Supplementary Material for: *Multimodal transportation flows in energy networks with an application to crude oil markets*

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Abstract

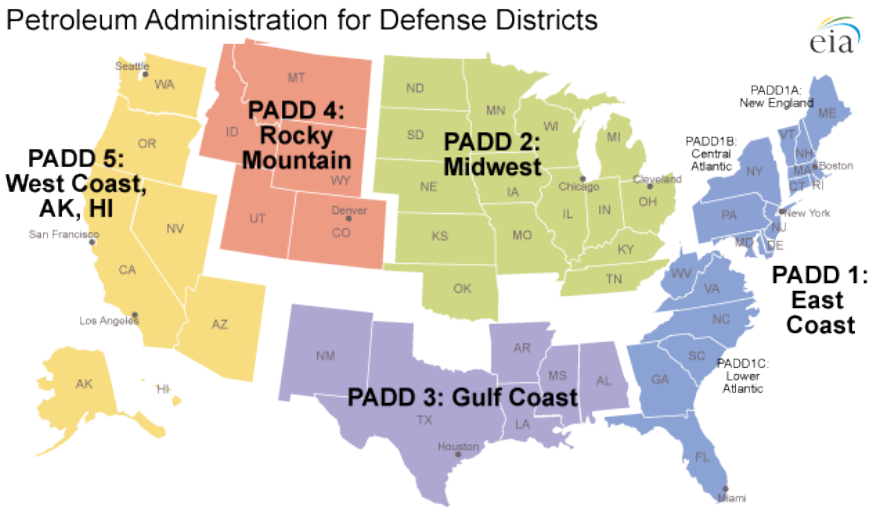
In this supplement, we provide further information for the North American crude oil model (NACOM). This includes a complete list of nodes and arcs in the model (Section 3 and Section 4), along with a brief background on the Petroleum Administration for Defense Districts (PADD) regional system in the United States (Section 2). We validate flow calibration for NACOM in Section 5. The input data for NACOM, along with the Python scripts used in processing and illustrating, are available for download at https://github.com/MODLJHU/nacom.

Contents

1 Data initialization recap

We set 2012 as the base year for our model, which proceeds for two subsequent periods in steps of 3 years, i.e. 2015 and 2018. All quantities are expressed in kilobarrel per day (kbpd) units. An annual discount factor of 91% and 95% is applied to investment decisions for producers and arc operators, respectively. Prices and all other monetary values are in US dollar terms. 100% capacity availability is assumed for all producers (thus $\text{avl}^P = 1$ in all cases). An energy service efficiency of 98% is assumed for all consumption nodes. We do not consider seasonal variations in either production or consumption patterns. Details on our data are provided in the following section.

2 The Petroleum Administration for Defense Districts



Supplementary Fig. S1 Petroleum Administration for Defense Districts (Source: EIA [2])

The Petroleum Administration Defense Districts (PADDs) were historically drawn up to organize gasoline distribution during wartime rationing [2], but they have now been established as the baseline for recording and analyzing crude oil movements in the US (Figure 1), especially by the US Energy Information Administration. As described in Section 5, we use the PADD regional crude oil movement data as the basis for calibrating base case flows through the US. We also occasionally use them in highlighting regional changes at various points in this paper.

3 List of nodes

Table 1 lists the nodes in the model, their abbreviations and their regions.

Supplementary Table S1 List of nodes, their abbreviations and regions in the model. A value of 1 or 0 indicates whether the node is a producing/consuming node or not.

Node	Abbreviation	Region	Producer	Consumer
Alabama	AL	PADD3	0	0
Alaska	AK	PADD5	1	1
Arizona	AZ	PADD5	0	0
Arkansas	AR	PADD3	0	0
California	CA	PADD5	1	1
Colorado	CO	PADD4	1	1

Supplementary Table S1 List of nodes, their abbreviations and regions in the model. A value of 1 or 0 indicates whether the node is a producing/consuming node or not.

Node	Abbreviation	Region	Producer	Consumer
Connecticut	CT	PADD1	0	0
Delaware	DE	PADD1	0	1
District of Columbia	DC	PADD1	0	0
Eastern Canada	EC	CAN	1	1
Florida	FL	PADD1	0	0
Georgia	GA	PADD1	0	0
Hawaii	HI	PADD5	0	0
Idaho	ID	PADD4	0	0
Illinois	IL	PADD2	0	1
Indiana	IN	PADD2	0	1
Iowa	IA	PADD2	0	0
Kansas	KS	PADD2	1	1
Kentucky	KY	PADD2	0	1
Louisiana	LA	PADD3	1	1
Maine	ME	PADD1	0	0
Maryland	MD	PADD1	0	0
Massachusetts	MA	PADD1	0	0
Mexico	MX	MEX	1	1
Michigan	MI	PADD2	0	0
Minnesota	MN	PADD2	0	1
Mississippi	MS	PADD3	0	1
Missouri	MO	PADD2	0	0
Montana	MT	PADD4	0	1
Nebraska	NE	PADD2	0	0
Nevada	NV	PADD5	0	0
New Hampshire	NH	PADD1	0	0
New Jersey	NJ	PADD1	0	1
New Mexico	NM	PADD3	1	1
New York	NY	PADD1	0	0
North Carolina	NC	PADD1	0	0
North Dakota	ND	PADD2	1	1
Ohio	OH	PADD2	0	1
Oklahoma	OK	PADD2	1	1
Oregon	OR	PADD5	0	0
Pennsylvania	PA	PADD1	0	1
Rest of World	RW	ONA	1	1
Rhode Island	RI	PADD1	0	0
South Carolina	SC	PADD1	0	0
South Dakota	SD	PADD2	0	0
Tennessee	TN	PADD2	0	1
Texas	TX	PADD3	1	1
Utah	UT	PADD4	0	0
Vermont	VT	PADD1	0	0
Virginia	VA	PADD1	0	0
Washington	WA	PADD5	0	1
West Virginia	WV	PADD1	0	0
Western Canada	WC	CAN	1	1
Wisconsin	WI	PADD2	0	0
Wyoming	WY	PADD4	1	1
Alabama Rail Terminal	AL_R	PADD3		
Alaska Rail Terminal	AK_R	PADD5		
Arizona Rail Terminal	AZ_R	PADD5		
Arkansas Rail Terminal	AR_R	PADD3		

Supplementary Table S1 List of nodes, their abbreviations and regions in the model. A value of 1 or 0 indicates whether the node is a producing/consuming node or not.

Node	Abbreviation	Region	Producer	Consumer
California Rail Terminal	CA_R	PADD5		
Colorado Rail Terminal	CO_R	PADD4		
Connecticut Rail Terminal	CT_R	PADD1		
Delaware Rail Terminal	DE_R	PADD1		
District of Columbia Rail Terminal	DC_R	PADD1		
Eastern Canada Rail Terminal	EC_R	CAN		
Florida Rail Terminal	FL_R	PADD1		
Georgia Rail Terminal	GA_R	PADD1		
Hawaii Rail Terminal	HI_R	PADD5		
Idaho Rail Terminal	ID_R	PADD4		
Illinois Rail Terminal	IL_R	PADD2		
Indiana Rail Terminal	IN_R	PADD2		
Iowa Rail Terminal	IA_R	PADD2		
Kansas Rail Terminal	KS_R	PADD2		
Kentucky Rail Terminal	KY_R	PADD2		
Louisiana Rail Terminal	LA_R	PADD3		
Maine Rail Terminal	ME_R	PADD1		
Maryland Rail Terminal	MD_R	PADD1		
Massachusetts Rail Terminal	MA_R	PADD1		
Michigan Rail Terminal	MI_R	PADD2		
Minnesota Rail Terminal	MN_R	PADD2		
Mississippi Rail Terminal	MS_R	PADD3		
Missouri Rail Terminal	MO_R	PADD2		
Montana Rail Terminal	MT_R	PADD4		
Nebraska Rail Terminal	NE_R	PADD2		
Nevada Rail Terminal	NV_R	PADD5		
New Hampshire Rail Terminal	NH_R	PADD1		
New Jersey Rail Terminal	NJ_R	PADD1		
New Mexico Rail Terminal	NM_R	PADD3		
New York Rail Terminal	NY_R	PADD1		
North Carolina Rail Terminal	NC_R	PADD1		
North Dakota Rail Terminal	ND_R	PADD2		
Ohio Rail Terminal	OH_R	PADD2		
Oklahoma Rail Terminal	OK_R	PADD2		
Oregon Rail Terminal	OR_R	PADD5		
Pennsylvania Rail Terminal	PA_R	PADD1		
Rhode Island Rail Terminal	RI_R	PADD1		
South Carolina Rail Terminal	SC_R	PADD1		
South Dakota Rail Terminal	SD_R	PADD2		
Tennessee Rail Terminal	TN_R	PADD2		
Texas Rail Terminal	TX_R	PADD3		
Utah Rail Terminal	UT_R	PADD4		
Vermont Rail Terminal	VT_R	PADD1		
Virginia Rail Terminal	VA_R	PADD1		
Washington Rail Terminal	WA_R	PADD5		
West Virginia Rail Terminal	WV_R	PADD1		
Western Canada Rail Terminal	WC_R	CAN		
Wisconsin Rail Terminal	WI_R	PADD2		
Wyoming Rail Terminal	WY_R	PADD4		

4 Transportation arcs in the model and their initial parameter values

The arc data gathered for the model are shown in Table 2. Some parameters were later adjusted for calibration purposes.

Supplementary Table S2 Transportation arcs for crude oil included in the model. Capacities shown are initial values, some of which are modified in calibration. The term "BargeS" represents sea-going barges, while "BargeR" represents river-going barges. A value of 1 for the "Capacity Constrained" parameter indicates that the capacity is active. Most of the waterway arcs were initialized with unlimited (or unconstrained) capacities, but limits were introduced during calibration. All tariff values are in US$/barrel.

Outgoing Node	Incoming Node	Type	Tariff	Capacity	Capacity Constrained
AK	CA	Ship	6	0	0
AK	RW	Ship	2	0	1
AK	WA	Ship	6	0	0
AL_R	FL_R	Rail	2.15	0	0
AL_R	GA_R	Rail	1.4	0	0
AL_R	MS_R	Rail	1.35	0	0
AL_R	TN_R	Rail	1.45	0	0
AR	MS	BargeR	5.5	0	0
AR_R	LA_R	Rail	1.61	0	0
AR_R	MO_R	Rail	1.56	0	0
AR_R	MS_R	Rail	1.49	0	0
AR_R	OK_R	Rail	1.61	0	0
AR_R	TN_R	Rail	1.78	0	0
AR_R	TX_R	Rail	2	0	0
AZ_R	CA_R	Rail	2.27	0	0
AZ_R	NM_R	Rail	1.72	0	0
AZ_R	NV_R	Rail	2.14	0	0
AZ_R	UT_R	Rail	2.1	0	0
CA	CA_R	Load	1	40	1
CA	RW	Ship	2	0	1
CA_R	AZ_R	Rail	2.27	0	0
CA_R	CA	UnLoad	1	215.76	1
CA_R	NV_R	Rail	1.48	0	0
CA_R	OR_R	Rail	2.52	0	0
CO	CO_R	Load	1	140.99	1
CO	OK	Pipeline	4.86	75	1
CO_R	CO	UnLoad	1	6	1
CO_R	KS_R	Rail	1.96	0	0
CO_R	NE_R	Rail	1.99	0	0
CO_R	NM_R	Rail	1.71	0	0
CO_R	OK_R	Rail	2.12	0	0
CO_R	UT_R	Rail	1.87	0	0
CO_R	WY_R	Rail	1.64	0	0
CT_R	NY_R	Rail	1.22	0	0
DE	DE_R	Load	1	0	1
DE_R	DE	UnLoad	1	145	1
DE_R	MD_R	Rail	1.09	0	0
DE_R	PA_R	Rail	1.24	0	0
EC	DE	Ship	1.5	0	0
EC	EC_R	Load	1	0	1
EC	NJ	Ship	1.5	0	0
EC	NY	Ship	1.5	0	0
EC	PA	Ship	1.5	0	0

Supplementary Table S2 Transportation arcs for crude oil included in the model. Capacities shown are initial values, some of which are modified in calibration. The term "BargeS" represents sea-going barges, while "BargeR" represents river-going barges. A value of 1 for the "Capacity Constrained" parameter indicates that the capacity is active. Most of the waterway arcs were initialized with unlimited (or unconstrained) capacities, but limits were introduced during calibration. All tariff values are in US$/barrel.

Outgoing Node	Incoming Node	Type	Tariff	Capacity	Capacity Constrained
EC	RW	Ship	4	0	0
EC_R	EC	UnLoad	1	240	1
EC_R	MI_R	Rail	7.88	0	0
EC_R	MN_R	Rail	9.01	0	0
EC_R	NY_R	Rail	3.35	0	0
EC_R	VT_R	Rail	2.88	0	0
EC_R	WC_R	Rail	6	0	0
FL_R	AL_R	Rail	2.15	0	0
FL_R	GA_R	Rail	1.92	0	0
GA	NC	Pipeline	4.81	860	1
GA_R	AL_R	Rail	1.4	0	0
GA_R	FL_R	Rail	1.92	0	0
GA_R	SC_R	Rail	1.36	0	0
GA_R	TN_R	Rail	1.36	0	0
IA_R	IL_R	Rail	1.57	0	0
IA_R	MN_R	Rail	1.61	0	0
IA_R	MO_R	Rail	1.58	0	0
IA_R	NE_R	Rail	1.63	0	0
IA_R	SD_R	Rail	1.86	0	0
IA_R	WI_R	Rail	1.55	0	0
ID_R	MT_R	Rail	1.64	0	0
ID_R	NV_R	Rail	2.06	0	0
ID_R	OR_R	Rail	12.93	0	0
ID_R	UT_R	Rail	1.76	0	0
ID_R	WA_R	Rail	13	0	0
ID_R	WC_R	Rail	10.39	0	0
ID_R	WY_R	Rail	1.94	0	0
IL	IL_R	Load	1	0	1
IL	IN	Pipeline	4.8	2,620	1
IL	KY	Pipeline	4.82	256	1
IL	MS	BargeR	5.5	0	0
IL	OH	Pipeline	4.78	290	1
IL_R	IA_R	Rail	1.57	0	0
IL_R	IL	UnLoad	1	312.04	1
IL_R	IN_R	Rail	1.3	0	0
IL_R	KY_R	Rail	1.71	0	0
IL_R	MO_R	Rail	1.49	0	0
IL_R	WI_R	Rail	1.64	0	0
IN	IN_R	Load	1	0	1
IN	MI	Pipeline	4.85	2,620	1
IN_R	IL_R	Rail	1.3	0	0
IN_R	IN	UnLoad	1	0	1
IN_R	KY_R	Rail	1.37	0	0
IN_R	MI_R	Rail	1.6	0	0
IN_R	OH_R	Rail	1.41	0	0
KS	KS_R	Load	1	0	1
KS	OK	Pipeline	4.78	230	1
KS_R	CO_R	Rail	1.96	0	0
KS_R	KS	UnLoad	1	32	1

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Outgoing Node	Incoming Node	Type	Tariff	Capacity	Capacity Constrained
KS_R	MO_R	Rail	1.56	0	0
KS_R	NE_R	Rail	1.43	0	0
KS_R	OK_R	Rail	1.26	0	0
KY	KY_R	Load	1	0	1
KY_R	IL_R	Rail	1.71	0	0
KY_R	IN_R	Rail	1.37	0	0
KY_R	KY	UnLoad	1	0	1
KY_R	MO_R	Rail	2.04	0	0
KY_R	OH_R	Rail	1.48	0	0
KY_R	TN_R	Rail	1.13	0	0
KY_R	VA_R	Rail	1.61	0	0
KY_R	WV_R	Rail	1.21	0	0
LA	LA_R	Load	1	10	1
LA	MS	BargeS	5.5	0	0
LA	RW	Ship	2	0	1
LA	TN	BargeR	6.8	0	0
LA	TN	Pipeline	4.84	1,200	1
LA	TX	Pipeline	4.8	325	1
LA_R	AR_R	Rail	1.61	0	0
LA_R	LA	UnLoad	1	687.23	1
LA_R	MS_R	Rail	1.36	0	0
LA_R	TX_R	Rail	1.83	0	0
MA_R	NY_R	Rail	1.37	0	0
MA_R	RI_R	Rail	1	0	0
MD_R	DE_R	Rail	1.09	0	0
MD_R	PA_R	Rail	1.19	0	0
MD_R	VA_R	Rail	1.22	0	0
MD_R	WV_R	Rail	1.52	0	0
ME	EC	Pipeline	4.78	300	1
MI	EC	Pipeline	4.85	40	1
MI	NJ	Pipeline	4.86	0	1
MI_R	EC_R	Rail	4.88	0	0
MI_R	IN_R	Rail	1.6	0	0
MI_R	OH_R	Rail	1.51	0	0
MI_R	WI_R	Rail	1.61	0	0
MN	MN_R	Load	1	0	1
MN_R	EC_R	Rail	5.01	0	0
MN_R	IA_R	Rail	1.61	0	0
MN_R	MN	UnLoad	1	0	1
MN_R	ND_R	Rail	1.73	0	0
MN_R	SD_R	Rail	1.68	0	0
MN_R	WC_R	Rail	11.2	0	0
MN_R	WI_R	Rail	1.53	0	0
MO	MS	BargeR	5.5	0	0
MO_R	AR_R	Rail	1.56	0	0
MO_R	IA_R	Rail	1.58	0	0
MO_R	IL_R	Rail	1.49	0	0
MO_R	KS_R	Rail	1.56	0	0
MO_R	KY_R	Rail	2.04	0	0

Supplementary Table S2 Transportation arcs for crude oil included in the model. Capacities shown are initial values, some of which are modified in calibration. The term "BargeS" represents sea-going barges, while "BargeR" represents river-going barges. A value of 1 for the "Capacity Constrained" parameter indicates that the capacity is active. Most of the waterway arcs were initialized with unlimited (or unconstrained) capacities, but limits were introduced during calibration. All tariff values are in US$/barrel.

Outgoing Node	Incoming Node	Type	Tariff	Capacity	Capacity Constrained
MO_R	NE_R	Rail	1.9	0	0
MO_R	OK_R	Rail	1.79	0	0
MO_R	TN_R	Rail	1.88	0	0
MS	MS_R	Load	1	0	1
MS	PA	BargeS	5	0	0
MS_R	AL_R	Rail	1.35	0	0
MS_R	AR_R	Rail	1.49	0	0
MS_R	LA_R	Rail	1.36	0	0
MS_R	MS	UnLoad	1	50	1
MS_R	TN_R	Rail	1.62	0	0
MT	MT_R	Load	1	0	1
MT	WA	Pipeline	4.86	0	1
MT	WY	Pipeline	4.81	145	1
MT_R	ID_R	Rail	1.64	0	0
MT_R	MT	UnLoad	1	0	1
MT_R	ND_R	Rail	2.25	0	0
MT_R	SD_R	Rail	2.41	0	0
MT_R	WA_R	Rail	20.43	0	0
MT_R	WC_R	Rail	9.82	0	0
MT_R	WY_R	Rail	1.79	0	0
MX	AL	Ship	0.4	0	0
MX	LA	Ship	0.4	0	0
MX	MS	Ship	0.4	0	0
MX	NJ	Ship	4	0	0
MX	RW	Ship	1.5	0	0
MX	TX	Ship	0.4	0	0
NC	NJ	Pipeline	4.86	860	1
NC_R	SC_R	Rail	1.28	0	0
NC_R	TN_R	Rail	1.66	0	0
NC_R	VA_R	Rail	1.37	0	0
ND	IL	Pipeline	4.91	2,620	1
ND	MT	Pipeline	4.75	145	1
ND	ND_R	Load	1	1,262.99	1
ND_R	EC_R	Rail	2	17	1
ND_R	MN_R	Rail	1.73	0	0
ND_R	MT_R	Rail	2.25	0	0
ND_R	ND	UnLoad	1	0	1
ND_R	SD_R	Rail	1.51	0	0
ND_R	WC_R	Rail	10.39	0	0
NE	OK	Pipeline	4.8	591	1
NE_R	CO_R	Rail	1.99	0	0
NE_R	IA_R	Rail	1.63	0	0
NE_R	KS_R	Rail	1.43	0	0
NE_R	MO_R	Rail	1.9	0	0
NE_R	SD_R	Rail	1.51	0	0
NE_R	WY_R	Rail	2.19	0	0
NJ	NJ_R	Load	1	0	1
NJ	RW	Ship	2	0	1
NJ_R	NJ	UnLoad	1	101.47	1

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Outgoing Node	Incoming Node	Type	Tariff	Capacity	Capacity Constrained
NJ_R	NY_R	Rail	1.25	0	0
NJ_R	PA_R	Rail	1.29	0	0
NM	NM_R	Load	1	173.98	1
NM	TX	Pipeline	4.9	400	1
NM_R	AZ_R	Rail	1.72	0	0
NM_R	CO_R	Rail	1.71	0	0
NM_R	NM	UnLoad	1	0	1
NM_R	OK_R	Rail	2.14	0	0
NM_R	TX_R	Rail	2.43	0	0
NV_R	AZ_R	Rail	2.14	0	0
NV_R	CA_R	Rail	1.48	0	0
NV_R	ID_R	Rail	2.06	0	0
NV_R	OR_R	Rail	2.26	0	0
NV_R	UT_R	Rail	1.73	0	0
NY_R	CT_R	Rail	1.22	0	0
NY_R	EC_R	Rail	4.85	0	0
NY_R	MA_R	Rail	1.37	0	0
NY_R	NJ_R	Rail	1.25	0	0
NY_R	PA_R	Rail	1.34	0	0
OH	LA	BargeR	5.5	0	0
OH	OH_R	Load	1	24	1
OH	TX	BargeR	5.5	0	0
OH_R	IN_R	Rail	1.41	0	0
OH_R	KY_R	Rail	1.48	0	0
OH_R	MI_R	Rail	1.51	0	0
OH_R	OH	UnLoad	1	56.76	1
OH_R	PA_R	Rail	1.44	0	0
OH_R	WV_R	Rail	1.09	0	0
OK	IL	Pipeline	4.91	913	1
OK	LA	BargeR	5	0	0
OK	OK_R	Load	1	722.97	1
OK	TX	Pipeline	3.11	850	1
OK_R	AR_R	Rail	1.61	0	0
OK_R	CO_R	Rail	2.12	0	0
OK_R	KS_R	Rail	1.26	0	0
OK_R	MO_R	Rail	1.79	0	0
OK_R	NM_R	Rail	2.14	0	0
OK_R	OK	UnLoad	1	176.76	1
OK_R	TX_R	Rail	0.99	0	0
OR	CA	BargeS	5	0	0
OR	WA	BargeS	5	0	0
OR_R	CA_R	Rail	2.52	0	0
OR_R	ID_R	Rail	5.93	0	0
OR_R	NV_R	Rail	2.26	0	0
OR_R	OR	UnLoad	1	200	1
OR_R	WA_R	Rail	1.43	0	0
PA	KY	BargeR	5.5	0	0
PA	LA	BargeR	5.5	0	0
PA	MS	BargeS	4	5.3	1

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Outgoing Node	Incoming Node	Type	Tariff	Capacity	Capacity Constrained
PA	PA_R	Load	1	0	1
PA_R	DE_R	Rail	1.24	0	0
PA_R	MD_R	Rail	1.19	0	0
PA_R	NJ_R	Rail	1.29	0	0
PA_R	NY_R	Rail	1.34	0	0
PA_R	OH_R	Rail	1.69	0	0
PA_R	PA	UnLoad	1	275	1
PA_R	WV_R	Rail	1.57	0	0
RI_R	MA_R	Rail	1	0	0
RW	AK	Ship	2	0	0
RW	AL	Ship	2	0	0
RW	CA	Ship	1.5	0	0
RW	DE	Ship	2	0	0
RW	EC	Ship	4	0	0
RW	LA	Ship	2	0	0
RW	MS	Ship	2	0	0
RW	MX	Ship	2	0	0
RW	NJ	Ship	2	0	0
RW	NY	Ship	2	0	0
RW	PA	Ship	2	0	0
RW	TX	Ship	2	0	0
RW	WA	Ship	2	0	0
SC_R	GA_R	Rail	1.36	0	0
SC_R	NC_R	Rail	1.28	0	0
SD_R	IA_R	Rail	1.86	0	0
SD_R	MN_R	Rail	1.68	0	0
SD_R	MT_R	Rail	2.41	0	0
SD_R	ND_R	Rail	1.51	0	0
SD_R	NE_R	Rail	1.51	0	0
SD_R	WY_R	Rail	2	0	0
TN	IL	Pipeline	4.78	1,200	1
TN	TN_R	Load	1	0	1
TN_R	AL_R	Rail	1.45	0	0
TN_R	AR_R	Rail	1.78	0	0
TN_R	GA_R	Rail	1.36	0	0
TN_R	KY_R	Rail	1.13	0	0
TN_R	MO_R	Rail	1.88	0	0
TN_R	MS_R	Rail	1.62	0	0
TN_R	NC_R	Rail	1.66	0	0
TN_R	TN	UnLoad	1	0	1
TN_R	VA_R	Rail	1.85	0	0
TX	EC	Ship	2	0	0
TX	GA	Pipeline	4.93	860	1
TX	LA	BargeR	5	0	0
TX	MS	BargeR	5	0	0
TX	NJ	Ship	5	0	0
TX	NY	BargeS	5	0	0
TX	OH	Pipeline	5	300	1
TX	OK	Pipeline	4.85	720	1

Supplementary Table S2 Transportation arcs for crude oil included in the model. Capacities shown are initial values, some of which are modified in calibration. The term "BargeS" represents sea-going barges, while "BargeR" represents river-going barges. A value of 1 for the "Capacity Constrained" parameter indicates that the capacity is active. Most of the waterway arcs were initialized with unlimited (or unconstrained) capacities, but limits were introduced during calibration. All tariff values are in US$/barrel.

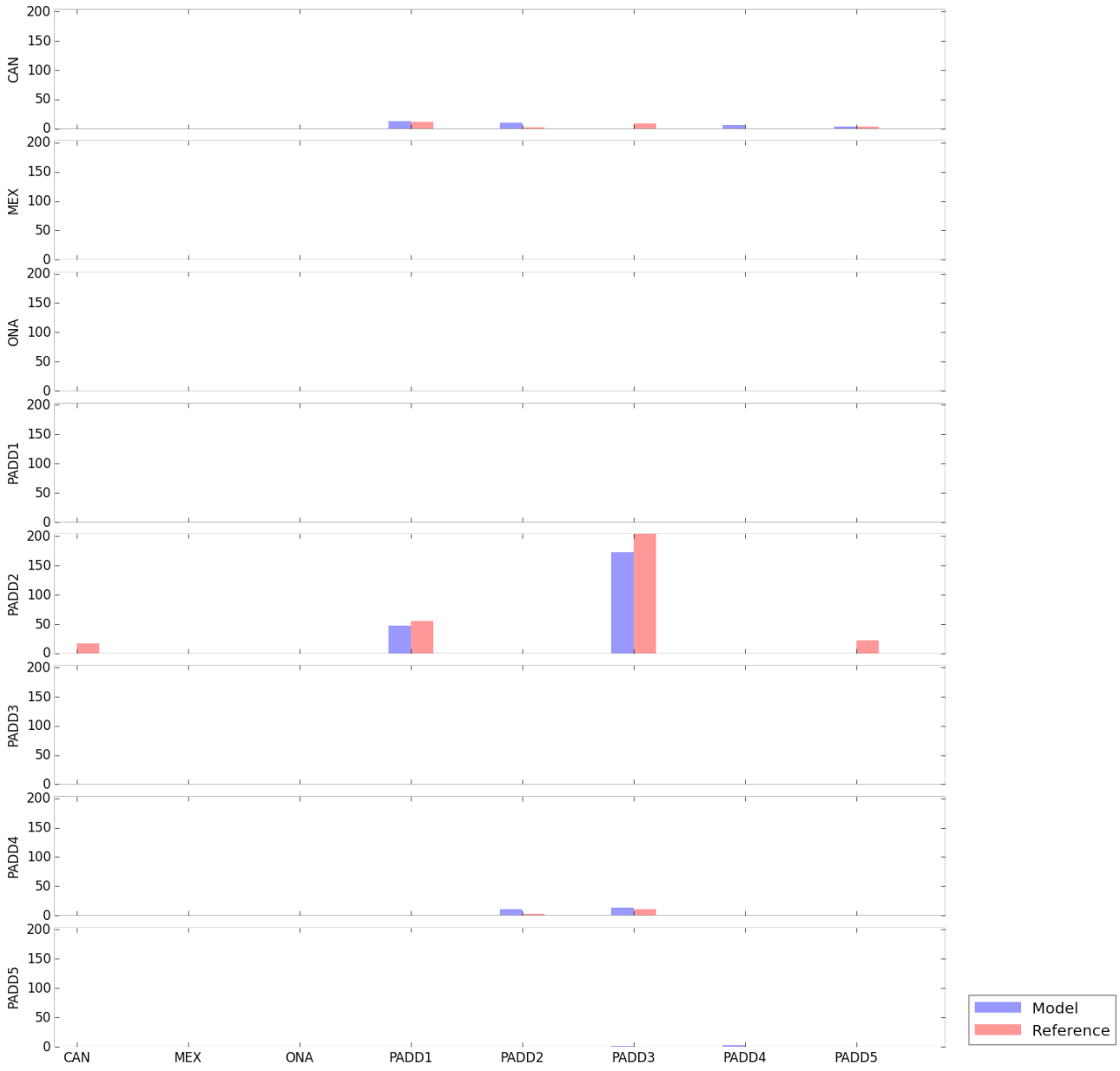
Outgoing Node	Incoming Node	Type	Tariff	Capacity	Capacity Constrained
TX	PA	BargeS	6	0	0
TX	RW	Ship	2	0	1
TX	TX_R	Load	1	741.95	1
TX_R	AR_R	Rail	2	0	0
TX_R	LA_R	Rail	1.83	0	0
TX_R	NM_R	Rail	2.43	0	0
TX_R	OK_R	Rail	1.74	0	0
TX_R	TX	UnLoad	1	752.51	1
UT_R	AZ_R	Rail	2.1	0	0
UT_R	CO_R	Rail	1.87	0	0
UT_R	ID_R	Rail	1.76	0	0
UT_R	NV_R	Rail	1.73	0	0
UT_R	WY_R	Rail	1.72	0	0
VA_R	KY_R	Rail	1.61	0	0
VA_R	MD_R	Rail	1.22	0	0
VA_R	NC_R	Rail	1.37	0	0
VA_R	TN_R	Rail	1.85	0	0
VA_R	WV_R	Rail	1.08	0	0
VT_R	EC_R	Rail	4.38	0	0
WA	OR	Pipeline	4.81	295	1
WA	RW	Ship	2	0	1
WA	WA_R	Load	1	0	1
WA_R	ID_R	Rail	2.5	0	0
WA_R	OR_R	Rail	1.43	0	0
WA_R	WA	UnLoad	1	163	1
WA_R	WC_R	Rail	10.38	0	0
WC	MN	Pipeline	4.96	880	1
WC	MT	Pipeline	4.99	145	1
WC	ND	Pipeline	4.93	2,620	1
WC	NE	Pipeline	4.92	591	1
WC	WC_R	Load	1	990.46	1
WC	WY	Pipeline	4.93	280	1
WC_R	EC_R	Rail	6	0	0
WC_R	ID_R	Rail	10.39	0	0
WC_R	MN_R	Rail	11.2	0	0
WC_R	MT_R	Rail	9.82	0	0
WC_R	ND_R	Rail	10.39	0	0
WC_R	WA_R	Rail	10.38	0	0
WC_R	WC	UnLoad	1	7	1
WI_R	IA_R	Rail	1.55	0	0
WI_R	IL_R	Rail	1.64	0	0
WI_R	MI_R	Rail	1.61	0	0
WI_R	MN_R	Rail	1.53	0	0
WV	KY	BargeR	5.5	0	0
WV	LA	BargeR	5.5	0	0
WV	TX	BargeR	5.5	0	0
WV_R	KY_R	Rail	1.21	0	0
WV_R	MD_R	Rail	1.52	0	0
WV_R	OH_R	Rail	1.09	0	0

Supplementary Table S2 Transportation arcs for crude oil included in the model. Capacities shown are initial values, some of which are modified in calibration. The term "BargeS" represents sea-going barges, while "BargeR" represents river-going barges. A value of 1 for the "Capacity Constrained" parameter indicates that the capacity is active. Most of the waterway arcs were initialized with unlimited (or unconstrained) capacities, but limits were introduced during calibration. All tariff values are in US$/barrel.

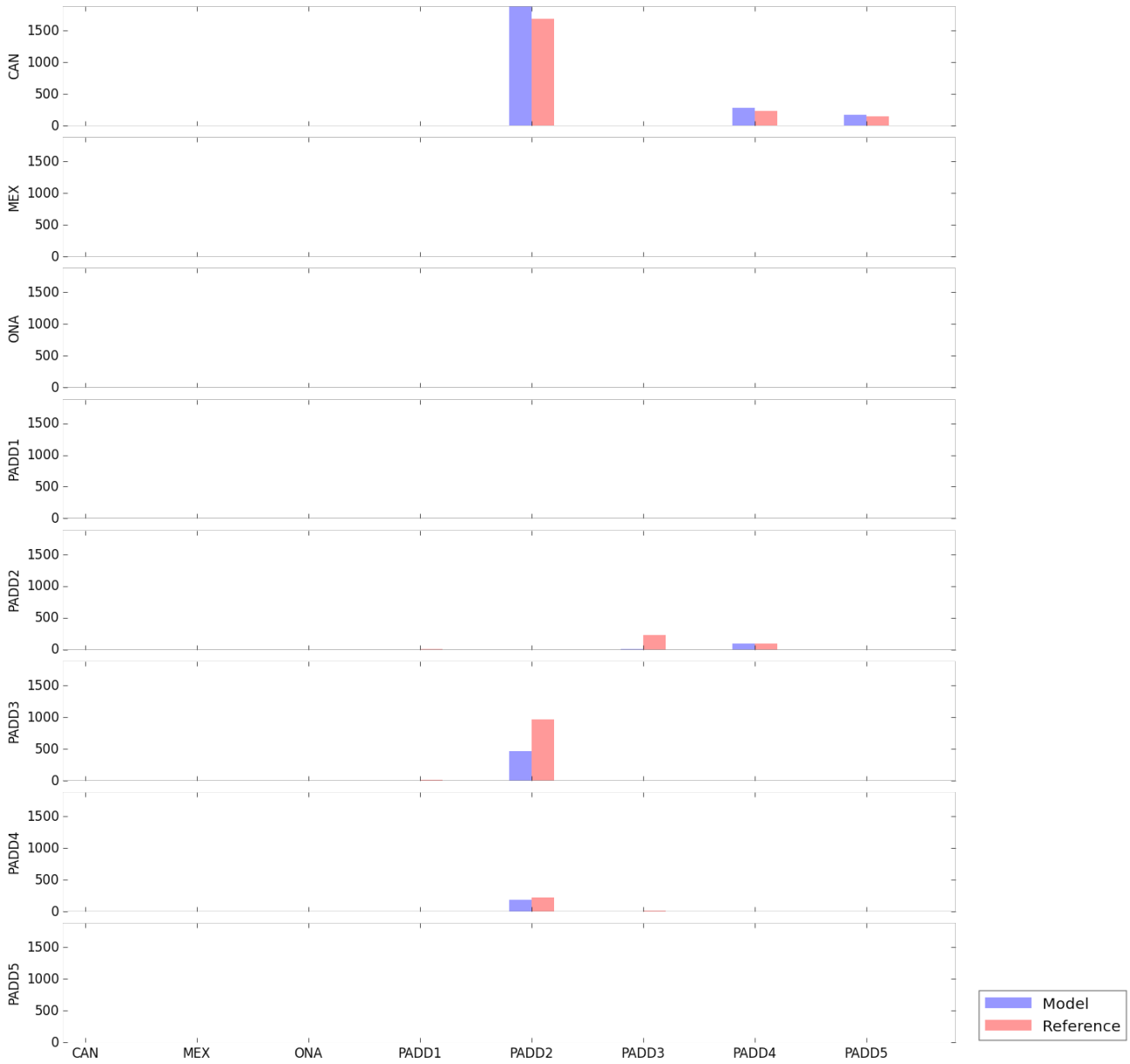
Outgoing Node	Incoming Node	Type	Tariff	Capacity	Capacity Constrained
WV_R	PA_R	Rail	1.57	0	0
WV_R	VA_R	Rail	1.08	0	0
WY	IL	Pipeline	4.99	280	1
WY	KS	Pipeline	4.84	230	1
WY	WY_R	Load	1	555	1
WY_R	CO_R	Rail	1.64	0	0
WY_R	ID_R	Rail	1.94	0	0
WY_R	MT_R	Rail	1.79	0	0
WY_R	NE_R	Rail	2.19	0	0
WY_R	SD_R	Rail	2	0	0
WY_R	UT_R	Rail	1.72	0	0
WY_R	WY	UnLoad	1	0	1

5 Model and reference flow comparisons

To validate our model, we compare equilibrium transportation quantities to reference data at the regional level, which is the best resolution available. The interregional flows in the base year 2012 for each of the modes are shown in Figure 2, Figure 3 and Figure 4.



Supplementary Fig. S2 Comparison of model and reference interregional transportation quantities via rail in 2012



Supplementary Fig. S3 Comparison of model and reference interregional transportation quantities via pipeline in 2012

Supplementary Fig. S4 Comparison of model and reference interregional transportation quantities via tanker/barge in 2012

Note on figures

All the figures in the main article and this supplement were created using the Matplotlib package in Python [1] (except for Figure 1, which was generated in LaTeXvia the PGF package).

References

[1] J. D. Hunter. Matplotlib: A 2d graphics environment. *Computing In Science & Engineering*, 9(3):90–95, 2007.

[2] US Energy Information Administration. PADD regions enable regional analysis of petroleum product supply and movements. https://www.eia.gov/todayinenergy/detail.cfm?id=4890, February 2012.