Is the U.S. Natural Gas Market Integrated or Segmented? A Dynamic Study of Regional Natural Gas Prices

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Outline

- Motivations and setting: The U.S. Gas Market
- Methodology: Kalman filter and distances
- Data properties and results: Price behaviors
- Conclusion: Time-varying market integration

Motivations

- Reported connections between U.S. gas prices: Wellhead hubs, Citygate prices, futures contracts (Huntington, 2016).
- Recent FERC reforms support regional natural gas prices and spatial market integration (Arano & Velikova, 2009; Ghoddusi, 2016; Mohammadi, 2011).
- Henry hub prices are linked with the economy (e.g. GDP), and some energy sectors/consumptions (Ghoddusi, 2016).
- Wide use of futures contracts on Henry Hub spot prices for hedging and cross-hedging prospects → HH Benchmark role.

Methodology (step 1): Kalman filter (1/2)

- We pick Henry Hub spot price (HH) plus a set of 9 Citygate prices: Florida, Kansas, Kentucky, Maine, New Mexico, Tennessee, Texas, Washington and Wisconsin (CP_i, $i = 1,\ldots,9$; regional view with coverage of 5 major regions, see figure later) → Regime indicator D_t (structural changes).
- **State space representation**:
  - 2 unobserved components: α as a ***fundamental price component***, and a ***transaction cost component*** (β for HH).
  - β appears to be non-random, according to data estimates.
  - Gas prices depend on α, β or a *normalized cost component*, and a dummy regime indicator (D_t) when it is significant.

Methodology: Kalman filter (2/2)

- **State space representation**: Unobserved component model

$$\alpha_t = a \times \alpha_{t-1} + \varepsilon_t$$ Fundamental price

$$\beta_t = b \times \beta_{t-1} + \eta_t$$ *HH transaction costs*

$$HH_t = \alpha_t + h_1 \times \beta_t + h_2 \times D_t + \eta_t^{HH}$$

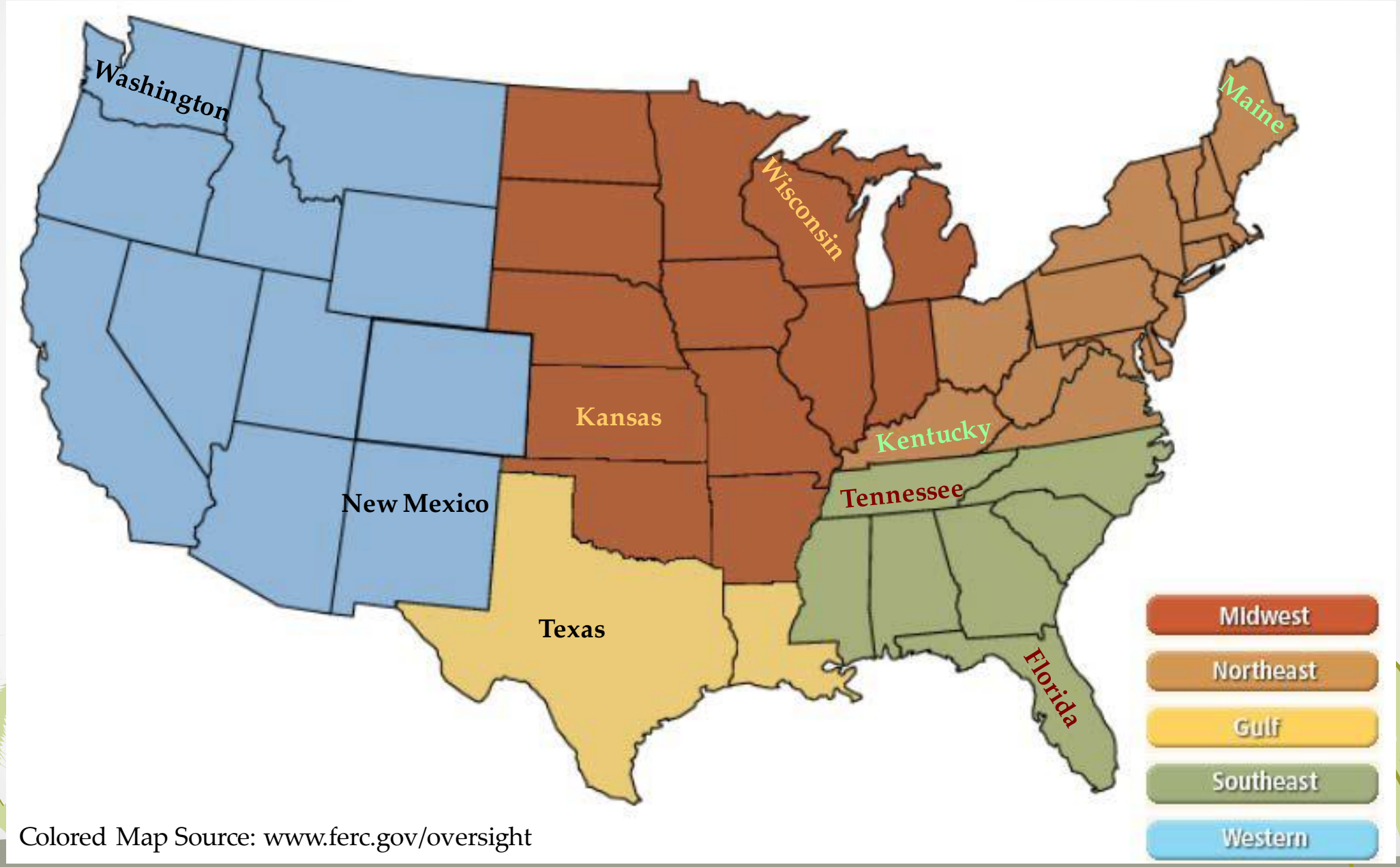
Fundamental price component

Transaction cost

$$CP_{i,t} = a_i \times \alpha_t + b_i \times \frac{|CP_{i,t} - HH_t|}{CP_{i,t}} + d_i \times D_t + \eta_t^i$$

- Following its benchmark role, HH follows the law of one price (i.e. fundamental price plus transaction costs).
- (ε_t), (η_t), (η_t^{HH}) and (η_t^i) are mutually independent and non-correlated Gaussian white noises, we handle data non-stationarity and breaks.

Data selection for Kalman filter



Colored Map Source: www.ferc.gov/oversight

Methodology (step 2): Distance measures

- Starting from a benchmark time series, we consider the distance or natural gas price series to the benchmark series (i.e. common stochastic trend).
- **10 Distance measures**:
  - *Classic measures*: Dissimilarity, Euclidean, Infinity-norm, Manhattan and Minkowski distances.
  - *Time series-based measures*: Complexity-invariant distance, Dissimilarity distance based on temporal correlation of order 1, Dynamic Time Warping distance, Distance based on the Fourier Discrete Transform, Fréchet distance.

Data and properties

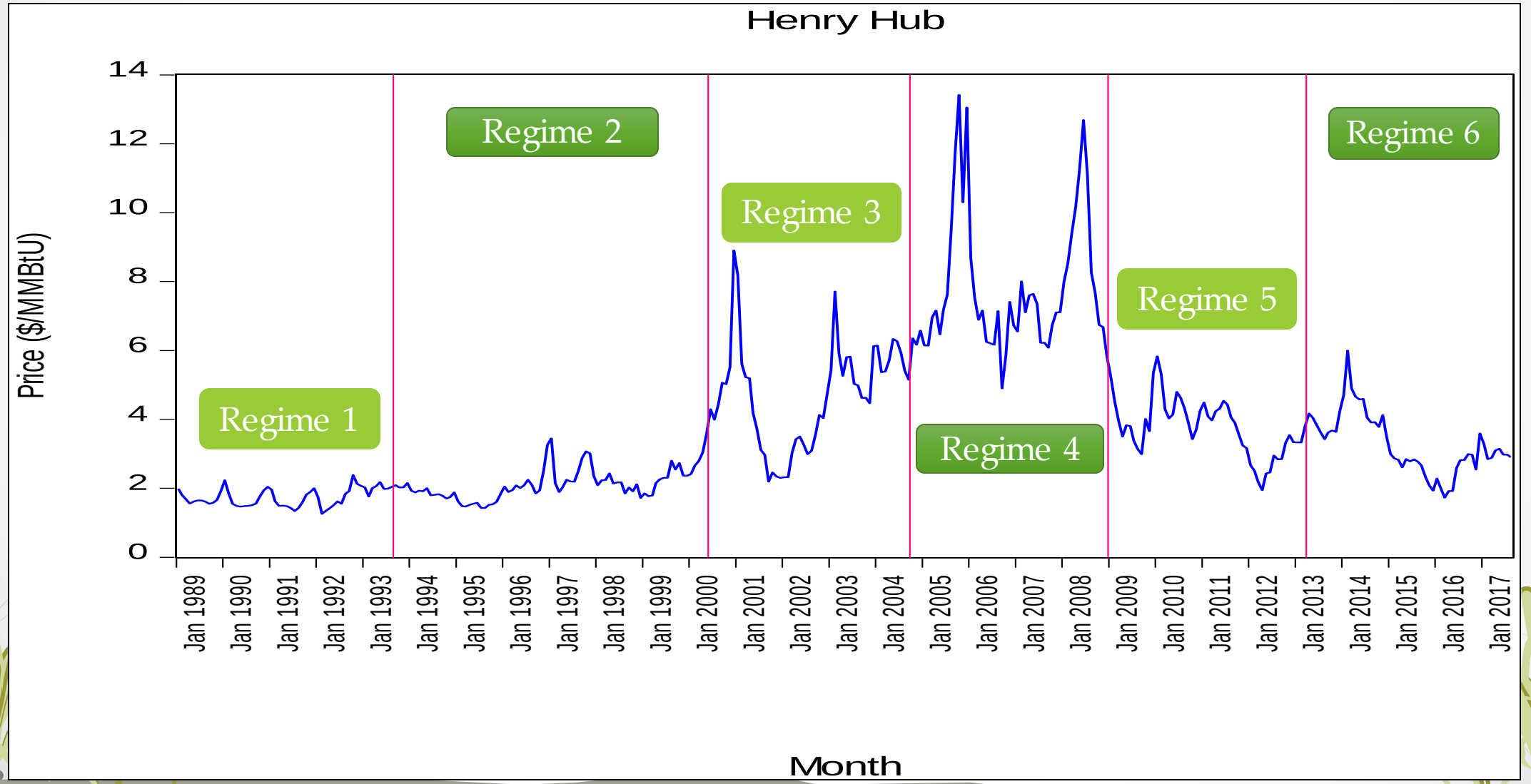
- Monthly EIA natural gas prices from January, 1989 to August, 2017.
- Henry Hub spot price and U.S. Citygate (aggregate) price.
- 50 Citygate prices from U.S. states (complete time series).

Supply side

- **Objective**: Check for price convergence across the U.S. gas market, and how far gas prices are from the benchmark price.
- Data are skewed, non-normal and nonstationary (Phillips-Perron 5% unit root test), exhibit kurtosis and strong Kendall correlation across natural gas price series.
- We exhibit 5 breaks, thus **6 regimes** according to the following break dates: July 1993, April 2000, August 2004, November 2008, and February 2013.

Structural breaks in price series

- Henry hub price behaviour:



Kalman filter's output about price convergence

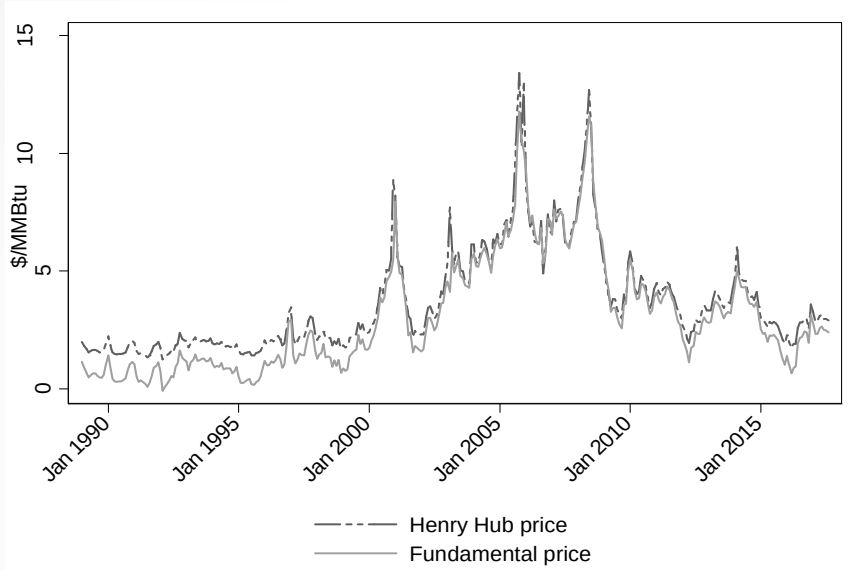
- Regime indicator is significant only for Kansas, New Mexico, Texas Washington and Wisconsin Citygate prices.
- All model coefficients are significant at a 5% test level, except $var(\eta_t)$.
- Interpretation relative to ***price convergence*** or ***law of one price***:
  - Look at the slope coefficient (close to 1 or not)
  - Observe also model residuals…
- Slope coefficients are not 1 so that the law of one price does not prevail all the time.
- But they are close to one, indicating that we face temporary deviations from the fundamental natural gas price for most series (law of 1 price).
- Confirm the difference between West and East natural gas price behaviours, but also West and other regional natural gas prices.

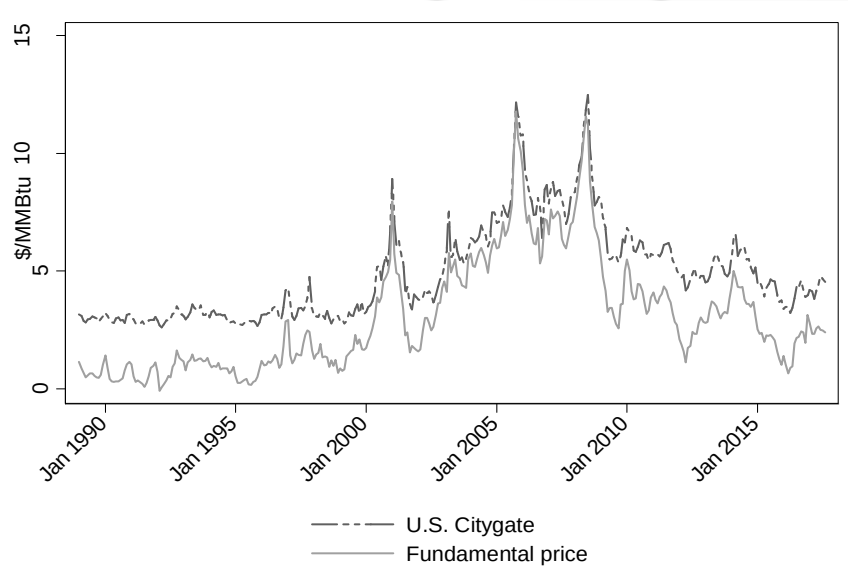
Kalman estimates (1/2)

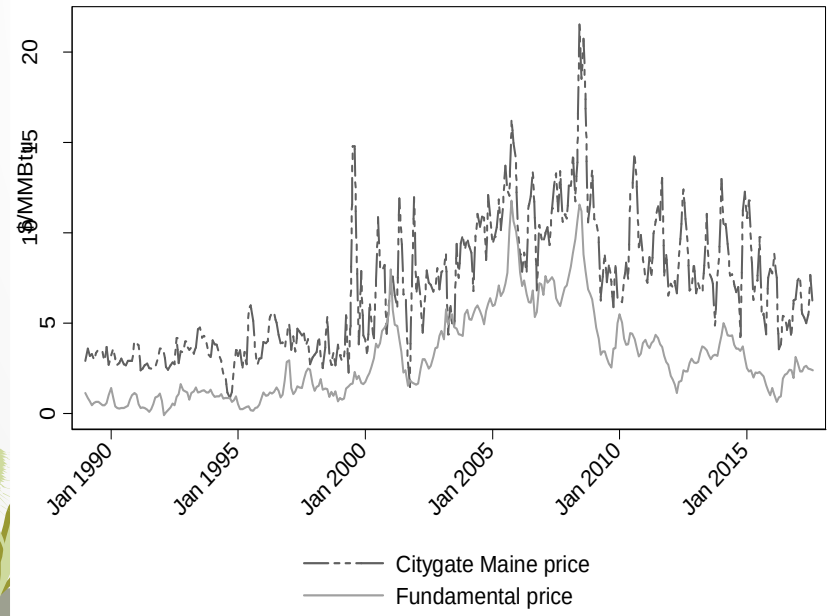
- Regime indicator is significant only for Henry Hub, U.S. Citygate, and Kansas, Maine as well as Washington Citygate prices.

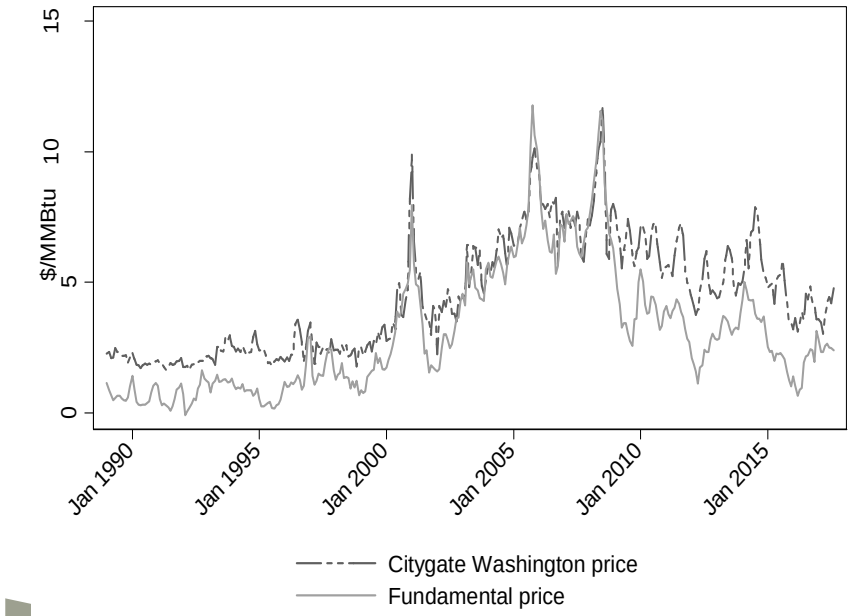
Prices	Slope of *a*	Residual's variance	Confidence Interval
Henry Hub	1	0.1306	
Florida	1.0785	0.0552	[0.9308,1.2262]
Kansas	1.0848	0.1768	[0.9263,1.2433]
Kentucky	1.1024	0.0437	[0.9462,1.2586]
Maine	**1.2458**	**2.0756**	**[1.0771,1.4145]**
New Mexico	**0.6928**	**0.5600**	**[0.5953,0.7904]**
Tennessee	1.0744	0.0778	[0.9188,1.2299]
Texas	0.9625	0.1472	[0.8062,1.1188]
Washington	**0.8377**	**0.3671**	**[0.6830,0.9924]**
Wisconsin	0.9800	0.1827	[0.8098,1.1503]

Kalman estimates (2/2)









Measuring average transaction costs

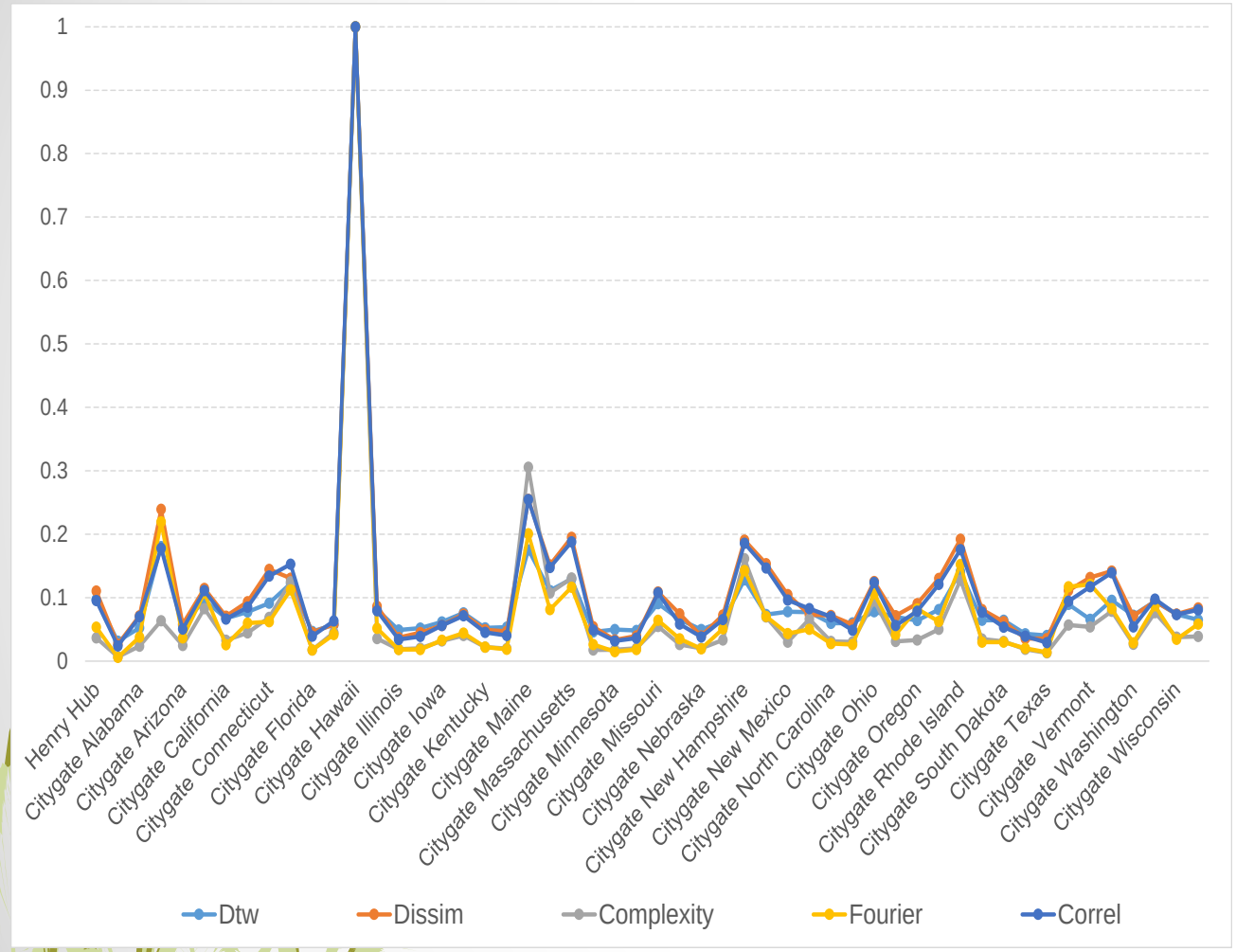
Average transaction cost in natural gas prices

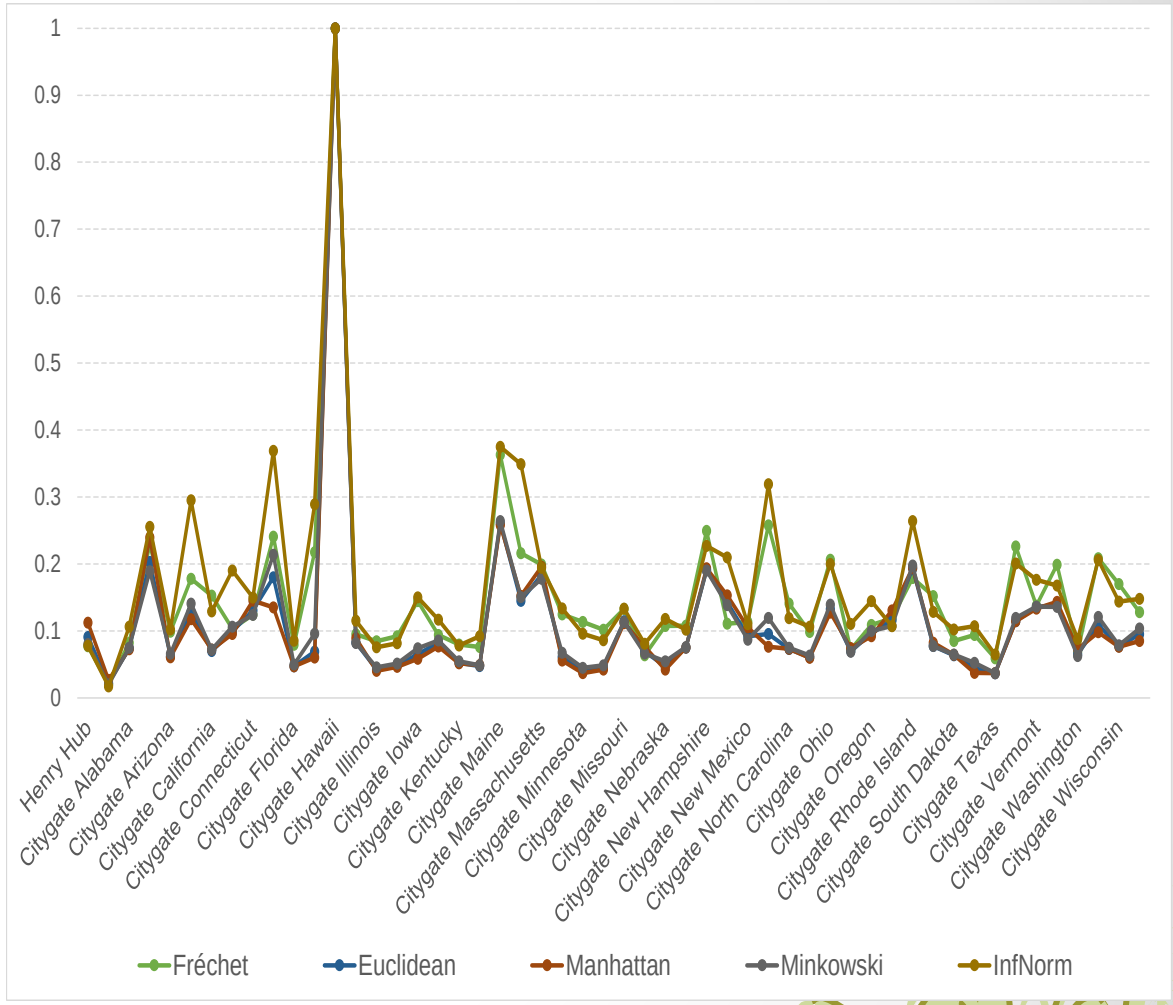
Natural gas prices	Transaction cost ($/MMBtu)	Proportion of transaction cost (%)
Henry Hub	***0.6093***	***16.4824***
Florida	1.4617	30.5377
Kansas	1.7308	34.2749
Kentucky	1.4894	30.4973
Maine	**3.2000**	**46.8281**
New Mexico	**0.4234**	**11.4578**
Tennessee	1.5598	31.9989
Texas	1.3068	28.2038
Washington	0.9468	21.3093
Wisconsin	1.9365	36.9439

Distance measures over the sample

- We compute the 10 distance measures over the whole sample for the 52 series under consideration.
- We normalize such distances by dividing them by the maximum value, which is observed across the sample of natural gas price series for any given distance measure.
- We get thus normalized distances, which are scaled measures between 0 and 1.

Normalized distances over the sample

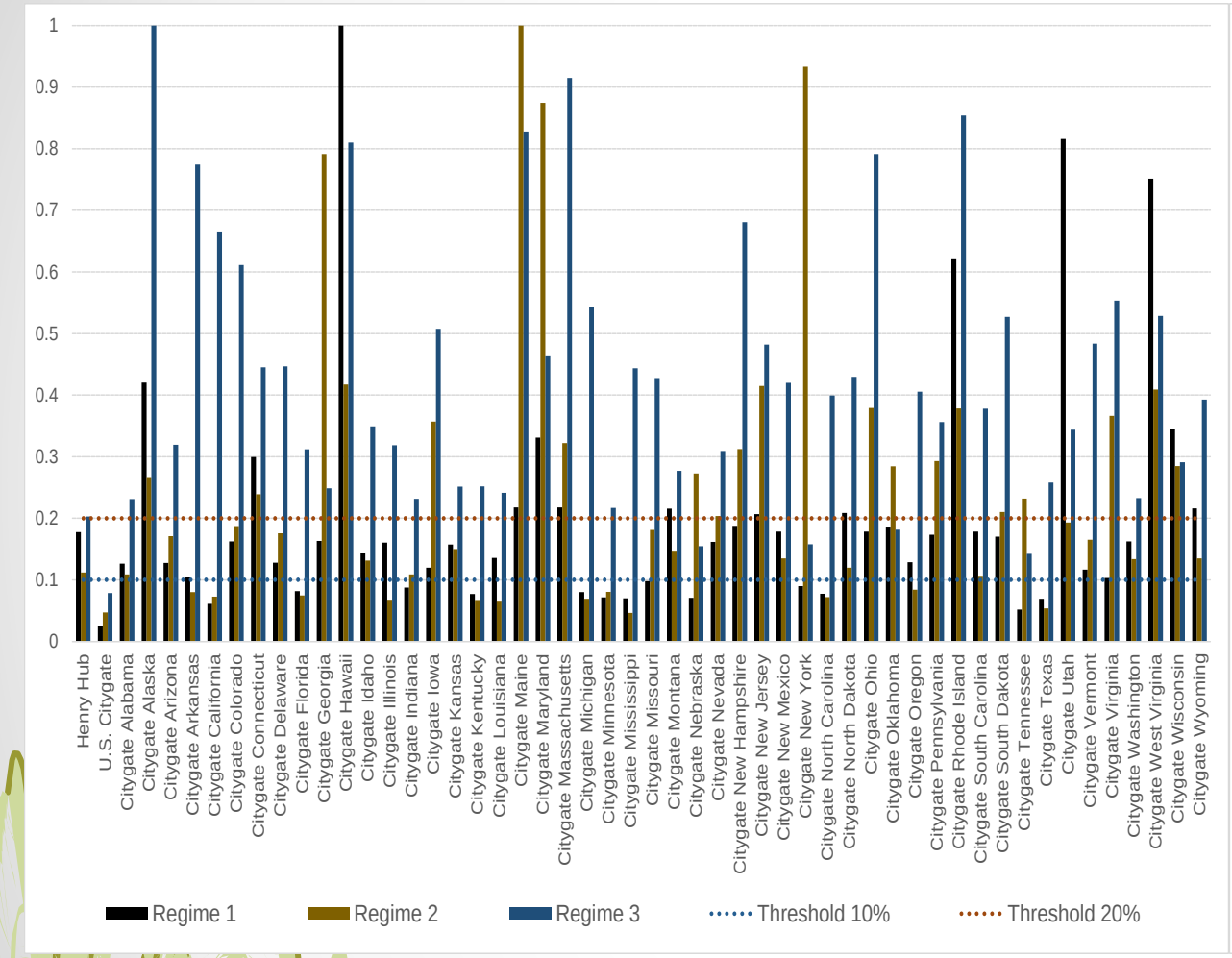


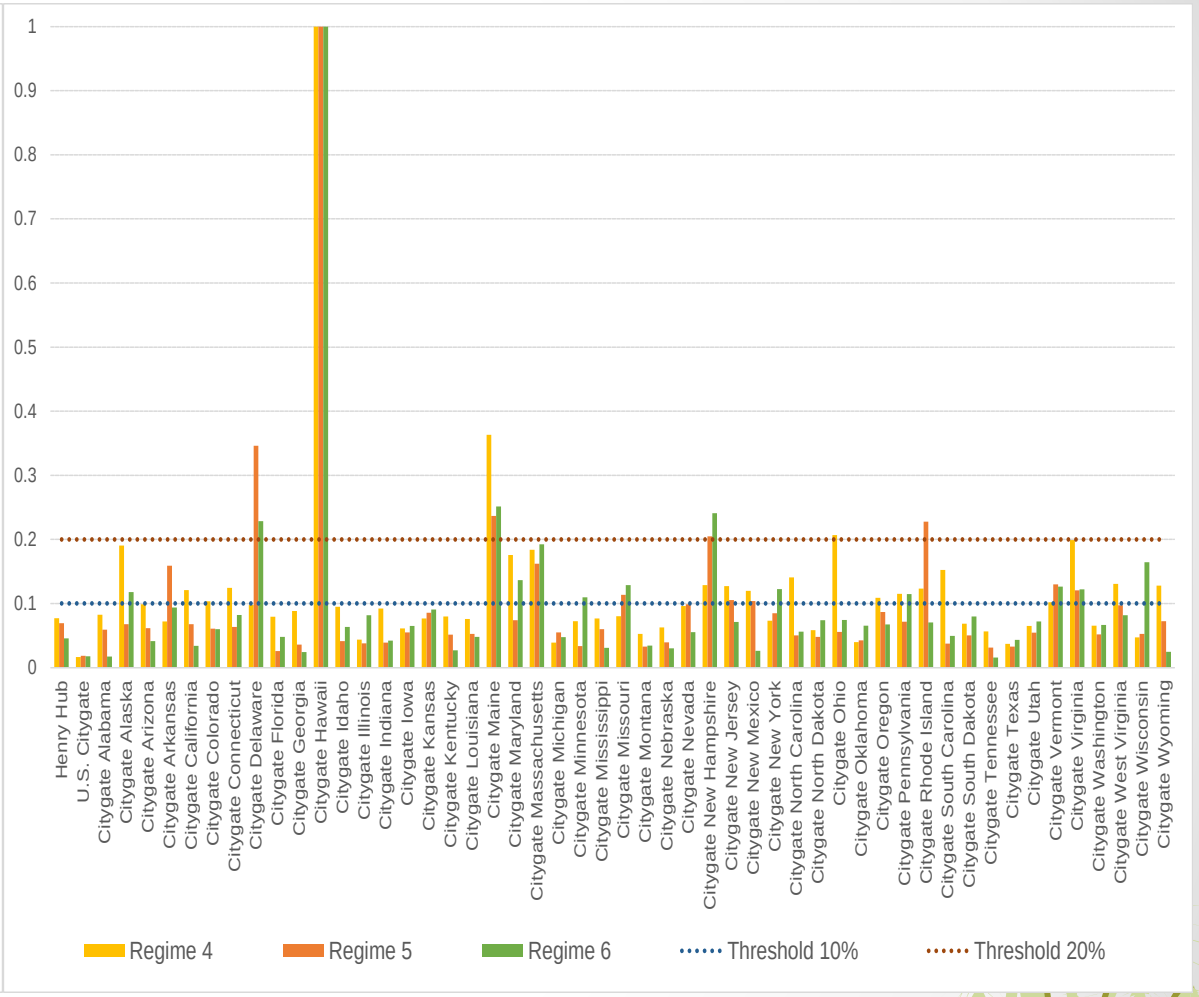


Dynamic distance analysis across periods

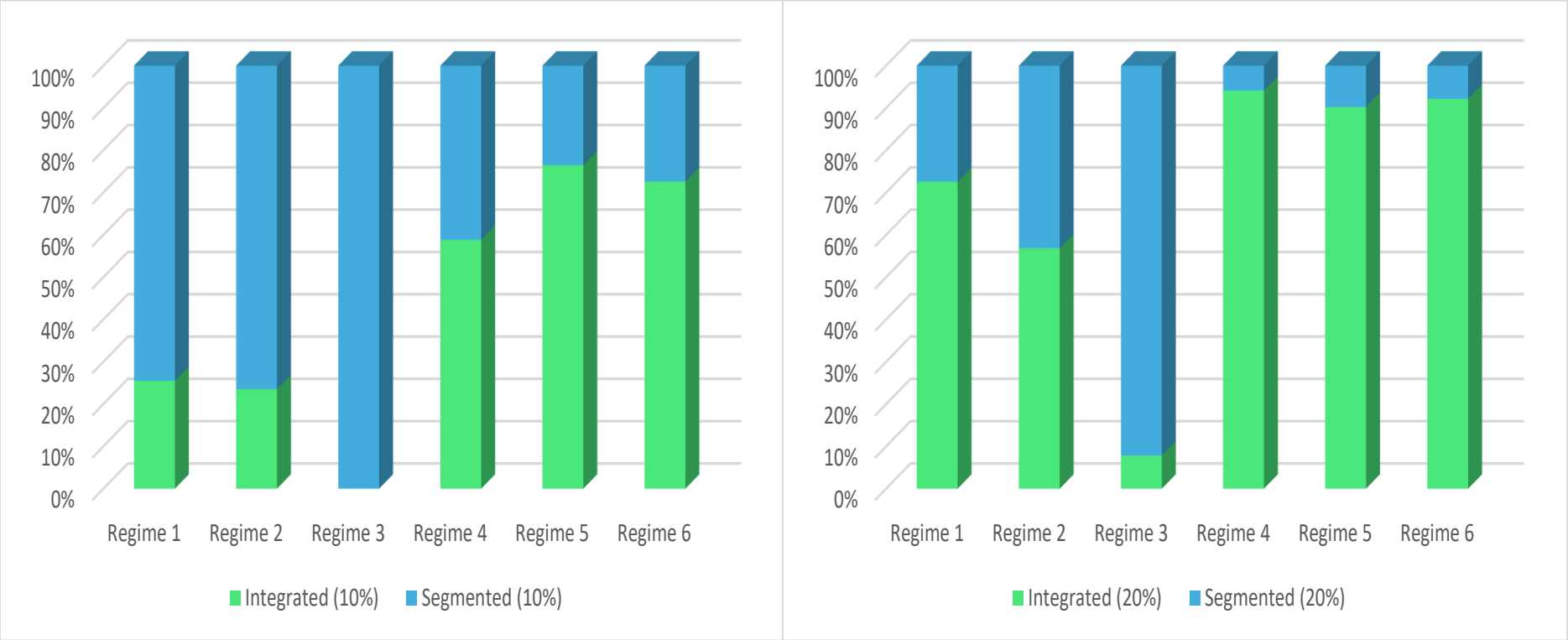
- We compute the Fréchet distance measure over each regime for the 52 natural gas price series under consideration.
- We normalize such distance measure by dividing it by the maximum value, which is observed across the sample of natural gas price series.
- We get thus a normalized Fréchet distance (i.e. measure of similarity between price curves), which is scaled between 0 and 1.
- We set up a 10% and 20% threshold to define the closeness between a natural gas price series and its fundamental price component.

Regime-specific Fréchet distance



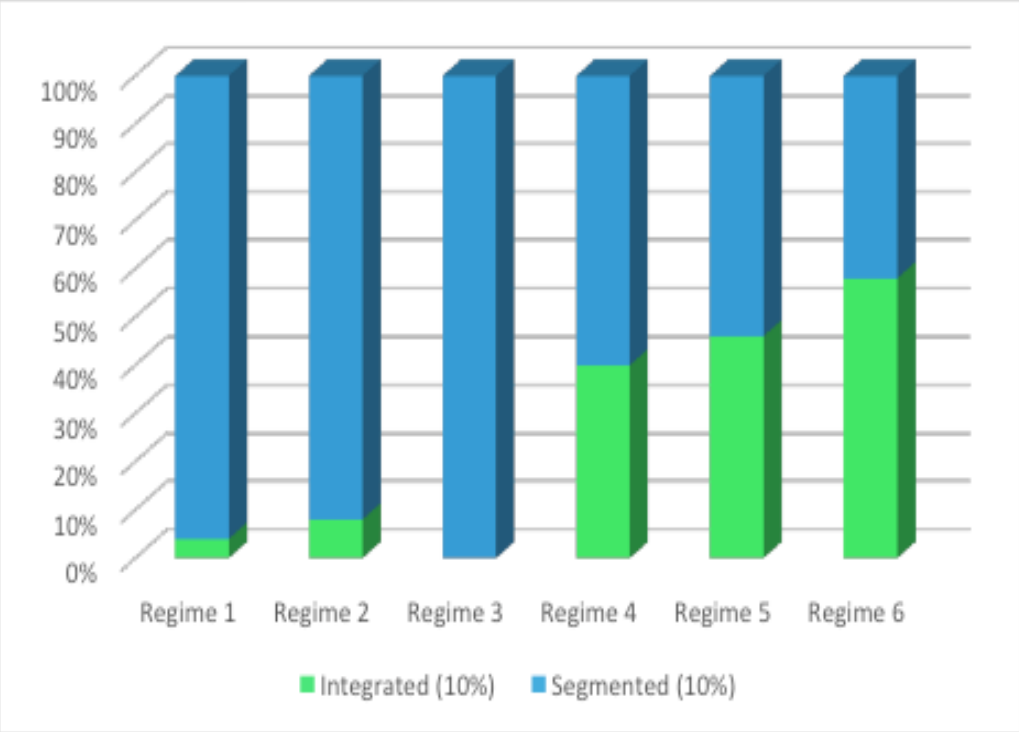


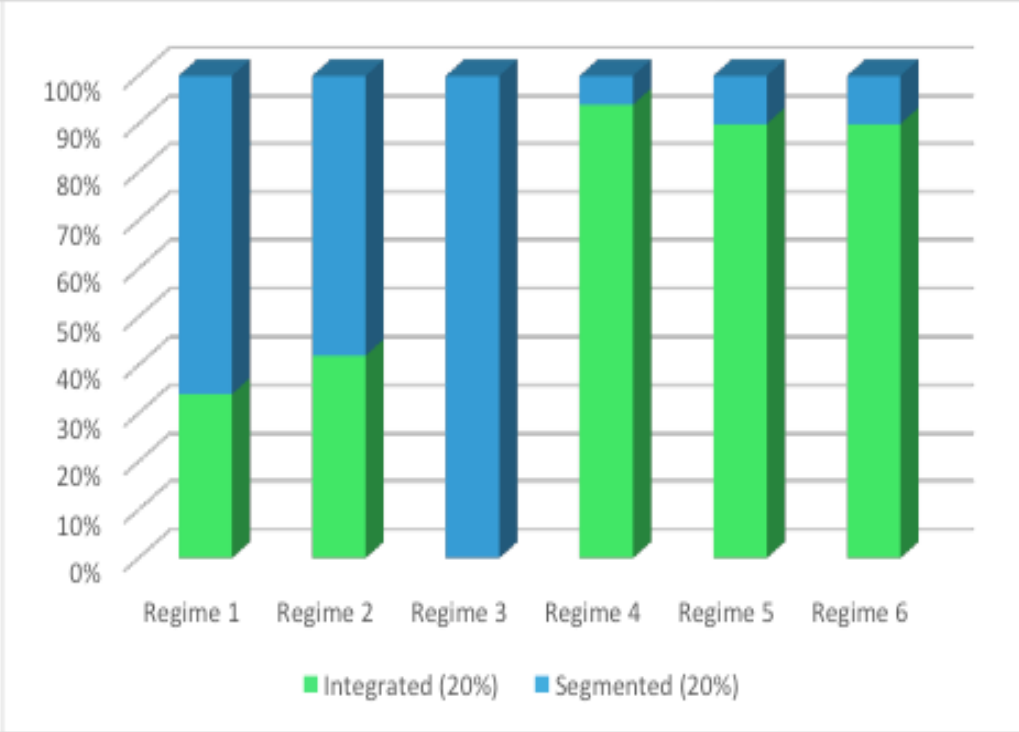
Integration across the 6 regimes



- The percentage of integrated and segmented states exhibits a structural change from regime 3 to regime 4. Whatever the threshold, the U.S. gas market shifts towards a more integrated structure from September 2004 (delayed impact of FERC reforms).

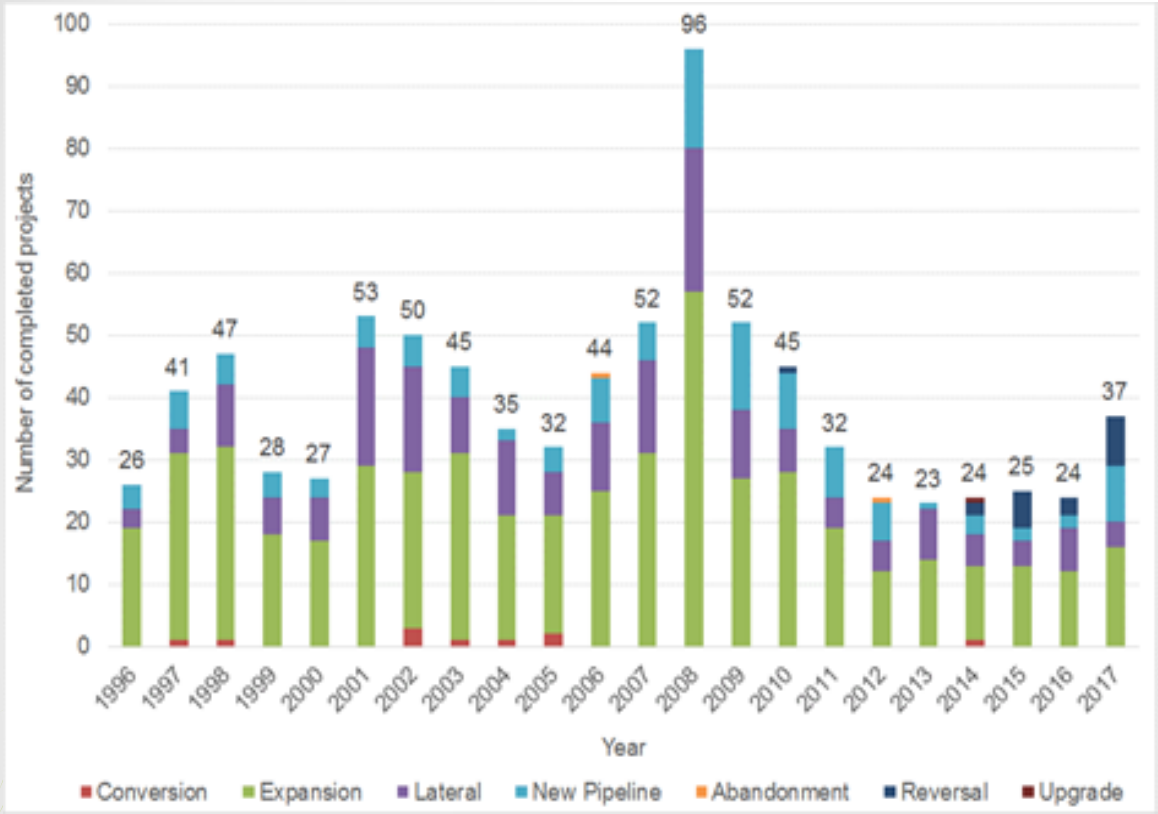
Back-testing with Henry Hub price



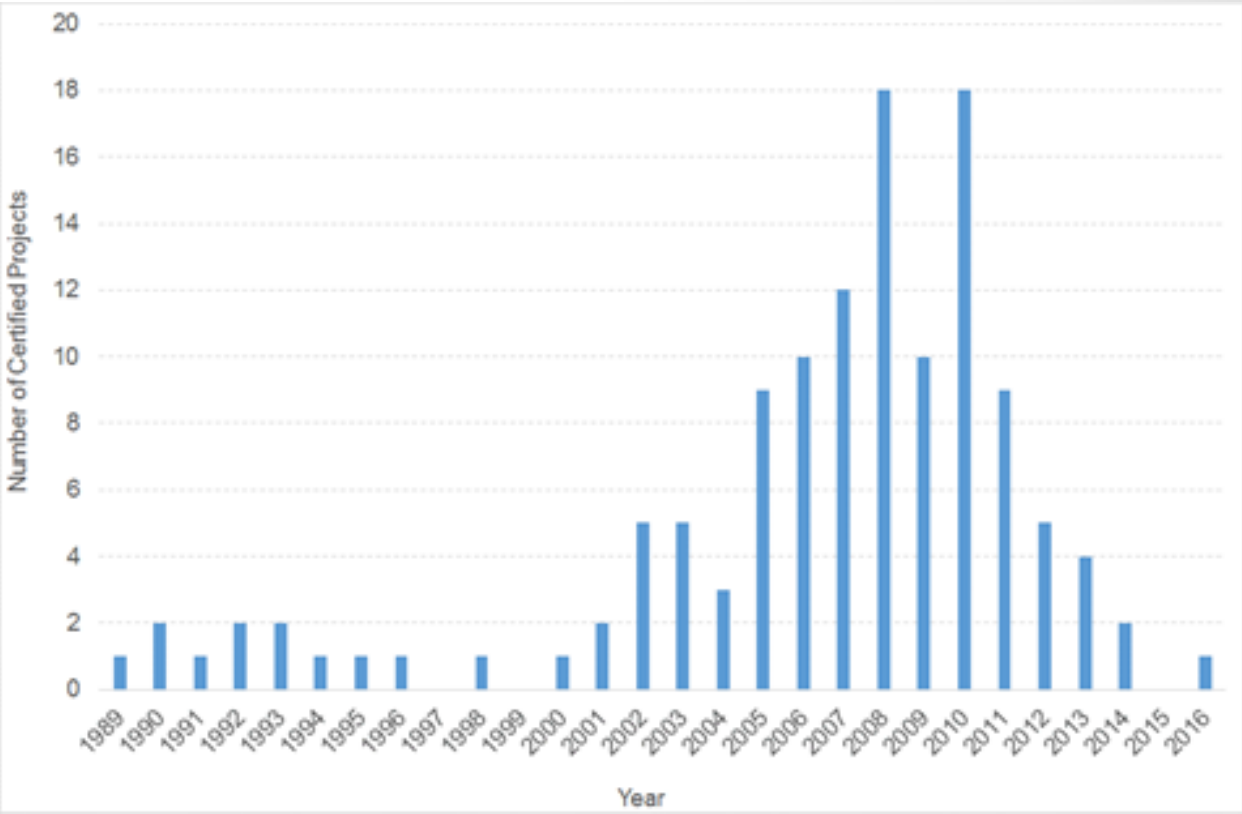


- Converging and diverging natural gas price series as a function of the Fréchet threshold, when benchmark price is Henry Hub spot price.
- Percentage of integrated and segmented states: close results and same conclusion as in the case of the fundamental natural gas price.

Linking integration to gas network



Number of natural gas pipeline projects per type of project



Number of FERC certified projects (on November 15th, 2016)

Conclusion

Apply Kalman filter to study the convergence in U.S. natural gas prices over time

Compute distances between fundamental and spot prices to gauge market integration

Fluctuating integration of prices, with existing segmentation

Market integration is strongly linked with the gas network

Expansion of the U.S. pipeline network is still needed