permission from a senior researcher before accessing GTAP8inGAMS. It will be called something else in later versions – probably something like GTAP9inGAMS for the next version. It is used under license, and we need to ensure we do not violate its terms. On GitHub, the EPPA6-ROIL folder has GTAP8inGAMS in the `∼/utilities` folder.

From `∼/GTAP8inGAMS/build`, run `flex2gdxUNIX_ROIL.gms`. The command line should read:

```
gams flex2gdxUNIX_ROIL.gms --yr=07 o=flex2gdx.lst
```

The number after `--yr=` represents the most recent year of data in (for example) the folders `data07` and `gtapdata07`. The most important output is in the `∼/GTAP8inGAMS/data07` folder. It is called `GSD_ROIL.gdx`.

`GSD_ROIL.gdx` is not balanced, but for the purposes of calculating shares, it is suitable. The `flex2gdxUNIX_ROIL.gms` script exports a series of 22 .csv files to the folder `∼/GTAP8inGAMS`

/data07/CSVImport. These will be the files from which the R script IEADataPrep-EPPA.R draws to calculate average tax rates, average imported vs. domestic price ratios, and average relative international prices of petroleum products. There are additional steps in preparing GTAP data for EPPA. One is the filterUNIX.gms file. This rounds the numbers and rounds and then re-balances key data series. These series will replace 5 of the 22 .csv files that were initially put there by flex2gdxUNIX_ROIL.gms. There are very minor differences, though, and they will not affect the calculations of shares.

From ~/GTAP8inGAMS/build, run filterUNIX.gms. Use the command line modifiers --yr= with the relevant year for future versions. "07" is the default year, and "001" is the default tolerance. The full command line modifications should read:

```
gams filterUNIX.gms --yr=07 --tol=001 o=filter07_001.lst qcp=cplex gdx=filter07_001.gdx
```

1.2 Calculating ROIL volume and value shares

This section discusses the incorporation of data from the IEA, the EIA, and the ICCT to break apart the *p_c* product in each of the 22 .csv files in ~/GTAP8inGAMS/data07/CSVImport. The GTAP *p_c* product normally becomes ROIL in EPPA. This section is the process to break ROIL volumes and value flows into RGAS, DISL, GSLN, OTHP, HFOL, and COKE.

1.2.1 Mapping files

A number of mapping files are necessary for the R script to function. For the most part they are described in the main text of the paper above. The mapping files that must be in the ~/IEADataPrep folder are ActivityMap.csv, FuelMap.csv, IEAPriceSectorMap.csv, KSLGRFMap.csv, NonEnergyMap.csv, RegionMap.csv, ROILMap.csv, ROILMapEPPA.csv, TaxFuelMap.csv, USASourceRatioMap.csv, and VolMap.csv. An additional mapping file called icctMap.csv should be in the ~/IEADataPrep/Vehicles folder. These maps translate the regions, products and sectors from the IEA, EIA, and ICCT formats to EPPA.

1.2.2 IEA Energy Statistics files

The key files relating to the IEA *Energy Statistics* are titled OECDEnergyStats-2007.csv and Non-OECDEnergyStats-2007.csv. They must be present in the folder ~/IEADataPrep. They come from the IEA website, to which MIT Libraries have full access if you go through libraries.mit.edu. In retrieving the data, choose the year matching the GTAP base year, and all sectors and countries in each set. They are usually e-mailed in archives that need to be unzipped. Then the entries in each column have to be unified (there are sometimes variations in spacing and titles). They should match the IEA column in the mapping files in each case. Then the files must be saved in .csv format. Also make sure that the column types in the final file match the formats specified in the colClasses portion of the read.csv import command for each file. If the file names are changed, make sure to adjust the read.csv commands in IEADataPrep-EPPA.R.

1.2.3 IEA Energy Prices and Taxes files

The file End-UsePrice2007-USDperTOE-wTaxSubsidy.csv was constructed by hand from the book version of *IEA Energy Prices and Taxes*. It should be in the ~/IEADataPrep folder. In the future these data may be supplied electronically from the IEA statistics website as well. The "...-TaxShare" column after the price of each fuel reports the *share* of the post-tax price that was due to taxes. This was backed out from the tax rates, which were reported separately. Make sure that the initial creation of `IEATaxShare` and `IEAPriceAgent` (currently starting on line 662 of `IEADataPrep-EPPA.R`) choose columns matching the tax share and the post-tax price, respectively.

1.2.4 EIA SEDS pricing relationship file

Also in the ~/`IEADataPrep` folder is the file `IEAPriceRatioSource.csv`. This file is a 24 x 24 matrix of the price ratios between each of the 24 petroleum products in the SEDS database and every other product. These are mapped to the EPPA product. The R script automatically weights and estimates the missing prices of products in each region based on these US-based ratios.

1.2.5 ICCT Roadmap data file

In the folder ~/`IEADataPrep/Vehicles` should be the following three data files: `icctDISL.csv`, `icctGSLN.csv`, and `icctRGAS.csv`. These contain the fuel usage by vehicle type reported in the ICCT Roadmap model's calibration data. Depending on the format of future versions of the ICCT Roadmap model, some re-coding of `IEADataPrep-EPPA.R` may be necessary. Additional files in the ~/`IEADataPrep/Vehicles` folder will provide clues as to how the .csv files were created.

1.2.6 Running the R script for disaggregation

Open R. Set the working directory to ~/`utilities/IEADataPrep`. In R, run `IEADataPrep-EPPA.R`. If you are using the R console, the command at the prompt is:

```
source("IEADataPrep- EPPA.R")
```

This will create .csv output files in the `Output` and `Output/forMaps` folders, and in the `EPPADisaggCSV` folder. This may be useful for examining the data. The important outputs are the 17 .dat files in the folder `EPPADisaggDAT`. These are turned into .gdx files for the disaggregation (they could be used directly as .dat files, but creating .gdx files allows them to be examined in the GAMSIDE application on a Windows-based machine).

1.2.7 Final disaggregation of GTAP with GAMS scripts

Return to the folder ~/`GTAP8inGAMS/build` and run `MakeIEAGDXEPPA.gms`. No command-line prompts are necessary. This creates two .gdx files in the folder ~/`GTAP8inGAMS/data07/EPPADisagg`. One is called `os.gdx`, and it contains the share of each fuel consumed by households used for personal transportation. The other is called `roilshares.gdx`, and it contains the volume and value flow shares of each petroleum sub-product for disaggregating the p_c commodity in GTAP.

Next run `gtapaggrUNIXROIL.gms`. It is also in the folder ~/`GTAP8inGAMS/build`. The solver needs to be CPLEX. The command line prompt is:

```
gams gtapaggrUNIXROIL.gms qcp=cplex
```

If CPLEX is not chosen, CONOPT is the default. It will eventually solve, but it may take hours. `gtapaggrUNIXROIL.gms` will produce the following files in the ~/`data07/EPPADisagg` folder: roiltargets.gdx (the initial estimates of petroleum sub-product values and volumes in each sector and in trade before optimization, based on roilshares.gdx), roilvariablesPRESOLVE. (the initial variables that will be modified under the optimization algorithm), roilvariables.gdx (the post-optimized volume and value flows and trade flows by sector and region for each petroleum product), and roiltaxrevenues.gdx (tax revenues collected on petroleum products). These are all potentially useful for separate examination, or for improving future versions of the model/disaggregation procedure. The crucial output is eppa6_18ROIL.gdx, in the ∼/data07 folder. This file will become the final data from which EPPA6-ROIL is run.

The final step in data disaggregation is the preparation of the data for EPPA. In the ∼/GTAP8inGAMS /build folder, run uno_201207UNIXROIL.gms. There are no command-line modifications necessary. uno_201207UNIXROIL.gms creates the files eppa6dataROIL.gdx and eppa6dataROIL.dat in the folder ∼/GTAP8inGAMS/data. The latter file is the principal input file for EPPA6-ROIL.

1.3 Migrate the disaggregated output files to EPPA6-ROIL folders

Copy eppa6dataROIL.dat from ∼/GTAP8inGAMS/data to eppa6git/data. Copy os.gdx from ∼/GTAP8inGAMS/data07/EPPADisagg to eppa6git/data. Replace any file that exists there already. EPPA6-ROIL is ready to run.

1.4 Additional materials

The following files are already in the ∼/data folder: roilshare10.gdx, refoghgfactor.gdx, and refourbfactor.gdx. The first is the share of the refined fuel volumes consumed in each region in 2010 according to the IEA's *Energy Statistics Database*. The other two are the emissions factors for each of the refined fuels relative to DISL in each sector and region. They are used to weight volumes consumed and thus disaggregate the ROIL commodity emissions in each sector into emissions of each of the six ROIL commodities in EPPA6-ROIL. The files containing the relative emissions factors are not likely to need frequent updating – most of the data in the EPA's WebFIRE database date back to the 1990s.

The roilshare10.gdx file can be created from within the ∼/utilities/OtherPrepFiles /2010VolPrep folder. Future versions of EPPA will use a year other than 2010 (most likely 2015) so the input file (currently IEA2010.csv) and the output file (currently roilshare10.dat) will probably need to be re-coded slightly. Running the R script IEA2010VolPrep.R will create the roilshare10.dat file. Running the GAMS script Makeroilshare10GDX.gms will generate the roilshare10.gdx file. The roilshare10.gdx is imported in the EPPA script eppatrend.gms. Changing any of the file labels will require some trivial re-coding in IEA2010VolPrep.R, Makeroilshare10GDX.gms, and eppatrend.gms from the ∼/parameters folder.

Procedures are similar for re-creating the refoghgfactor.gdx, and refourbfactor.gdx files. The folder ∼/utilities/OtherPrepFiles/Emissions contains all of the files necessary to generate them. The R script EPPAEmissions-EPA.R imports the 16 .csv files beginning with "2014. . . ". Each of those files is the saved output from a web search of the EPA WebFIRE database (http://cfpub.epa.gov/webfire/index.cfm?action=fire.SearchEmissionFactors). The word immediately preceding the ".csv" was the keyword for the search: Coke, Gasoline, LPG, Propane, Resid, Ammonia, Methane, Carbon Monoxide, Nitrous Oxide, NOx, PM10, PM2.5, Particulate Matter, Sulfur Dioxide, SOx, and Volatile Organic Compounds. The mapping files

EPASectorMap.csv, EPAFuelMap.csv, EPATypeMap.csv, EPAGasMap.csv, and EPAMeasureMap.csv are imported as well. Then EPAFormCalc.csv is imported to provide factors where only a formula was reported in the database.

The script calculates the emissions factor of each of the six ROIL products relative to the DISL emissions and adjusts for differences between environmental policies across regions. The output files are refoghgfactor.dat and refourbfactor.dat. Running the GAMS script MakeEPAGDXEPPA.gms creates the .gdx versions of each file. These files are imported to the EPPA model in the eppaghg.gms script.

All three final output files reside in the ~/data folder.

In addition, the Excel worksheets used for updating the ROIL backstop technologies and developing the GTL backstop are contained in the folder ~/utilities/OtherPrepFiles/BackstopWorksheets. The GTL prep file is called GTL-DCFAnalysis-EPPAMarkup-OrigPrice.xlsm. It has macros to re-calculate the CGE input and output value shares based on the costs of inputs and outputs and the engineering data in the DCF model. The other backstop technologies were updated using the file ROILBackstopWorksheet-141017.xlsx. Basically, the old input shares were updated by proportionally shifting their values according to the change in the cost of each input. This also generated new markup values.

1.5 Calibrating changes to EPPA-ROIL files unique to EPPA6-ROIL

The particular disaggregation scripts, in combination with the 2007 base year data that happened to be included with GTAP8, are a unique combination. There were very few modifications that needed to be made to the EPPA model to ensure that it would solve through 2100. They are detailed below. It is possible that more careful initial disaggregation would eliminate the need for these fixes.

1.5.1 Changes to ~core/eppacalib.gms

The only change required of eppacalib.gms was to include a minimum trade flow to and from each region. The code is `wtflow0(r,rr,refpp) = max(1.5e-8, wtflow0(r,rr,refpp));` It is the last line in the file. 1.5×10^{-8} sets a minimum trade flow between each region of $150 for each refined fuel. This is too small to affect model solutions in any significant way, but allows for all variables to be defined in the model so it can solve. Future versions of the EPPA-ROIL disaggregation may not require this line.

1.5.2 Changes to ~core/eppaloop.gms

Almost all of the problems with solutions occurred because of the inclusion of non-homothetic preferences (see Chen *et al.* (2015) for more information). In layman's terms, the new version of EPPA allows for user preferences to evolve over time. Not only can a user substitute between goods to achieve a desired end, the user's preferences update with each model iteration to gradually shift long-term preferences. This only occurs for certain goods. For usage that was very small in the base year data, that can cause the model to crash as variables disappear. These issues are corrected in eppaloop.gms

All of the goods preference updates surround the variables sa(r,g,i) and xa(r,g,i). These variables automatically update preferences through a multiplier. If the good falls to far out of favor, the sa value will be so small that the variable value shrinks to zero. In these cases, there will be "no source" or "no sink" errors for certain activities. Between lines 1704 and 1780, a number of times a minimum value for `sa` is set, or it is set at 1 (disabling the updating of preferences for that input for that good in that region). Future data sets will probably have different cases where this occurs. By default, these lines should be commented out until needed, and others may have to be added in the future.

Another issue occurred when natural gas production costs are manipulated by setting `tkm(``gas'',r,t)` values other than 1 (the defualt) in ~`parameters/eppaparm.gms`. When they are significantly below 1, South Korea (`KOR`) produces unrealistic amounts of natural gas under certain trade configurations. To prevent this, the code `d.up("gas","kor") = 6;` was added at line 291 (as of this draft). This prevents South Korea from producing more than 6 times the natural gas it produced in the base year.

APPENDIX B: Shifting between Armington and Heckscher-Ohlin trade for key refined products

All ROIL products are treated under an Armington trade specification by default. Under the Armington theory of trade, goods from one region are not perfect substitutes for goods from another region. In the case of refined fuels, the reasons might be political or practical rather than the quality or makeup of the fuels themselves. However, diesel fuels, gasolines, and heavy fuel oils are heavily traded internationally. One or more of these three fuels could conceivably be treated as a globally-traded product like crude oil. This trading paradigm is a reflection of the Heckscher-Ohlin theorem of trade, in which products are internationally homogenous. In reality, trade in these products is not as liquid as trade in crude oil, so they likely fall somewhere on a spectrum between Armington and Heckscher-Ohlin goods.

The potential benefit of treating DISL, GSLN, and/or HFOL as homogenous goods is in the study of scenarios in which international trade flows would be a key influence on the outcome. Treating them as homogenous goods requires slightly less time to solve as well. Ultimately, whether to model the products under the Armington or Heckscher-Ohlin trade paradigms will be a matter of choice.

2.1 Changes to the EPPA-ROIL model files

For the most part, EPPA-ROIL will adapt to whether a good is traded under the Armington or Heckscher-Ohlin specification automatically. A few files will need minor modifications in order to treat DISL, GSLN, and/or HFOL as homogenous goods for the purposes of international trade. Some more careful coding could eliminate the need to make some of these changes altogether.

2.1.1 ~`parameters/eppaset.gms`

`eppaset.gms` is the file that defines whether a good should be traded as an Armington or as a homogenous product. The definition of `SET X(I)` will list the goods that should be treated as homogenous. Only crude oil should always be homogenous. Comment out the lines that are not needed, and un-comment the line that reflects the desired set of homogenous goods. In the Summer 2015 version, this occurs around lines 245-250 of the file. The default position (as of this writing) is for DISL, GSLN, and HFOL to be homogenous along with OIL.

2.1.2 ~`core/elecpower.gms`

The EPPA model only allows for international trade of homogenous products if there were trade flows of the product in the base year data. This precludes examining how trade flows evolve in cases where one region's supply of a homogenous product increases significantly. It would preclude exports from that country if the country did not export in the base year. The same restriction applies to imports. Near the beginning of `elecpower.gms` are some lines that will allow for DISL to be traded between every trading region by initializing a nominal trade flow for imports and exports. Around line 21 is `homm0("disl",r) = max(1.5e-6, homm0("disl",r));` and around line 32 is `homx0("disl",r) = max(1.5e-6, homx0("disl",r));`. Comment both of these lines out if (1) DISL is an Armington good, or (2) DISL is treated as a homogenous good but DISL trade is to be restricted to the same countries that traded DISL in the base year. Similar lines could be added to allow unrestricted trade of GSLN and HFOL if they are homogenous. These minimal amounts are the equivalent of about 1,000 barrels of diesel trade, which is insignificant from the perspective of the model. The default position (as of this writing) is to comment out those lines so that trade flows reflect historical patterns.

2.1.3 ∼core/report.gms

`report.gms` exports key outputs from the EPPA-ROIL model as .csv files that can be read by every statistics program. Users can add new features as required. If DISL, GSLN, or HFOL are homogenous goods then the lines in `report.gms` that include "disl", "gsln", and/or "hfol" and that begin with `datasec(``702_Price of homogenous goods`... need to be uncommented. This goes for all letter suffixes to 702 as well: 702a, 702b, 702c, and 702d. The default position (as of this writing) is to leave these active.

2.2 Final Thoughts

After these modifications, EPPA-ROIL can be run the same way as the EPPA model in terms of setting up `.cas` files, start and stop dates, etc. The model takes significantly longer than the non-ROIL version of EPPA, so it should only be used in cases where the competition *between* refined fuels is a relevant factor in the research. It might also be useful to run comparisons of otherwise identical scenarios between EPPA6 and EPPA6-ROIL to determine whether the added detail is significant to larger-scale results.

A tedious but thorough "lab book" is also included in the ∼`/utilities` folder. It is called `EPPA6 Methodology-120610-150409-ARCHIVE.pdf`. This should help clarify the exact procedures followed, but it also includes dead-ends and revisions, sometimes long after initial runs, so it should be used with caution.

TECHNICAL NOTE SERIES of the MIT Joint Program on the Science and Policy of Global Change

FOR THE COMPLETE LIST OF JOINT PROGRAM TECHNICAL NOTES: http://globalchange.mit.edu/research/publications/other/technical

1. **Emissions inventories and Time Trends for Greenhouse Gases and Other Pollutants.** *Mayer et al.,* July 2000
2. **Probabilistic Emissions Scenarios.** *Reilly et al.,* July 2001
3. **MIT EPPA Projections and the Administration Proposal.** *Reilly,* March 2002
4. **Moving from Static to Dynamic General Equilibrium Economic Models (Notes for a beginner in MPSGE).** *Paltsev,* June 2004
5. **Disaggregating Household Transport in the MIT-EPPA Model.** *Paltsev et al.,* July 2004
6. **Computable General Equilibrium Models and Their Use in Economy-wide Policy Analysis.** *Sue Wing*, September 2004
7. **Comparing Tax Rates Using OECD and GTAP6 Data.** *Gurgel et al.,* May 2006
8. **Historical Anthropogenic Emissions Inventories for Greenhouse Gases and Major Criteria Pollutants.** *Asadoorian et al.,* July 2006
9. **Improving the Refining Sector in EPPA.** Choumert *et al.,* July 2006
10. **Analyzing Methane-Emitting Activities: Longitudinal Data, Emissions Coefficients, and Spatial Distributions.** *Asadoorian et al.,* July 2006
11. **Computing Tax Rates for Economic Modeling: A Global Dataset Approach.** Gurgel *et al.,* January 2007
12. **Emissions Inventory for Non-CO_2 Greenhouse Gases and Air Pollutants in EPPA 5.** *Waugh et al.,* July 2011
13. **A Global General Equilibrium Model with US State-Level Detail for Trade and Environmental Policy Analysis—Technical Notes.** *Caron & Rausch,* February 2013
14. **WRS-US Version 2–Technical Note.** *Blanc*, November 2015
15. **Updates to disaggregating the refined oil sector in EPPA: EPPA6-ROIL.** *Ramberg and Chen,* December 2015

Contact the Joint Program Office to request a copy. The Technical Note Series is distributed at no charge.