Universität Augsburg
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Spillover effects in oil markets

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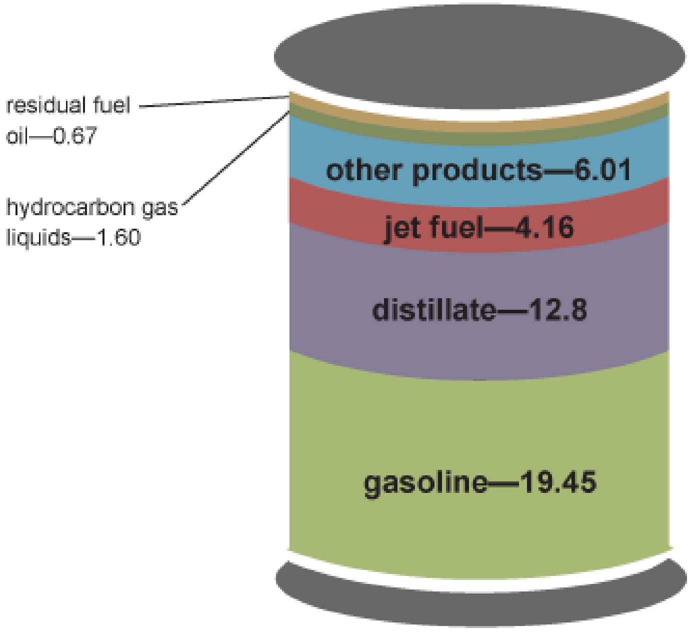
Materials Resource Management

Introduction (I)

Economic importance of crude oil – „black gold“

- U.S. total petroleum consumption: 20.28 million barrels per day (b/d) in 2022
- Main raw material for a wide range of products, such as plastics, pharmaceuticals, and chemicals as well as refined petroleum products like gasoline, kerosene, diesel, and heating oil
- Energy Supply: Crude oil is the world’s primary energy source
- Industrial Use: Crude oil is a key raw material in many industries.
- Employment and Economic Growth: The oil industry is a major employer worldwide.
- Global Trade: Crude oil is one of the most traded commodities in the world.

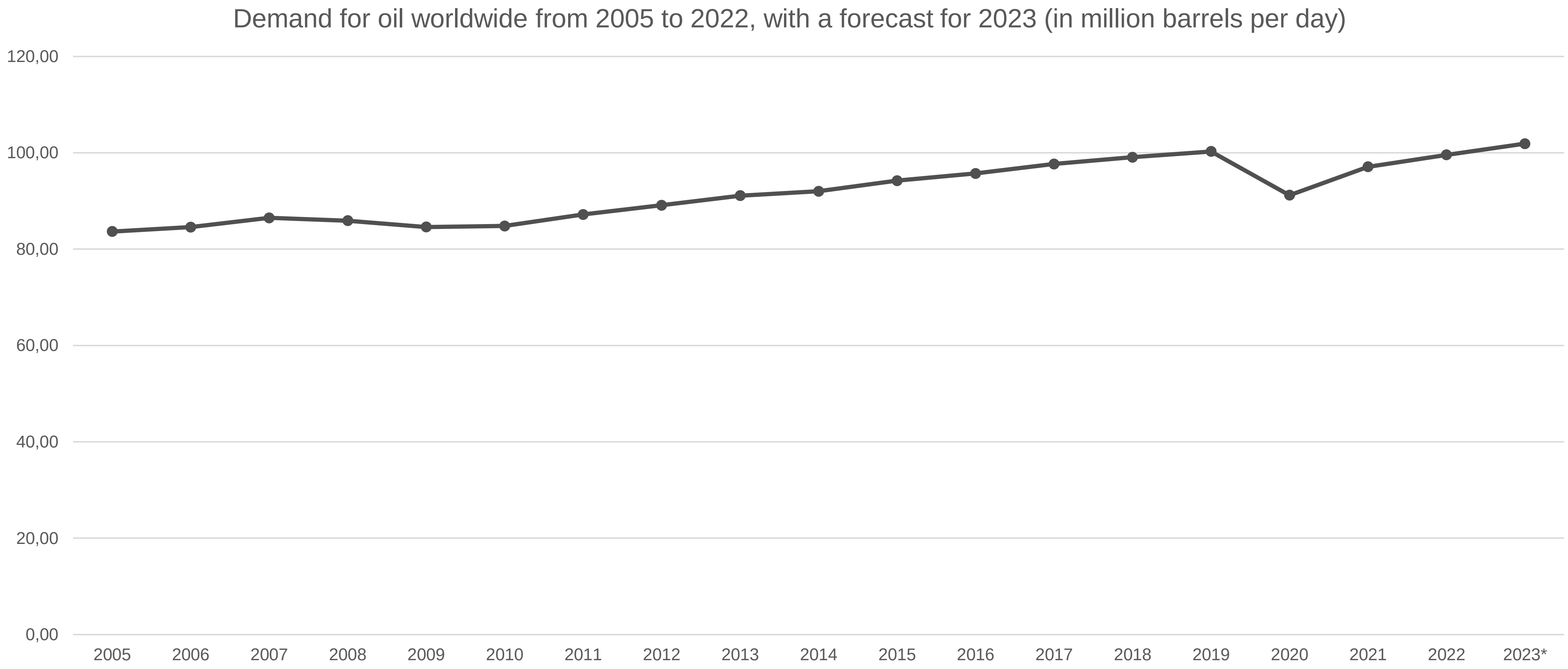
Petroleum products made from a barrel of crude oil, 2022
gallons



Data source: U.S. Energy Information Administration, *Petroleum Supply Monthly*, March 2023, preliminary data
Note: A 42-gallon (U.S.) barrel of crude oil yields about 45 gallons of petroleum products because of refinery processing gain. The sum of the product amounts in the image may not equal 45 because of independent rounding.

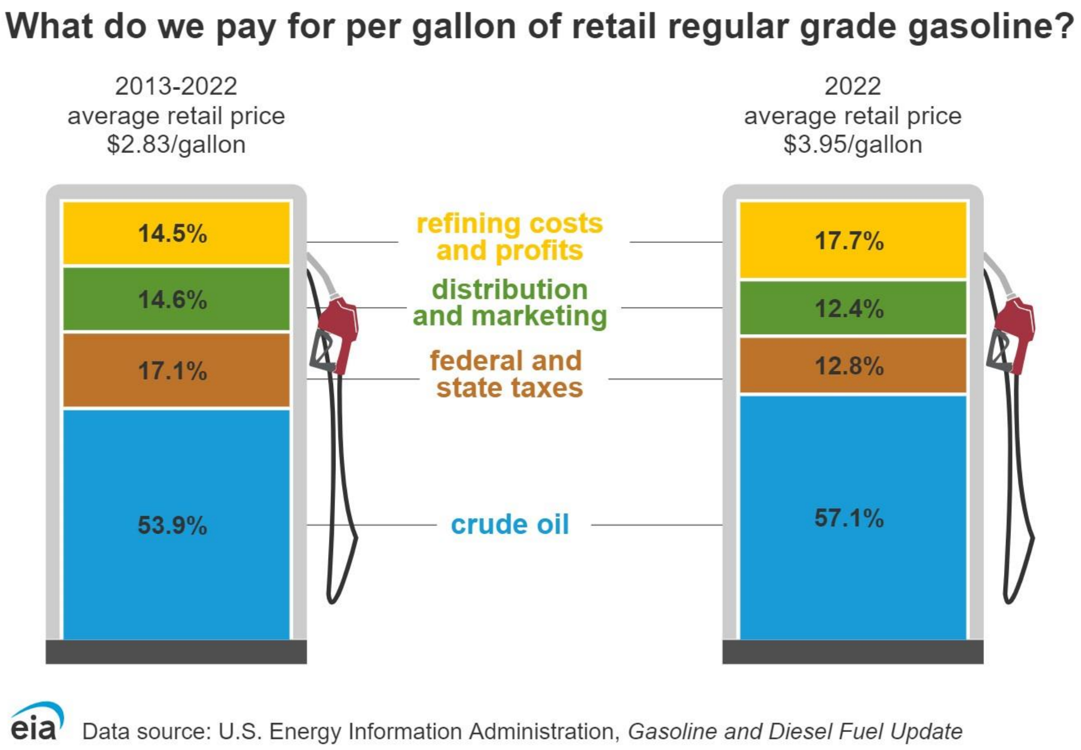
Introduction (II)

Global oil demand 2005-2023



Introduction (III)

Factors affecting refined product prices



Factors affecting refined product prices:

- The cost of crude oil
- Refining costs and profits
- Distribution and marketing costs and profits
- Taxes (federal, state, county, and local government)
- Seasonality (Heating oil)

→ refined product prices depend on the crude oil price, see Karali and Ramirez (2014)

Literature (I)

General Overview

Previous studies

- Relation between the crude oil and natural gas market (Pindyck (2004a), Ewing et al. (2002), Hartley et al. (2008), Serletis and Rangel-Ruiz (2004), Batten et al. (2017), and Zhang and Ji (2020))
- Regional differences between energy prices (Chang et al. (2010), Feng-bin et al. (2008), Lin and Tamvakis (2001) and Zavaleta et al. (2015))
- Volatilities of different energy prices separately (Lee et al. (2007), Pindyck (2004b) and Suenaga and Smith (2011))

Relation between energy commodities

- Long-term relationships in energy prices: (Asche et al. (2003), Gjolberg and Johnsen(1999), Lahiani et al. (2017), Serletis (1994))
- Spillover effects between energy prices: (Barunik et al. (2015), Han et al. (2015), Karali and Ramirez (2014), Mensi et al. (2021), Rahman (2016))
- Spillover effects from the crude oil market: (Ederington et al. (2019), Ederington et al. (2021), Kaufmann et al. (2009), Kilian (2010))

- Recent economic instabilities affect all energy markets :
  Russia-Ukraine war (supply shock), Covid-19 (supply & demand shock)

→ Spillover effects between price, but also production volume, stock volume and consumption of crude oil as well as the refined products gasoline, kerosene-type jet fuel and heating oil

Literature (II)

Spillover effects

Spillover effects between energy prices

- **Barunik et al. (2015)** (Diebold and Yilmaz spillover index): strong spillover effects in crude oil, gasoline, and heating oil prices, but neither energy commodity dominates the others
- **Mensi et al. (2021)** (Diebold and Yilmaz spillover index): crude oil mainly causes the volatility spillovers in the other markets, whereas the gas oil, gasoline, heating oil, and natural gas markets receive the risks
- **Han et al. (2015)** (VECM): significant spillover effects in both directions for the spot prices of crude oil and gasoline
- **Rahman (2016)** (bivariate GARCH(1,1)-in-Mean SVAR): gasoline prices respond to pos. and neg. oil price shocks
- **Karali and Ramirez (2014)** (multivariate GARCH model): time-varying volatility and spillover effects in crude oil, heating oil, and natural gas futures markets while controlling for exogenous factors and detect significant effects between the prices

Spillover effects from the crude oil market

- **Kaufmann et al. (2009):** disturbances to crude oil prices affect inventory behaviors, refinery utilization rates, and the price of motor gasoline
- **Kilian (2010):** new framework to model the relationships between the crude oil and gasoline markets
  → limited impact of crude oil supply shocks on gasoline prices and consumption.
  → oil-market specific demand shocks, and global crude oil demand shocks significantly influence the gasoline market
- **Ederington et al. (2021):**
  → causality from crude oil prices to refined product prices and, reverse causality in the period subsequent to 2005.
  → real spot gasoline prices and real heating oil prices barely affected by crude oil supply shocks
  → real spot gasoline prices and real heating oil prices significantly respond to oil-specific demand shocks

Methodology (I)

Commodity-specific VAR models for each energy market

Data

- Markets: crude oil, gasoline, kerosene-type jet fuel, heating oil
- 2005/01 – 2019/12, U.S. Energy Information Administration

Commodity-specific variables

- $\boldsymbol{x}_{i,t} = \begin{pmatrix} production_{i,t} \\ stocks_{i,t} \\ consumption_{i,t} \\ price_{i,t} \end{pmatrix}$

Economic variables

- $\boldsymbol{x}_{econ} = \begin{pmatrix} IP_t \\ FX_t \\ FFR_t \end{pmatrix}$

External variables

- $\boldsymbol{x}^*_{i,t} = \begin{pmatrix} production^*_{i,t} \\ stocks^*_{i,t} \\ consumption^*_{i,t} \\ price^*_{i,t} \end{pmatrix},$
- $production^*_{i,t} = \sum_{\iota=1}^{N} w_{i,\iota} production_{\iota,t}$
- $stocks^*_{i,t} = \sum_{\iota=1}^{N} w_{i,\iota} stocks_{\iota,t}$
- $consumption^*_{i,t} = \sum_{\iota=1}^{N} w_{i,\iota} consumption_{\iota,t}$
- $price^*_{i,t} = \sum_{\iota=1}^{N} w_{i,\iota} price_{\iota,t}$

→ link individual VARs via weight matrices, representing refined output share

Barrel of crude oil	
Gasoline	19.45
Heating oil	23.80
Kerosene	4.16
Others	8.28

- Commodity-specific VAR models:
  - $\boldsymbol{x}_{i,t} = \sum_{p=1}^{P} \boldsymbol{\Phi}_{i,p}\, \boldsymbol{x}_{i,t-p} + \sum_{p=0}^{P_{exog}} \boldsymbol{\Lambda}_{i,p} \boldsymbol{x}^*_{i,t-p} + \sum_{p=0}^{P_{exog}} \boldsymbol{\Psi}_{i,p} \boldsymbol{x}_{econ,t-p} + \boldsymbol{\varepsilon}_{i,t},$ with $\boldsymbol{\varepsilon}_{i,t} \sim \aleph(\boldsymbol{0}, \boldsymbol{\Sigma}_{ii})$
  - $\boldsymbol{x}_{econ,t} = \sum_{p=1}^{P} \boldsymbol{\Phi}_{econ,p}\, \boldsymbol{x}_{econ,t-p} + \sum_{p=0}^{P_{exog}} \boldsymbol{\Lambda}_{econ,p} \boldsymbol{x}^*_{econ,t-p} + \boldsymbol{\varepsilon}_{econ,t},$ with $\boldsymbol{\varepsilon}_{econ,t} \sim \aleph(\boldsymbol{0}, \boldsymbol{\Sigma}_{econ,econ})$

Methodology (II)

Aggregation of commodity-specific VAR models to a global commodity model

- Commodity-specific VAR models:
  - $\boldsymbol{x}_{i,t} = \sum_{p=1}^{P} \boldsymbol{\Phi}_{i,p}\, \boldsymbol{x}_{i,t-p} + \sum_{p=0}^{P_{exog}} \boldsymbol{\Lambda}_{i,p} \boldsymbol{x}^{*}_{i,t-p} + \sum_{p=0}^{P_{exog}} \boldsymbol{\Psi}_{i,p} \boldsymbol{x}_{econ,t-p} + \boldsymbol{\varepsilon}_{i,t}$, with $\boldsymbol{\varepsilon}_{i,t} \sim \aleph(\mathbf{0}, \boldsymbol{\Sigma}_{ii})$
  - $\boldsymbol{x}_{econ,t} = \sum_{p=1}^{P} \boldsymbol{\Phi}_{econ,p}\, \boldsymbol{x}_{econ,t-p} + \sum_{p=0}^{P_{exog}} \boldsymbol{\Lambda}_{econ,p} \boldsymbol{x}^{*}_{econ,t-p} + \boldsymbol{\varepsilon}_{econ,t}$, with $\boldsymbol{\varepsilon}_{econ,t} \sim \aleph\left(\mathbf{0}, \boldsymbol{\Sigma}_{econ,econ}\right)$
- Aggregation to a GVAR model:
  - Global vector of commodities $\boldsymbol{x}_t = (\boldsymbol{x}'_{1,t}, \boldsymbol{x}'_{2,t} \ldots, \boldsymbol{x}'_{N,t}, \boldsymbol{x}'_{\text{econ},t})'$
  - $\boldsymbol{x}_t = \sum_{p=1}^{P} \boldsymbol{G}_p\ \boldsymbol{x}_{t-p} + \boldsymbol{\varepsilon}_t$, with $\boldsymbol{\varepsilon}_t \sim \aleph(\mathbf{0}, \boldsymbol{\Sigma})$
- Analysis of spillover effects:
  - generalized impulse response functions (GIRFs), whereby inference is based following Kilian (2009) by applying the recursive-design wild bootstrap with 1000 replications of Goncalves and Kilian (2004)
    - $\boldsymbol{GI}(n, \boldsymbol{\delta}, \Omega_{t-1}) = E[\boldsymbol{x}_{t+n} | \boldsymbol{\varepsilon}_t = \boldsymbol{\delta}, \Omega_{t-1}] - E[\boldsymbol{x}_{t+n} | \Omega_{t-1}]$,
      where $\boldsymbol{\delta} = (0, \ldots, 0, \sqrt{\sigma_{kk}}, 0, \ldots, 0)'$ denotes the shock hitting the system at time t
  - generalized forecast error variance decomposition (GFEVD)

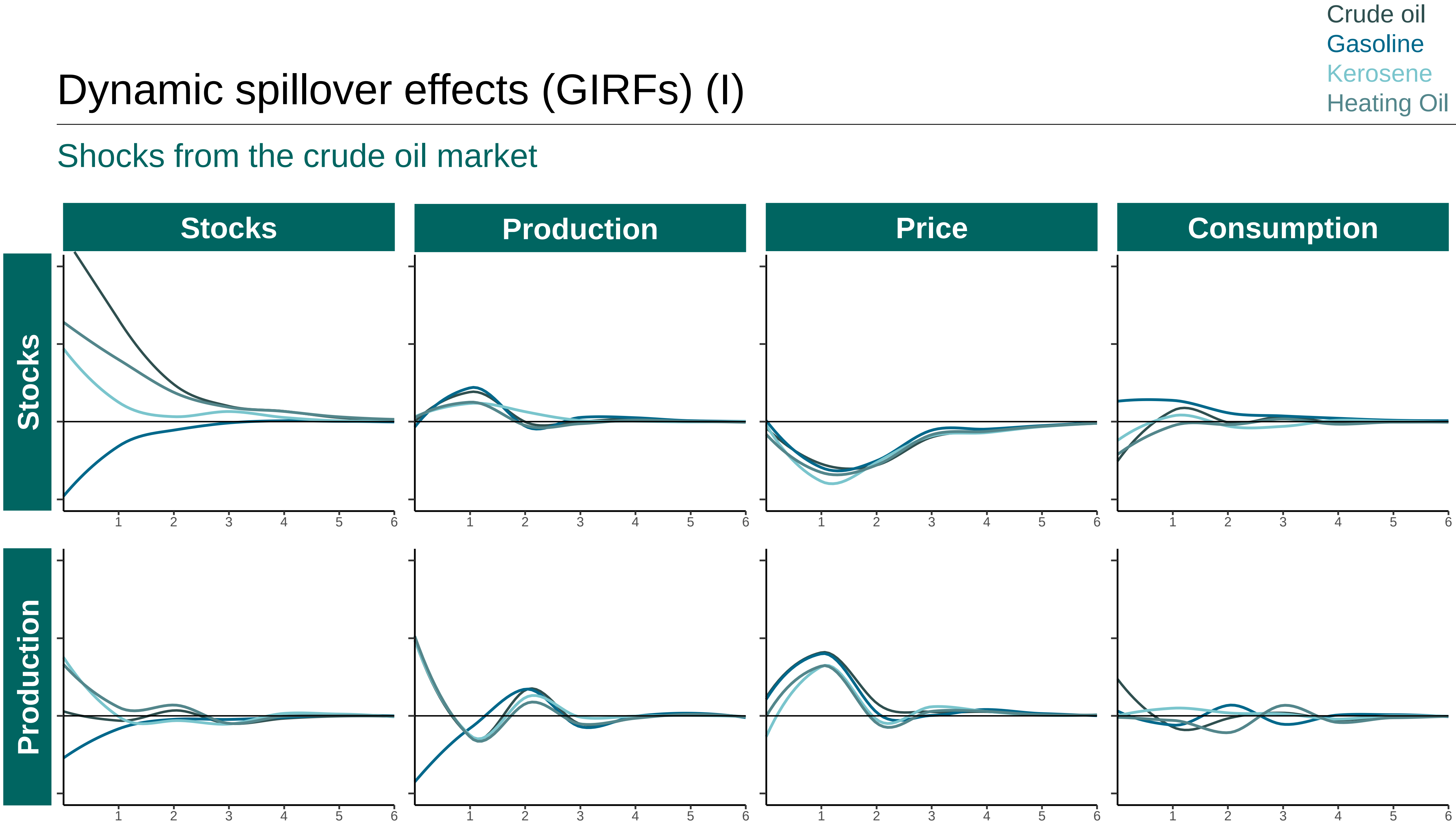
Dynamic spillover effects (GIRFs) (I)

Overview of spillover effects

		Crude oil				Gasoline				Kerosene				Heating oil			
		Stocks	Prod.	Price	Cons.	Stocks	Prod.	Price	Cons.	Stocks	Prod.	Price	Cons.	Stocks	Prod.	Price	Cons.
Crude oil	Stocks	+			(-)	-				+				+			-
	Prod.		+		(+)	(-)	-			+	+			(+)	+		
	Price			+												+	
	Cons.	(-)	(+)		+				(-)		(+)		(+)		(+)		+
Gasoline	Stocks					+	(+)			(-)				(-)			
	Prod.		+			(+)	+			(-)	(-)			(-)	-		
	Price					(-)		+		(+)						(+)	
	Cons.					(-)			+								
Kerosene	Stocks					(-)				+	+		(-)				
	Prod.		(+)				(-)			+	+			(+)			(-)
	Price		(-)							(-)	(-)	+		(-)		+	(+)
	Cons.									-	(+)		+				(-)
Heating oil	Stocks					-	(-)			(+)				+	+		-
	Prod.		+				-							+	+		
	Price					(+)					(-)	(+)		(-)		+	(+)
	Cons.										(-)			-			+

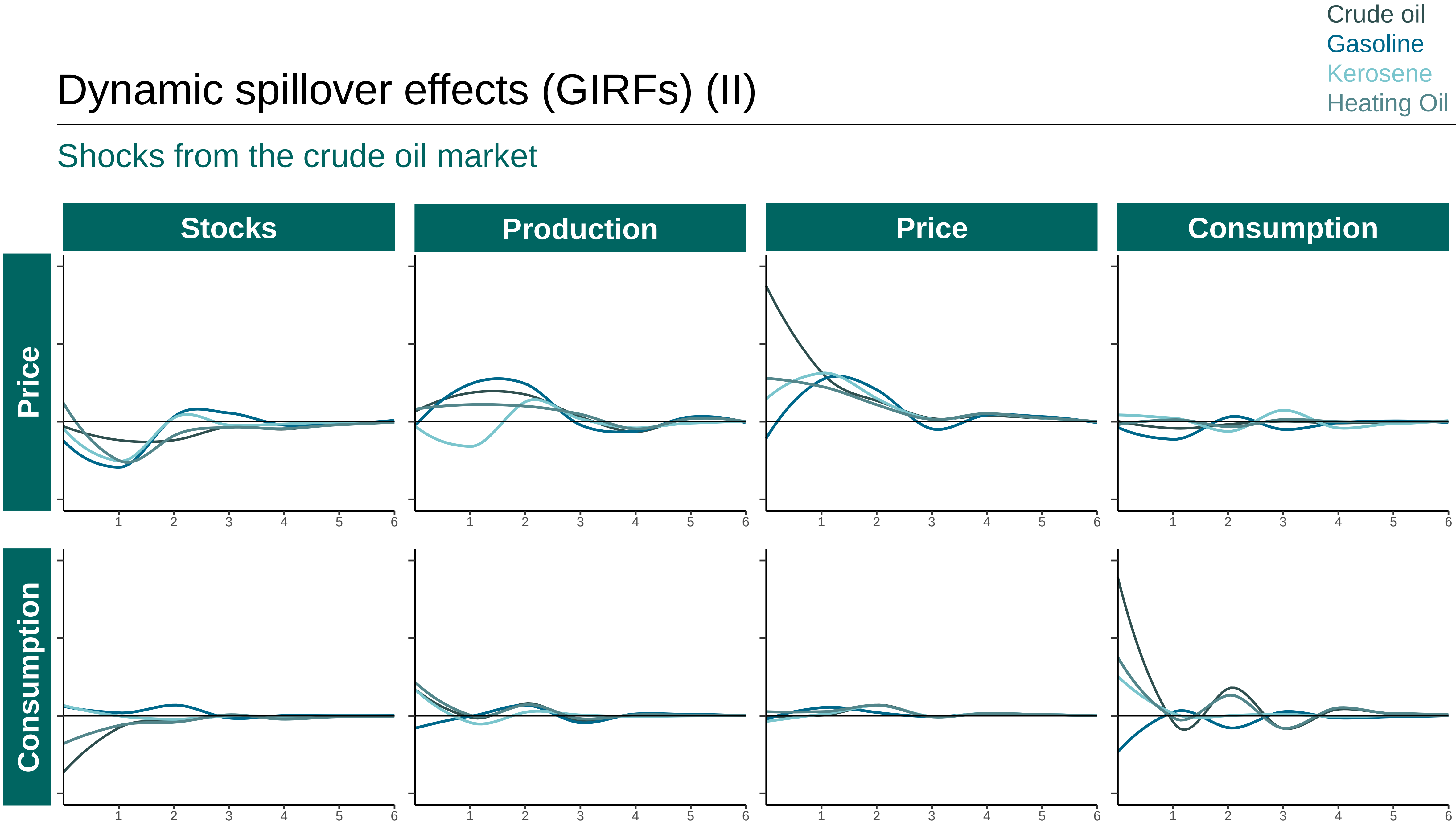
Dynamic spillover effects (GIRFs) (I)

Shocks from the crude oil market



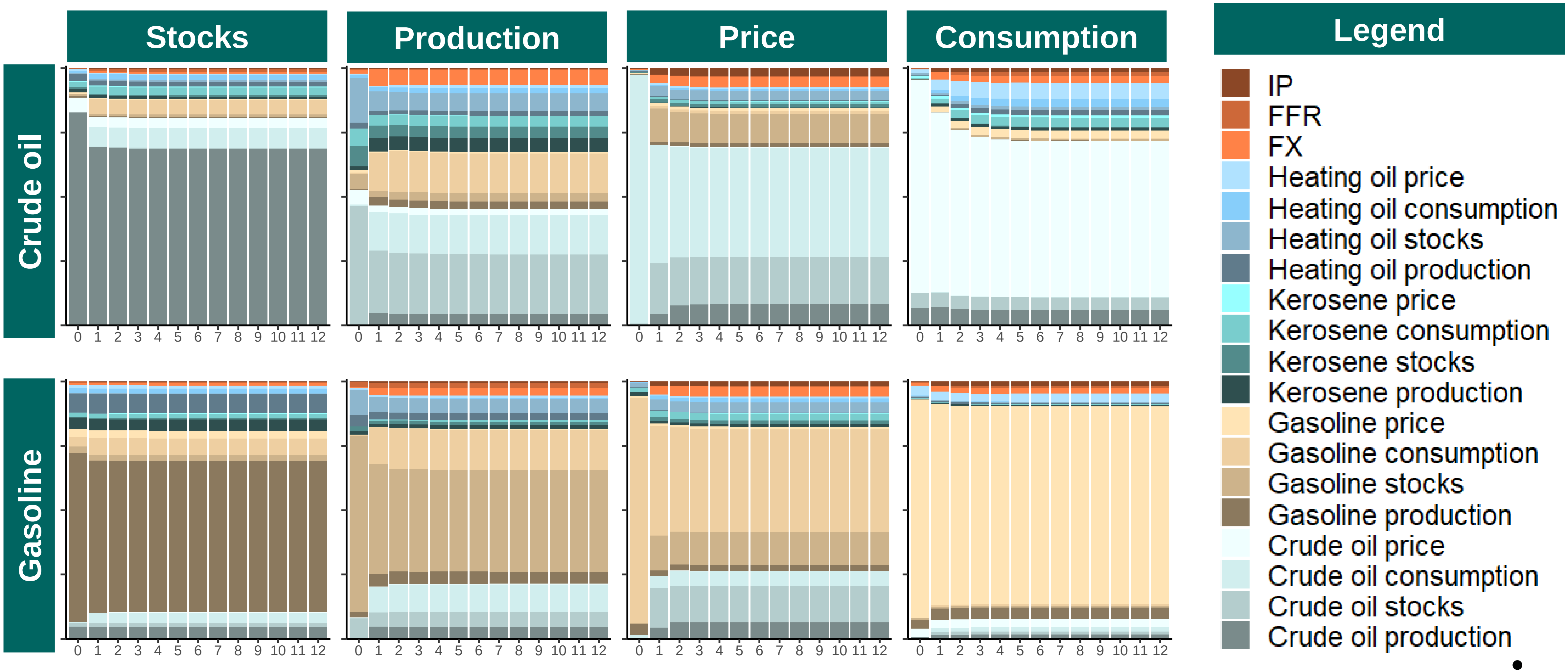
Dynamic spillover effects (GIRFs) (II)

Shocks from the crude oil market



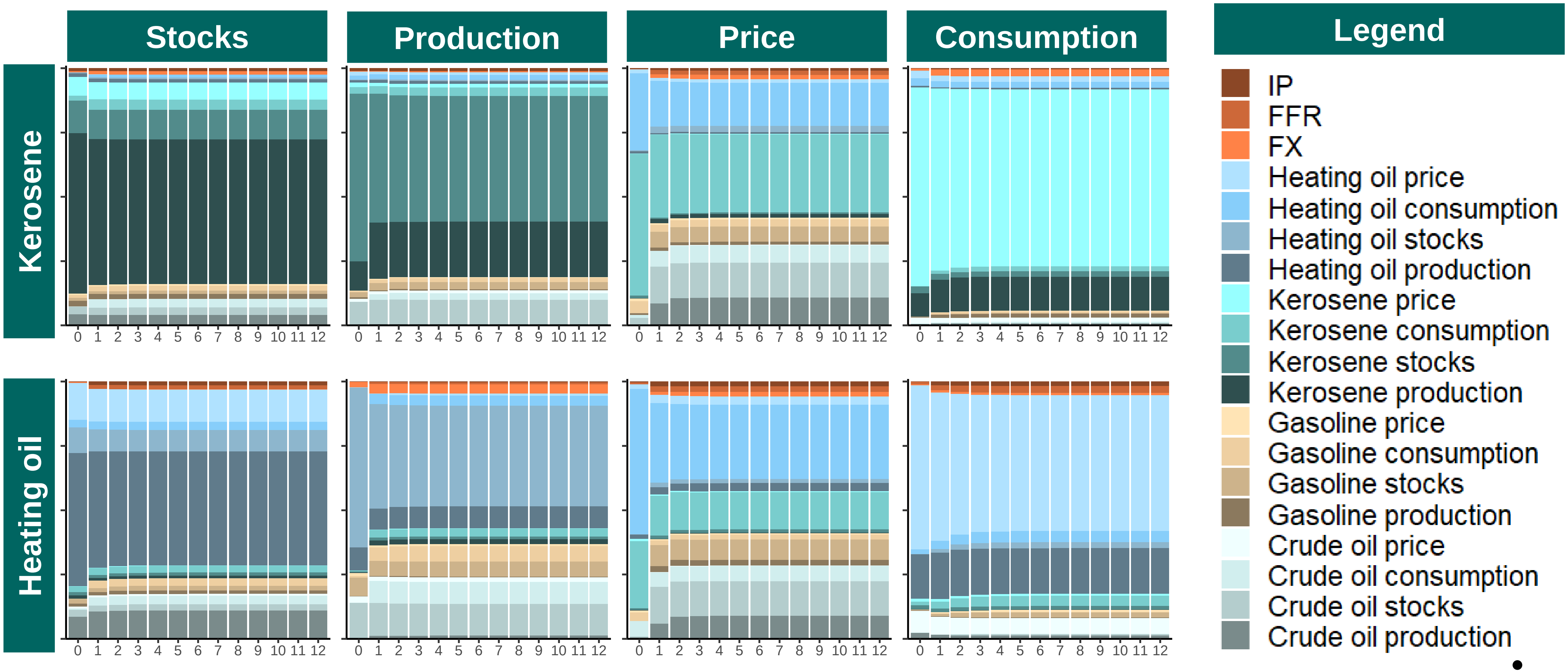
Dynamic spillover effects (GFEVD) (I)

Variance decomposition for the crude oil and gasoline market



Dynamic spillover effects (GFEVD) (II)

Variance decomposition for the kerosene-type jet fuel and heating oil market



Conclusion

Spillover effects between crude oil and refined product markets

Spillover effects between energy markets

Overview	Results
- Global vector autoregressive (GVAR) model, according to Pesaran et al. (2004) - Monthly data, 2005 – 2019 - Crude oil, gasoline, kerosene-type jet fuel, heating oil market - Interdependencies between production volume, stocks volume, consumption and price	- Shocks to the crude oil market cause significant changes in the refined product markets - Crude oil market barely affected by shocks to the refined product markets - Kerosene-type jet fuel market and heating oil market are highly interdependent - Forecast error variance of stocks volume and consumption less sensitive to other energy markets, compared to prices and production

Thank you for your attention!

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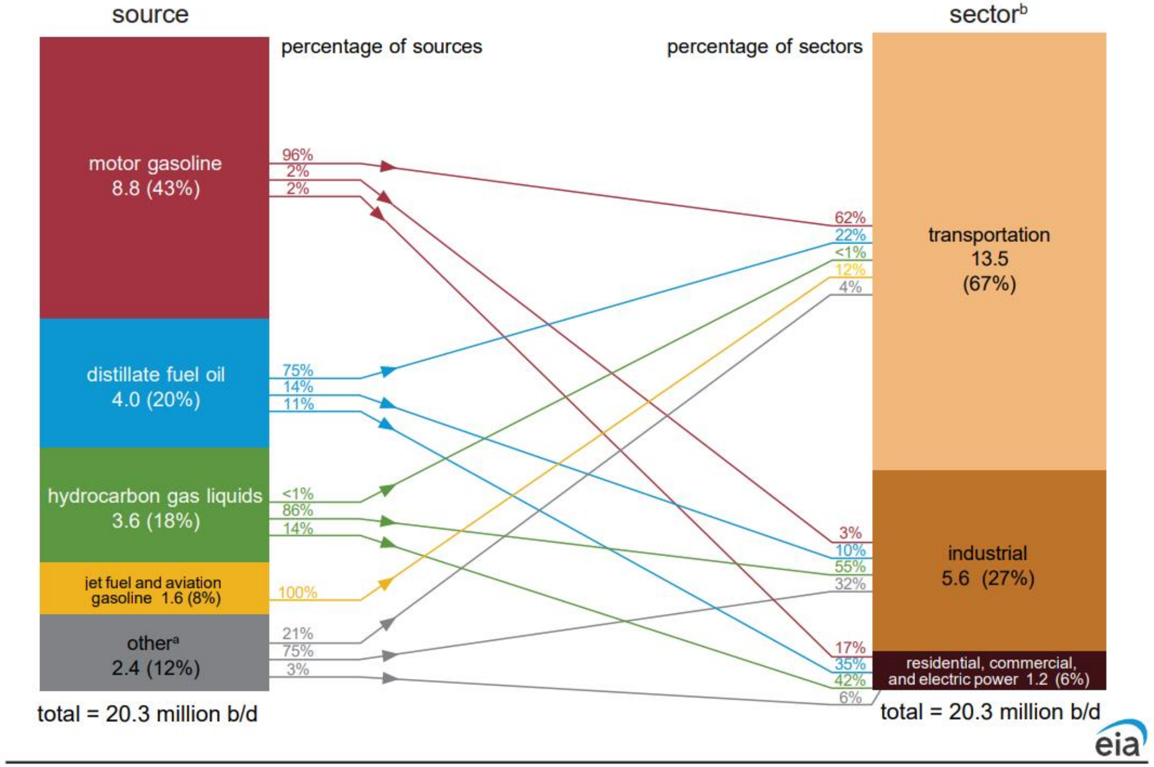
Introduction (II)

U.S. total petroleum consumption: 20.28 million barrels per day (b/d) in 2022

U.S. petroleum products consumption by source and sector, 2022

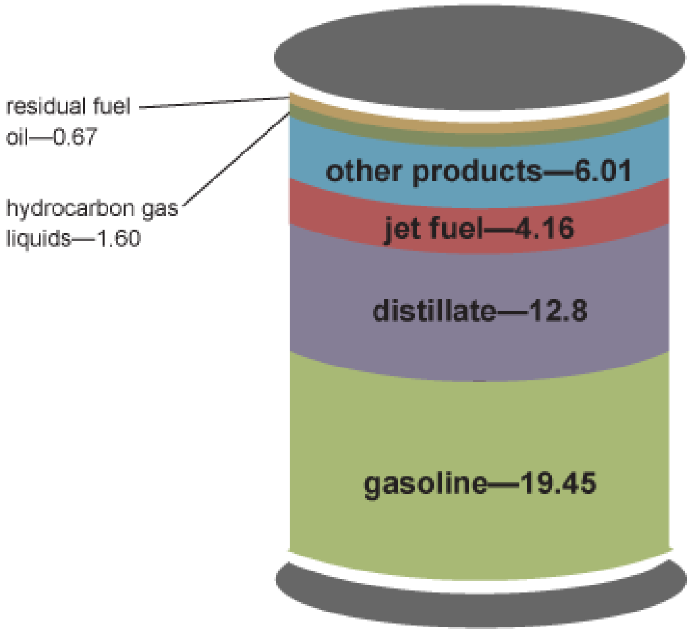
million barrels per day (b/d)



Sources: U.S. Energy Information Administration (EIA), *Monthly Energy Review* (April 2023), Tables 3.5, 3.7a, 3.7b, and 3.7c.
Note: Data include biofuels mixed with petroleum products. Sum of components may not equal total due to independent rounding. See "Extended Chart Notes" on next page.
[a] Includes asphalt and road oil, aviation gasoline blending components, lubricants, kerosene, petrochemical feedstocks, petroleum coke, residual fuel oil, still gas (refinery gas), special naphthas, waxes, unfinished oils, and miscellaneous products. Also includes biofuels (excluding fuel ethanol) products supplied.
[b] Industrial, commercial, and electric power sectors include primary energy consumption by combined-heat-and-power (CHP) and electricity-only plants in the sector.

Petroleum products made from a barrel of crude oil, 2022

gallons



Data source: U.S. Energy Information Administration, *Petroleum Supply Monthly*, March 2023, preliminary data
Note: A 42-gallon (U.S.) barrel of crude oil yields about 45 gallons of petroleum products because of refinery processing gain. The sum of the product amounts in the image may not equal 45 because of independent rounding.

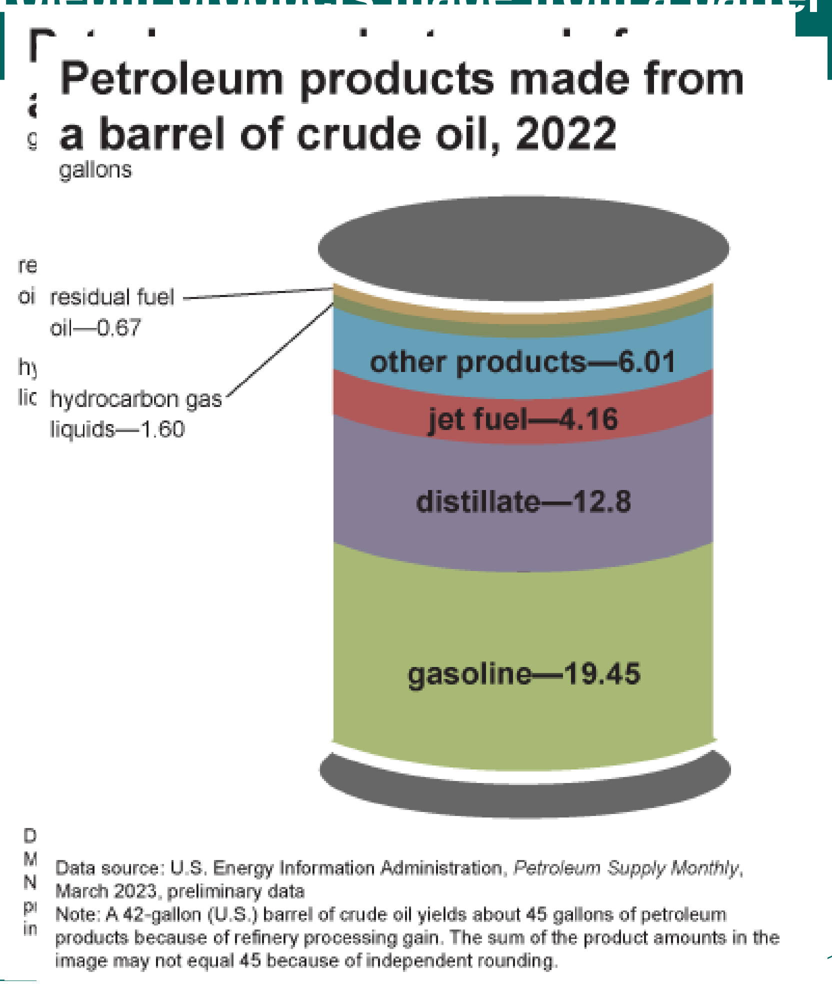
Application of the framework to the industrial metal markets (I)

Data

Data

- Oil markets: crude oil, gasoline, kerosene-type jet fuel, heating oil
- 2005/01 – 2022/12
- Commodity-specific data:
  - U.S. production volume
  - U.S. stock volume
  - U.S. consumption
  - Price
- Macroeconomic data:
  - U.S. IP
  - U.S. Dollar index
  - Federal Funds Rate

Petroleum products made from a barrel of



Methodology (I)

Commodity-specific VAR models for each energy market

Data

- Markets: crude oil, gasoline, kerosene-type jet fuel, heating oil
- 2005/01 – 2022/12

Commodity-specific variables

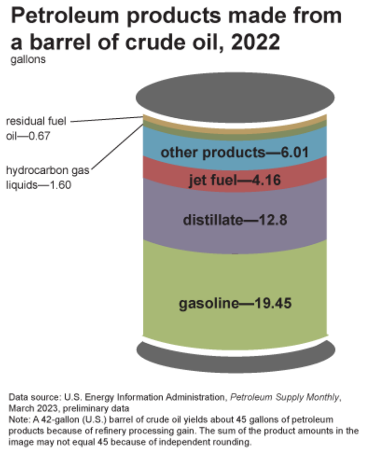
- $\boldsymbol{x}_{i,t} = \begin{pmatrix} production_{i,t} \\ stocks_{i,t} \\ consumption_{i,t} \\ price_{i,t} \end{pmatrix}$

Economic variables

- $\boldsymbol{x}_{econ} = \begin{pmatrix} IP_t \\ FX_t \\ FFR_t \end{pmatrix}$

- Commodity-specific VAR models:
  - $\boldsymbol{x}_{i,t} = \sum_{p=1}^{P} \boldsymbol{\Phi}_{i,p}\, \boldsymbol{x}_{i,t-p} + \sum_{p=0}^{P_{exog}} \boldsymbol{\Lambda}_{i,p} \boldsymbol{x}^{*}_{i,t-p} + \sum_{p=0}^{P_{exog}} \boldsymbol{\Psi}_{i,p} \boldsymbol{x}_{econ,t-p} + \boldsymbol{\varepsilon}_{i,t}$, with $\boldsymbol{\varepsilon}_{i,t} \sim \aleph(\mathbf{0}, \boldsymbol{\Sigma}_{ii})$
  - $\boldsymbol{x}_{econ,t} = \sum_{p=1}^{P} \boldsymbol{\Phi}_{econ,p}\, \boldsymbol{x}_{econ,t-p} + \sum_{p=0}^{P_{exog}} \boldsymbol{\Lambda}_{econ,p} \boldsymbol{x}^{*}_{econ,t-p} + \boldsymbol{\varepsilon}_{econ,t}$, with $\boldsymbol{\varepsilon}_{econ,t} \sim \aleph(\mathbf{0}, \boldsymbol{\Sigma}_{econ,econ})$

External variab



- $\boldsymbol{x}^{*}_{i,t} = \begin{pmatrix} production^{*}_{i,t} \\ stocks^{*}_{i,t} \\ consumption^{*}_{i,t} \\ price^{*}_{i,t} \end{pmatrix}$,
- $production^{*}_{i,t} = \sum_{\iota=1}^{N} w_{i,\iota} production_{\iota,t}$
- $stocks^{*}_{i,t} = \sum_{\iota=1}^{N} w_{i,\iota} stocks_{\iota,t}$
- $consumption^{*}_{i,t} = \sum_{\iota=1}^{N} w_{i,\iota} consumption_{\iota,t}$
- $price^{*}_{i,t} = \sum_{\iota=1}^{N} w_{i,\iota} price_{\iota,t}$

→ link individual VARs via weight matrices, representing refined output share

DY Spillover Index (on returns)

- total spillover index:

	0	1	2	3	4	5	6	7	8	9	10	11	12
total	36.70	47.36	52.63	55.82	58.29	60.15	61.96	63.78	64.56	65.54	66.19	66.81	67.28

- net spillover (transmitted – received)

	0	1	2	3	4	5	6	7	8	9	10	11	12
total	36.70	47.36	52.63	55.82	58.29	60.15	61.96	63.78	64.56	65.54	66.19	66.81	67.28

Conclusion

Spillover effects between crude oil refined product markets

- Global vector autoregressive (GVAR) model, according to Pesaran et al. (2004)
- Monthly data, 2005 – 2022
- Crude oil, gasoline, kerosene-type jet fuel, heating oil market
- Interdependencies between production volume, stocks volume, consumption and price
- Results:
  - Crude oil price shock cause rising prices of the refined products
  - Most pronounced spillover effects from the gasoline market
  - Kerosene-type jet fuel market and heating oil market do not affect crude oil market
  - Forecast error variance of energy prices most affected by other energy markets
  - Forecast error variance of production volume, stocks volume and consumption less sensitive to other energy markets