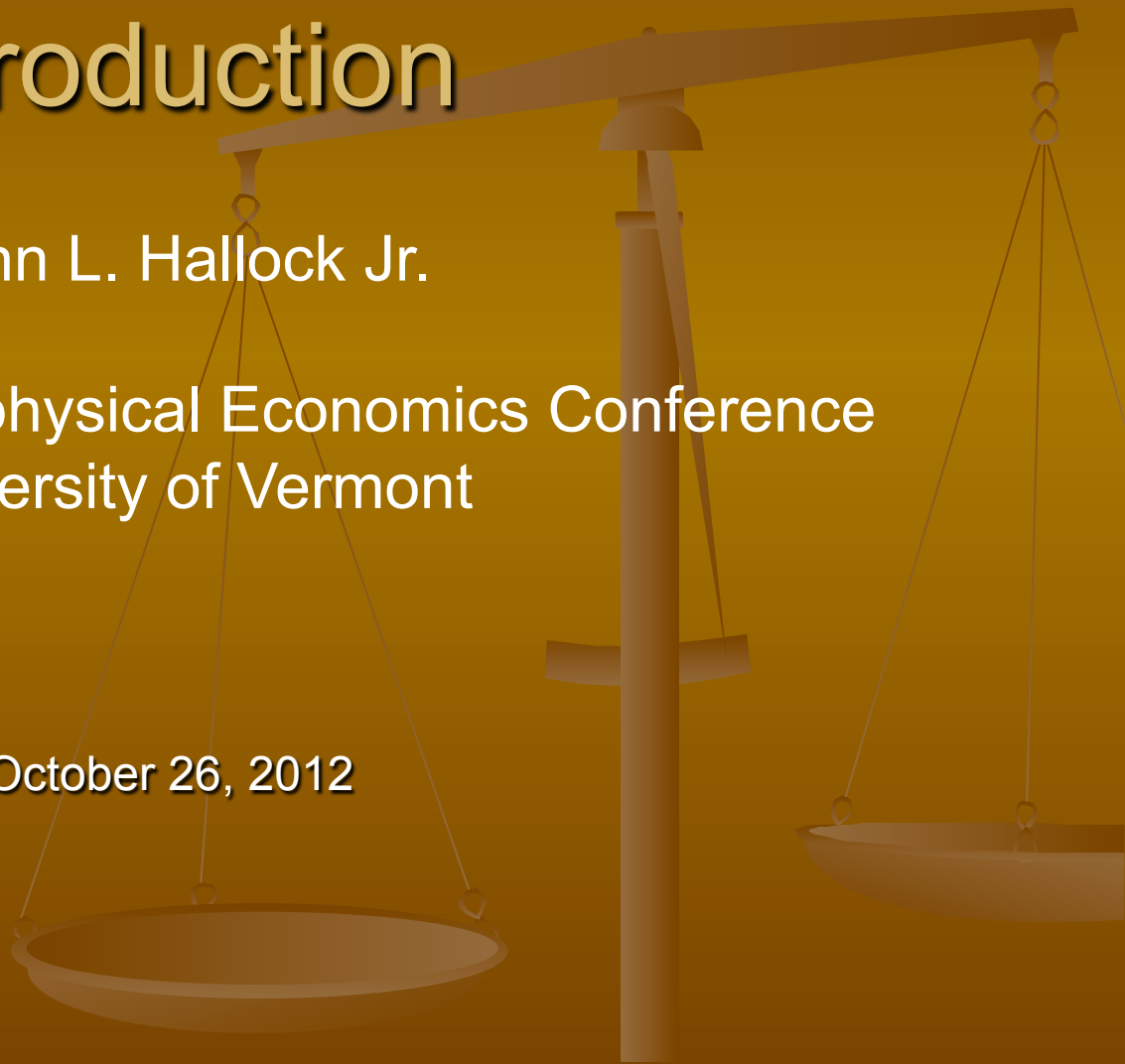
The Worst Case – Empirical Data and Conventional Oil Production

John L. Hallock Jr.

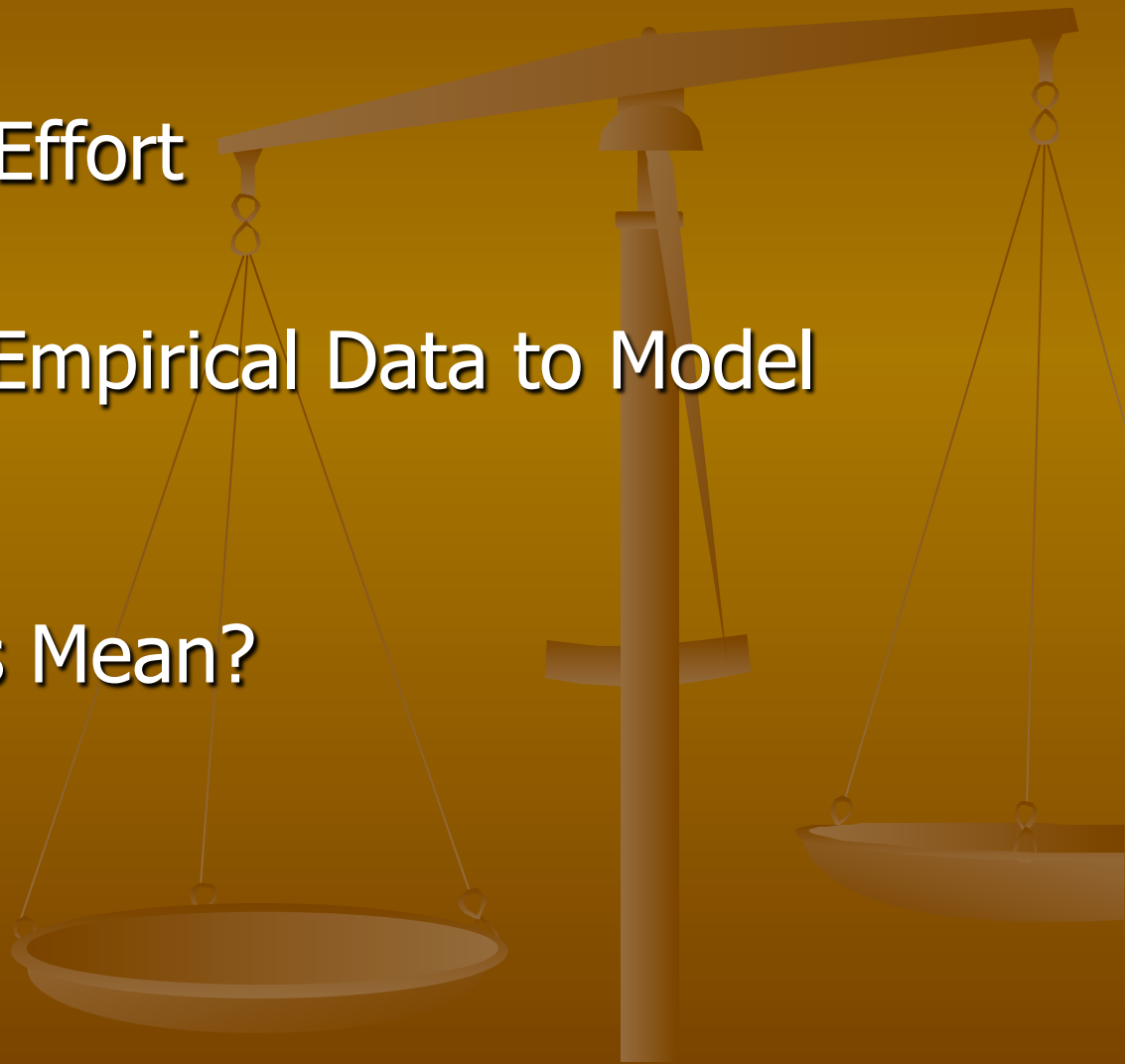
Fourth Annual Biophysical Economics Conference
University of Vermont

October 26, 2012



Outline

- Importance of Petroleum
- 2004 Modeling Effort
- Comparison of Empirical Data to Model Scenarios
- What Does This Mean?



Energy Densities of Various Fuels

- **Dry Wood** **16.2 (G joules/tonne)**
- **Black Coal** -elec. gen. **27.0**
- Black Coal -coking 29.0
- Ethanol 29.6
- Bitumen (tar/asphalt) 42.7
- **Crude Oil** **44.9**
- Kerosene – lighting 46.5
- **Gasoline – auto** **49.6**
- LPG (Propane) 49.6
- Liquid NG 54.4

Source: Http://astro.berkely.edu/~wright/fuel_energy.html

The Present: More Petroleum Please…

- Increasing oil production has driven economic growth.
- World relied on oil for ~40% of total energy in 2000. Add 20% for Nat Gas.
- Oil used for ~60% of transport globally.
  - In US? – much closer to 100%.
- Feedstock – industrial chems, pesticides, pharmaceuticals, plastics…
- Economic growth will rely on increasing inputs of these fuels as long as this dependence continues.

Our 2004 Effort

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Energy 29 (2004) 1673–1696

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Forecasting the limits to the availability and diversity of global conventional oil supply

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Our 2004 Effort

- Why? Lot of debate at time over estimates of total global oil resources still available, how long they' d last.

  - What difference does 1 trillion barrels of reserves vs. 2 make, or how fast demand rises?

- Goal: To use consistent method to define range of uncertainty in decline point date (~ "peak").

  - Analyze sensitivity to changes in key variables.

Conventional vs. Non-conventional oil

- Conventional oil - generally considered to be oil pumped from a well-head using 1º, 2º, EOR means.
  - Uppsala-Campbell (UC) – > 17.5 API, shallower than 500 meters, not above Arctic Circle.
  - USGS – discrete formations only – not continuous plays
- Non-conventional – other that may require mining of or in-situ processing of the oil media, extreme effort not meeting above definitions.
- N. Gas Liquids – propane, butane, hexane...

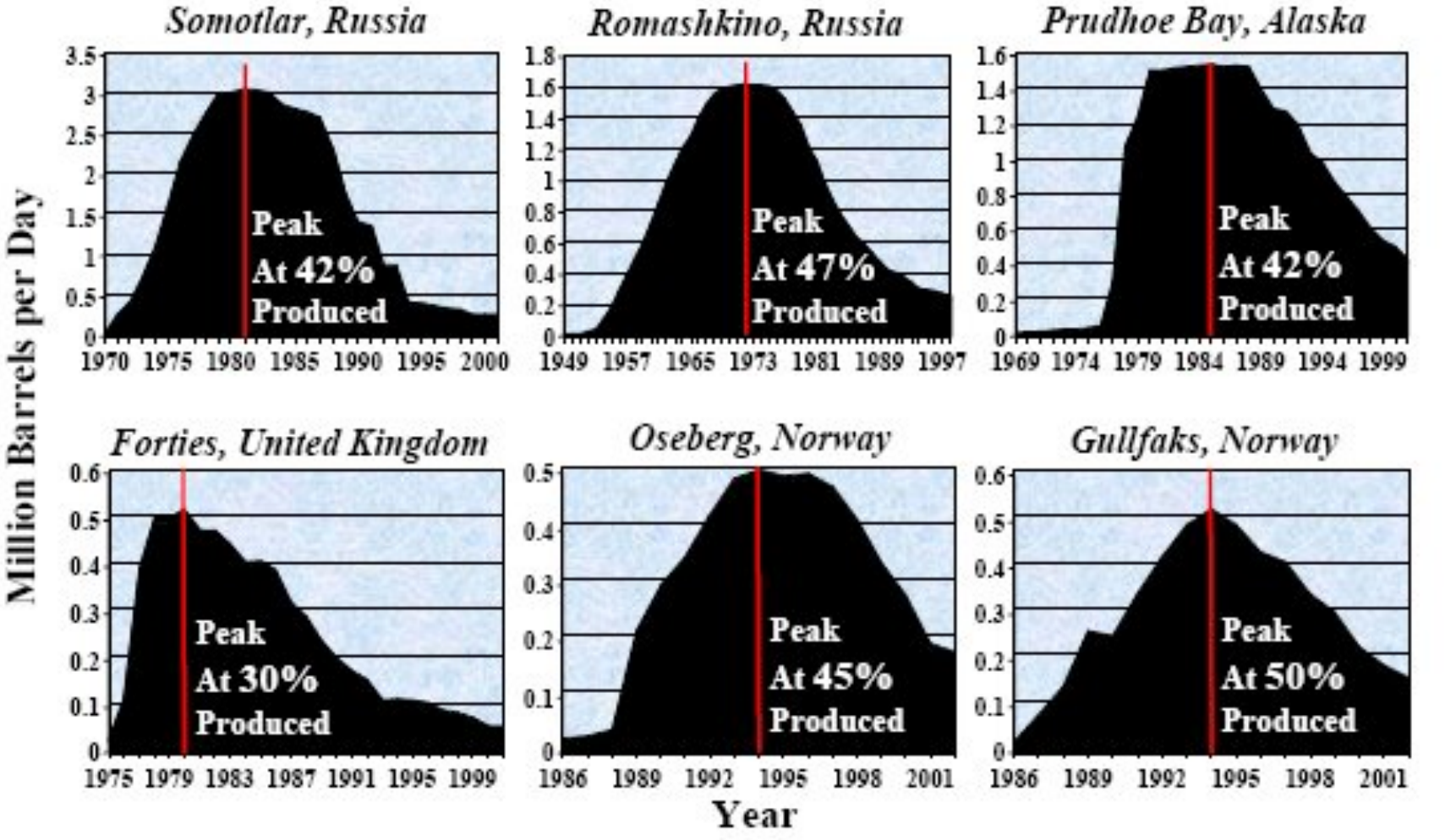
  -Produced @ special plants from N Gas

  -Not considered in analysis
- Crude Oil – very basically it is everything but NGL, biofuels, and "anything" to liquids.

Model Basics

- Production of individual oil fields tends to increase until ~50% of original oil depleted…
- Scaling up to nation or world yields 50% peak there too.
- Start with estimate of original oil vol. (EUR) for a nation. Deplete it by subtracting annual production.
- Production increases until ~50% of EUR extracted – then declines exponentially.

Peaking Profiles of Giant and Super Giant Fields at 30-50% of Total Production



(data from Simmons, "The Saudi Arabia Oil Miracle", February, 2004)

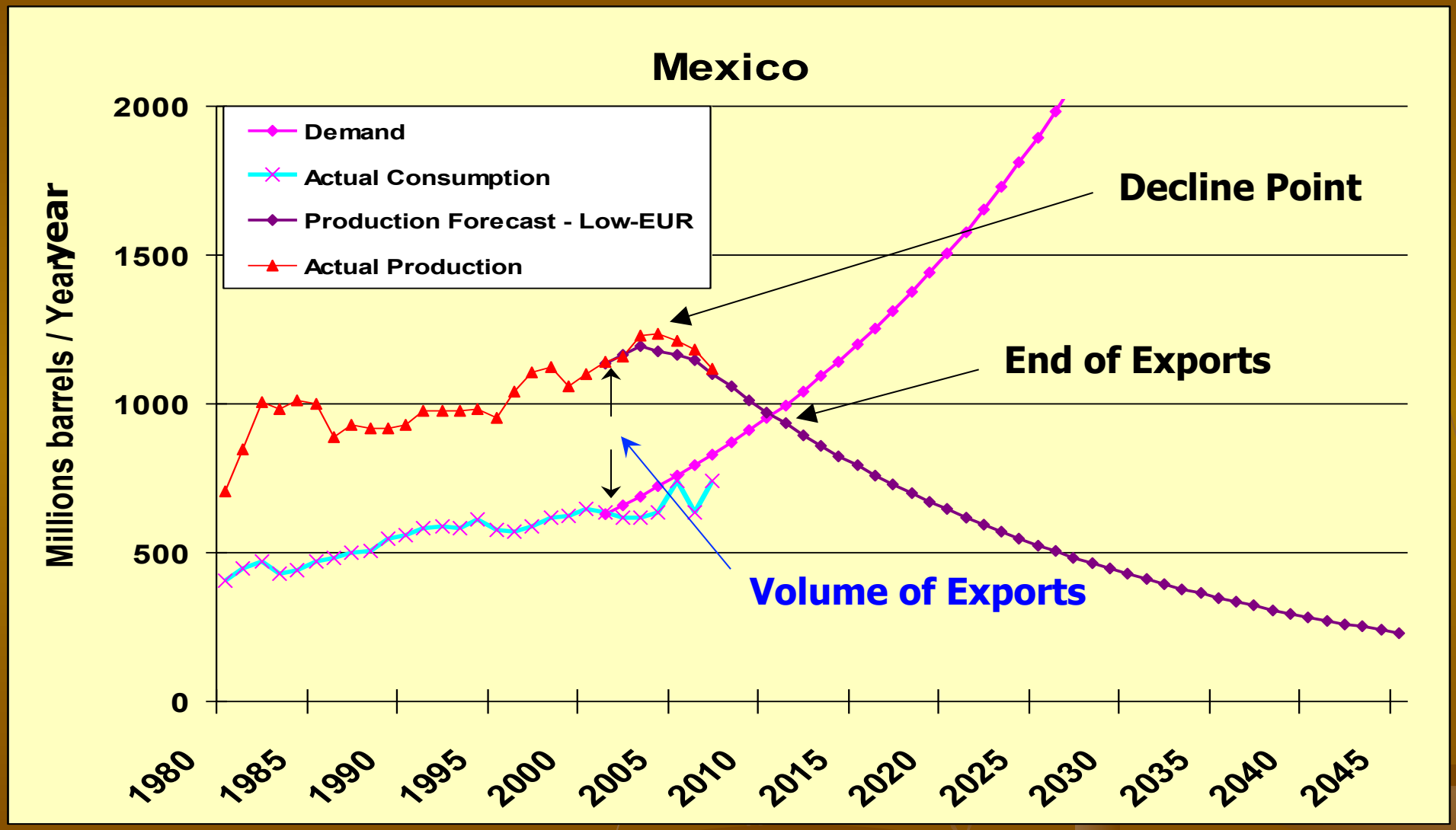
Our 2004 Effort – 42 scenarios for conventional oil

- 3 levels Extractable Resources (EUR):
  - Low: from Campbell estimates (1.9 TB global)
  - Medium: from USGS 2000 mean (2.9 TB)
  - High: from USGS 2000 5% (4.0 TB)
- 2 levels Demand Growth: – Low (1.5% globally) and High (3%) estimates from USDOE EIA
- 2 points of Decline: at 50% or 60% of EUR
- 3 levels Maximum Growth: 5%, 7.5%, 15% /year.
- 6 zero growth scenarios.

Our 2004 Effort – model basics

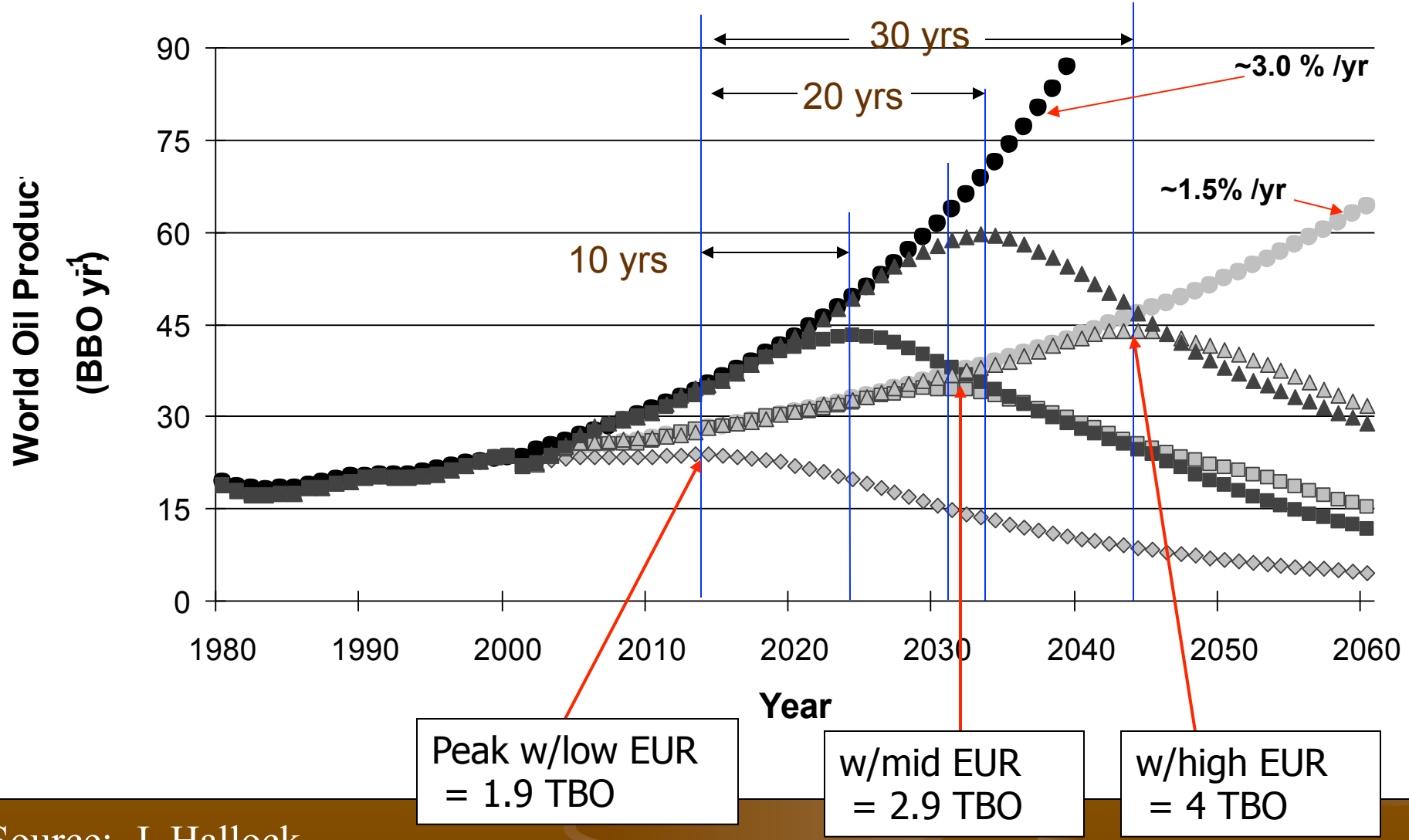
- Nations modeled individually, 2002-2060. Total of all nations = world for any year.
- Pre-peak production increases in a nation to meet domestic demand plus portion of demand for exports.
- Decline sets in when 50-60% extracted and continues exponentially.

Nation example



Source: J. Hallock

Sensitivity to changes in EUR, demand increase

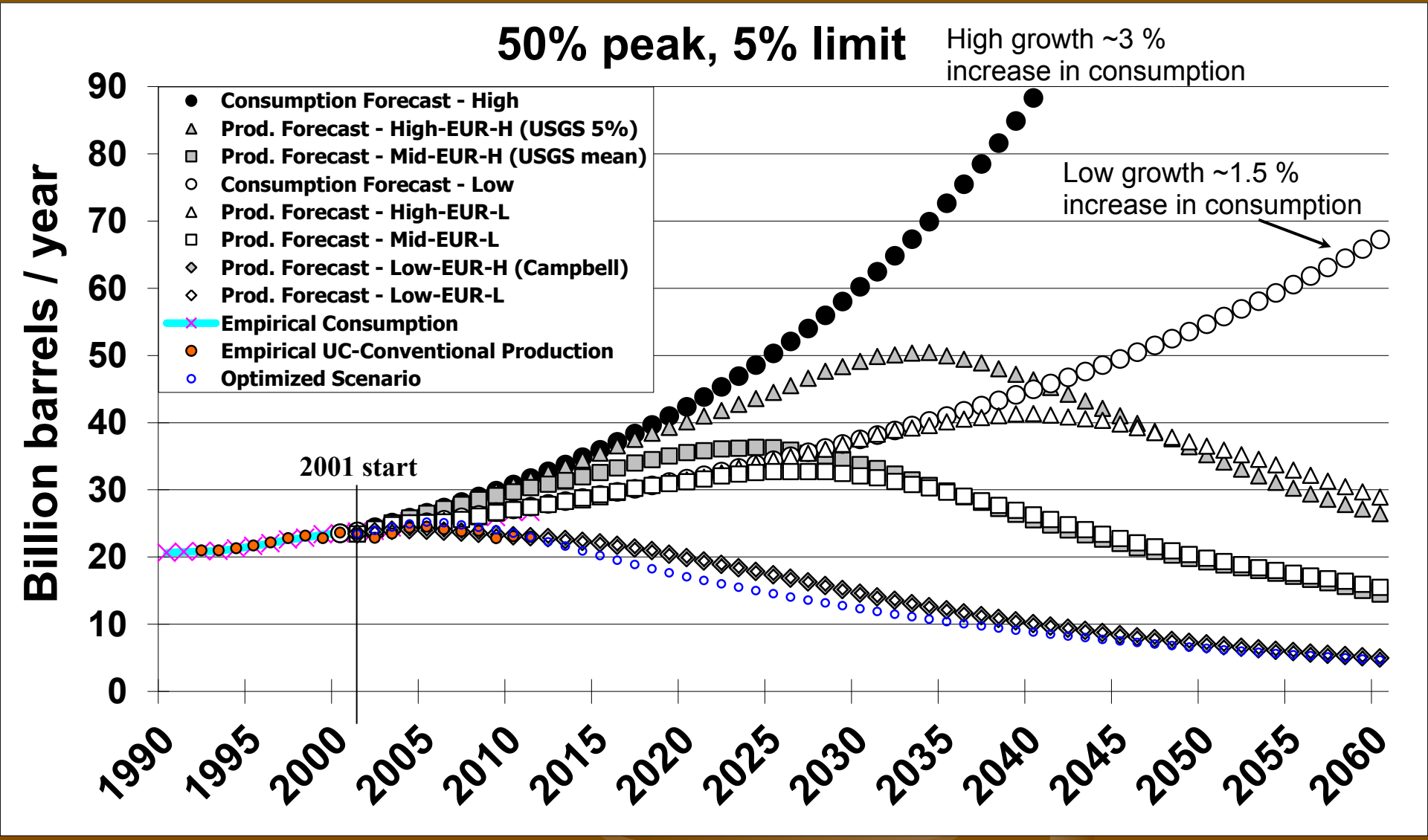


Source: J. Hallock

Current Effort – Comparing Empirical Data to Scenarios

- Derive Comparable data
  - Uppsala-Campbell Conventional
  - USGS Conventional
- Update starting point of models to match updated/revised 2001 data
- Plot model scenarios with empirical data
- Calculate Indices of Similarity to complement
- Source of Data – USEIA, BSSE, company Annual reports and online data, etc.

World UC-Conventional Oil Production model scenarios vs. historical data



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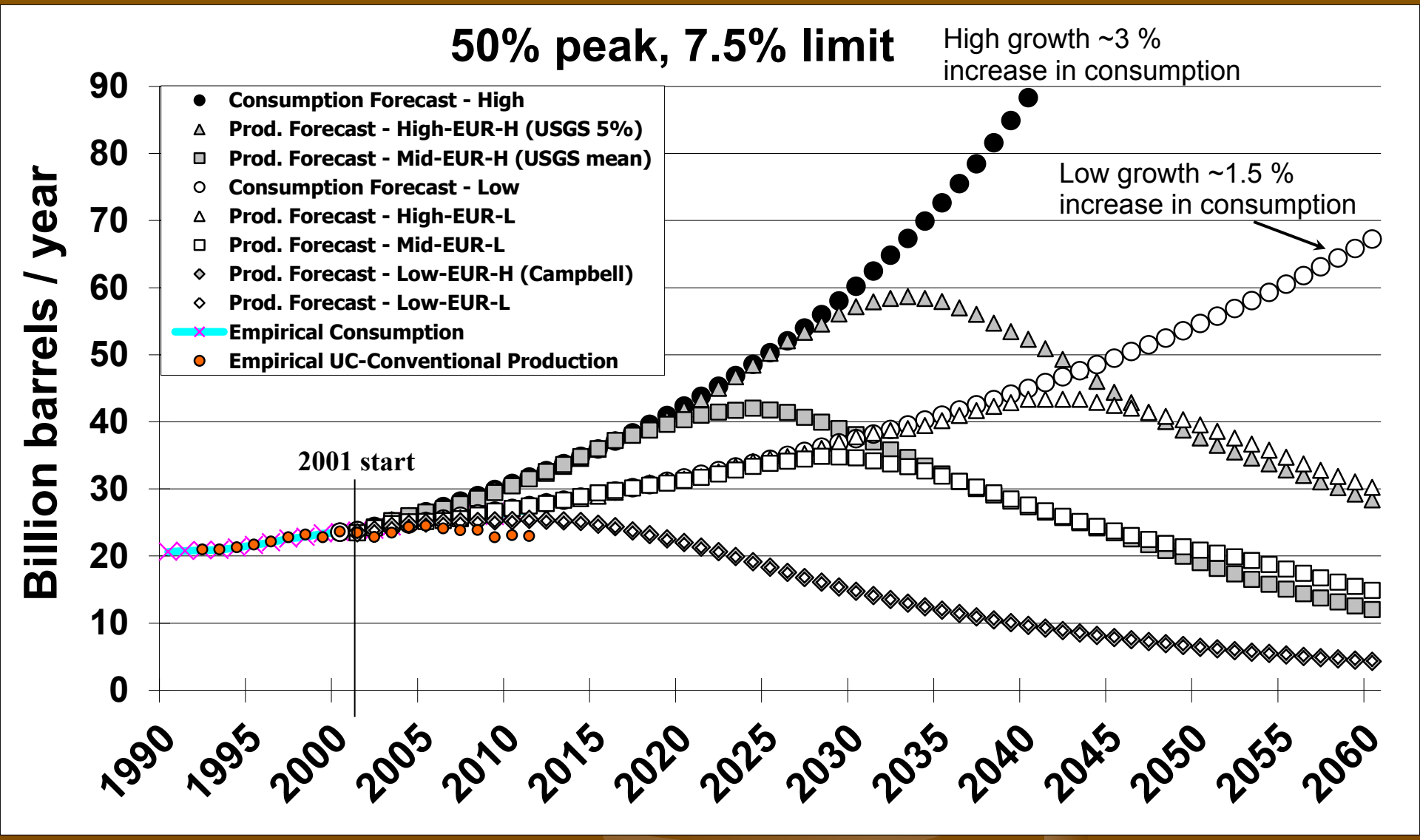
World UC-Conventional Oil Production model scenarios vs. historical data



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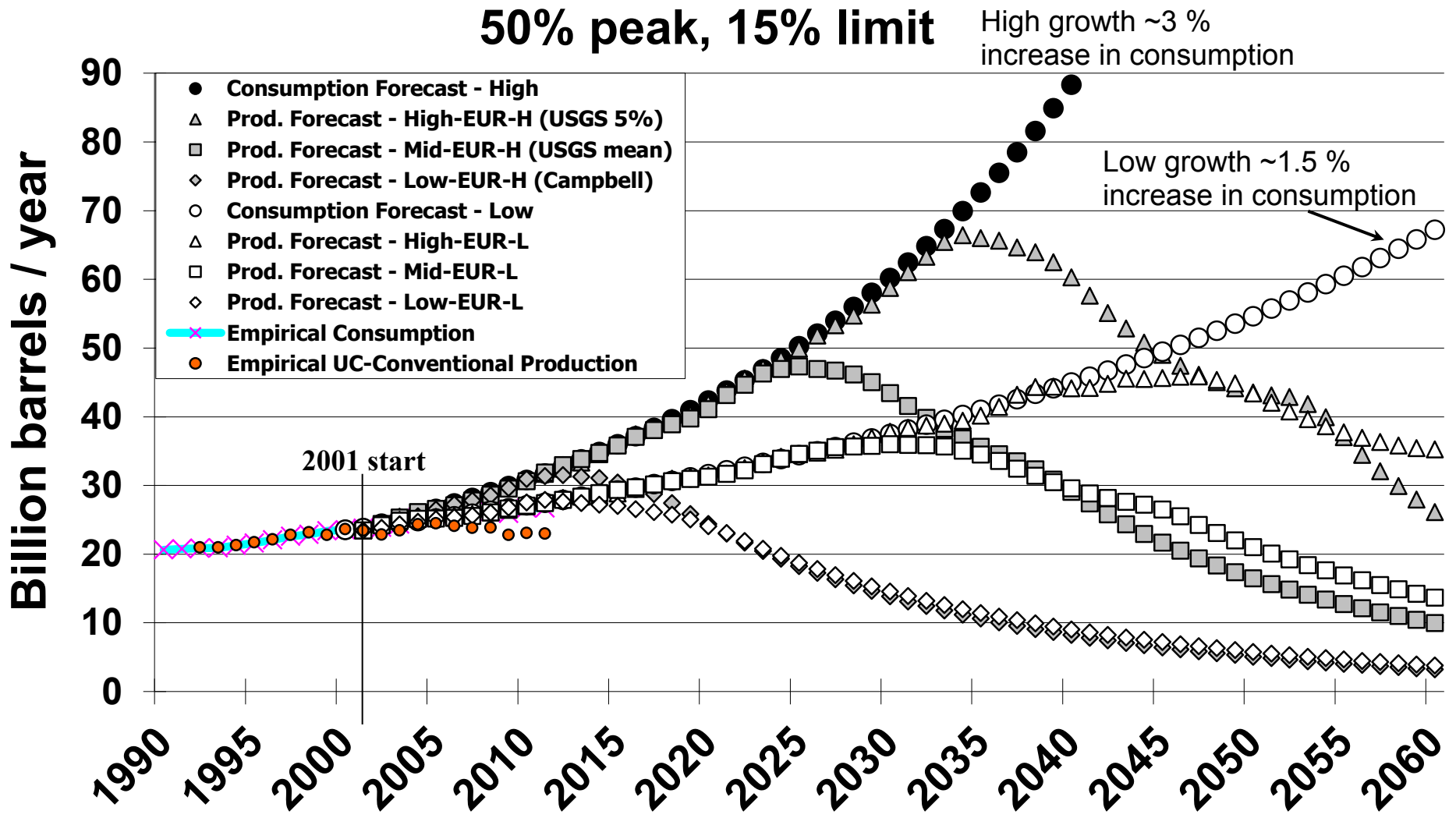

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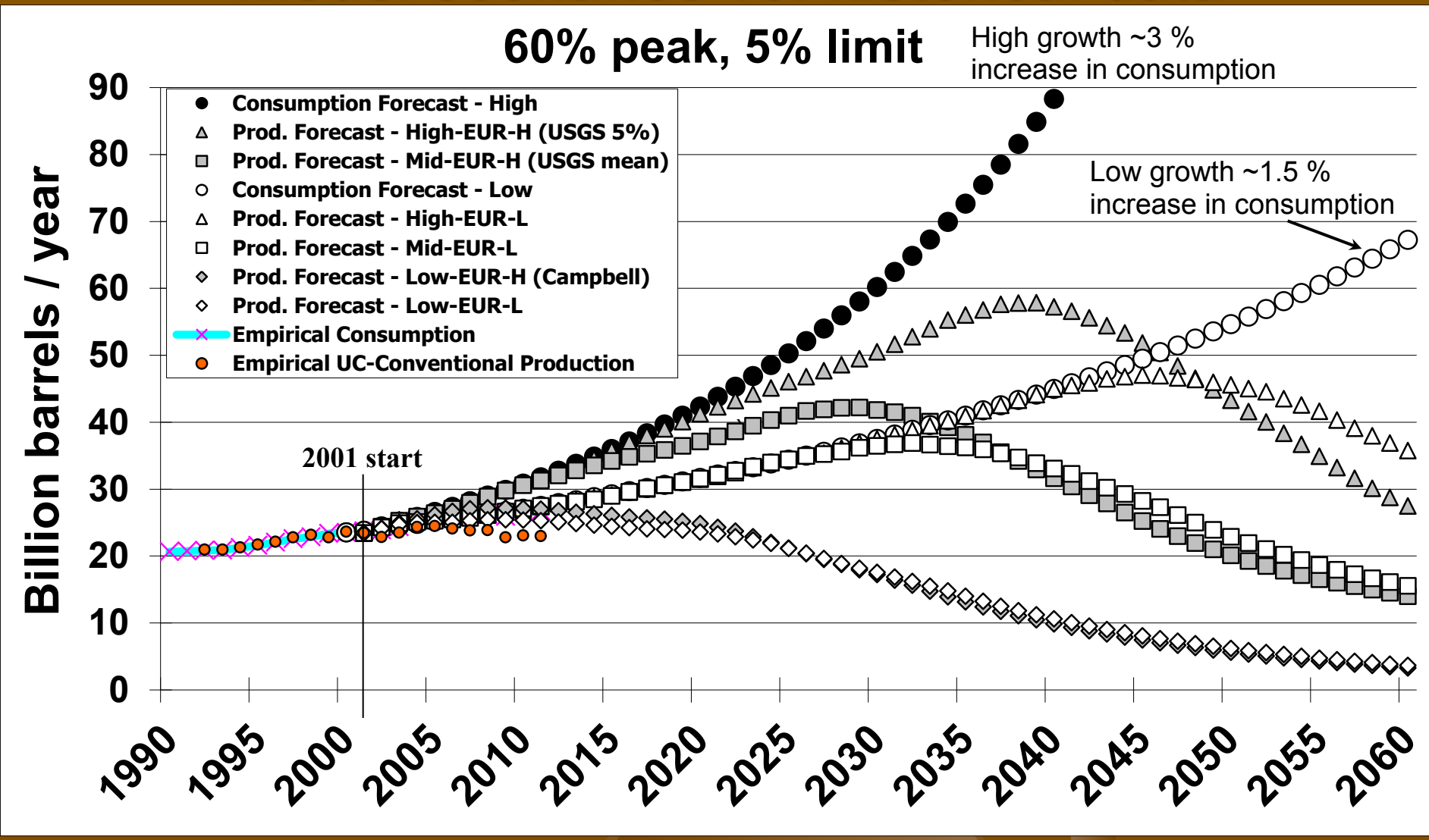

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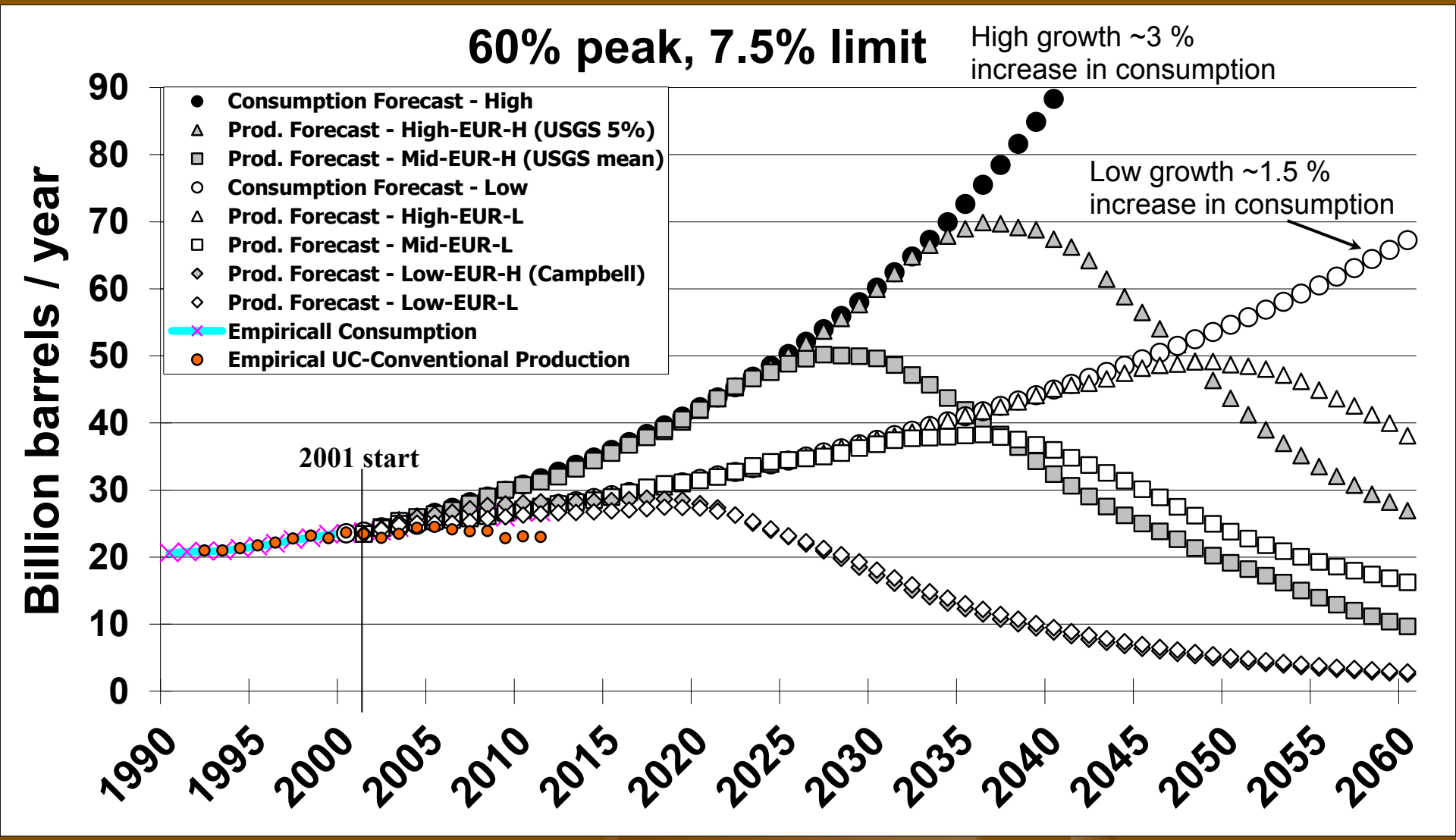

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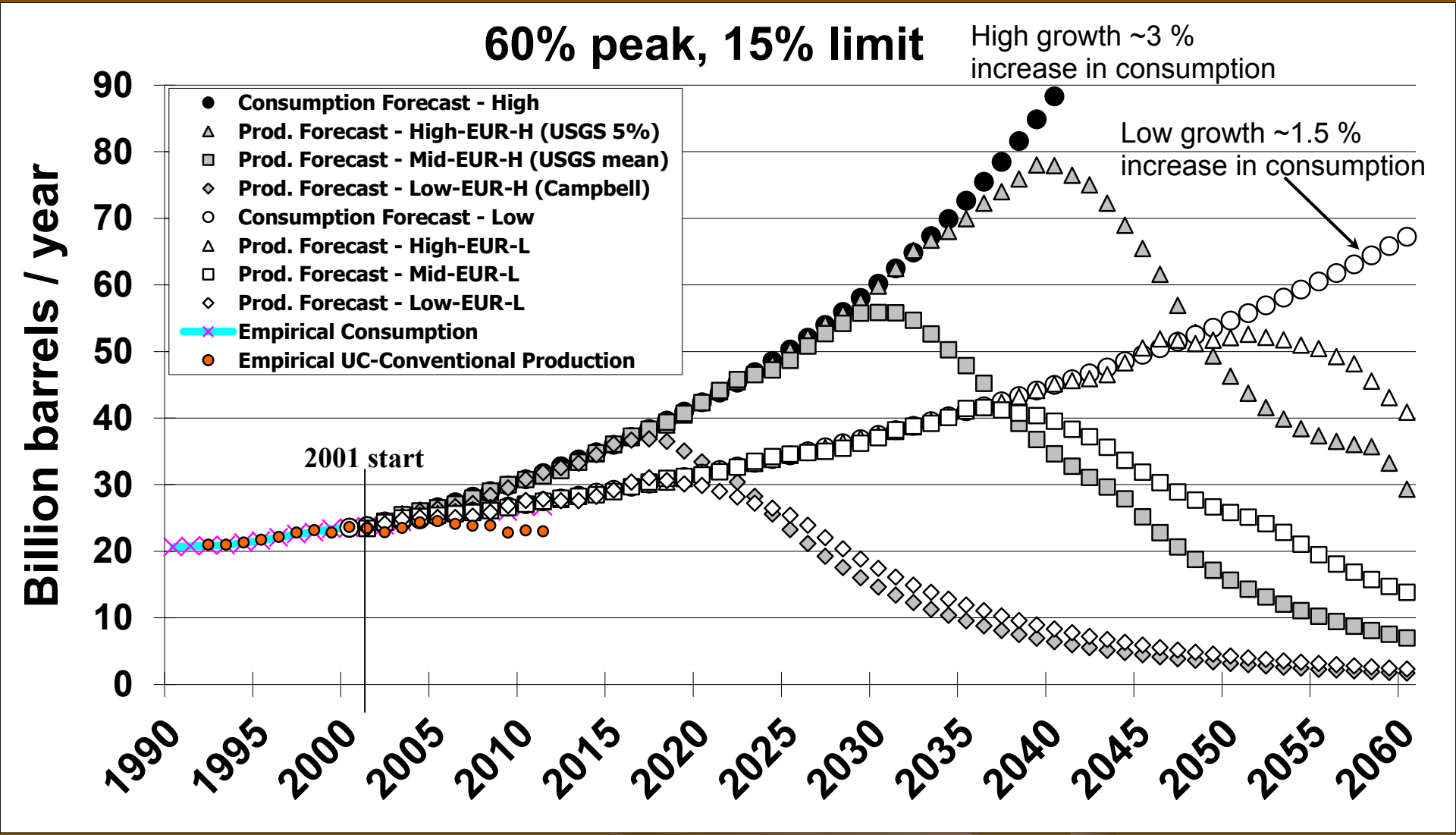

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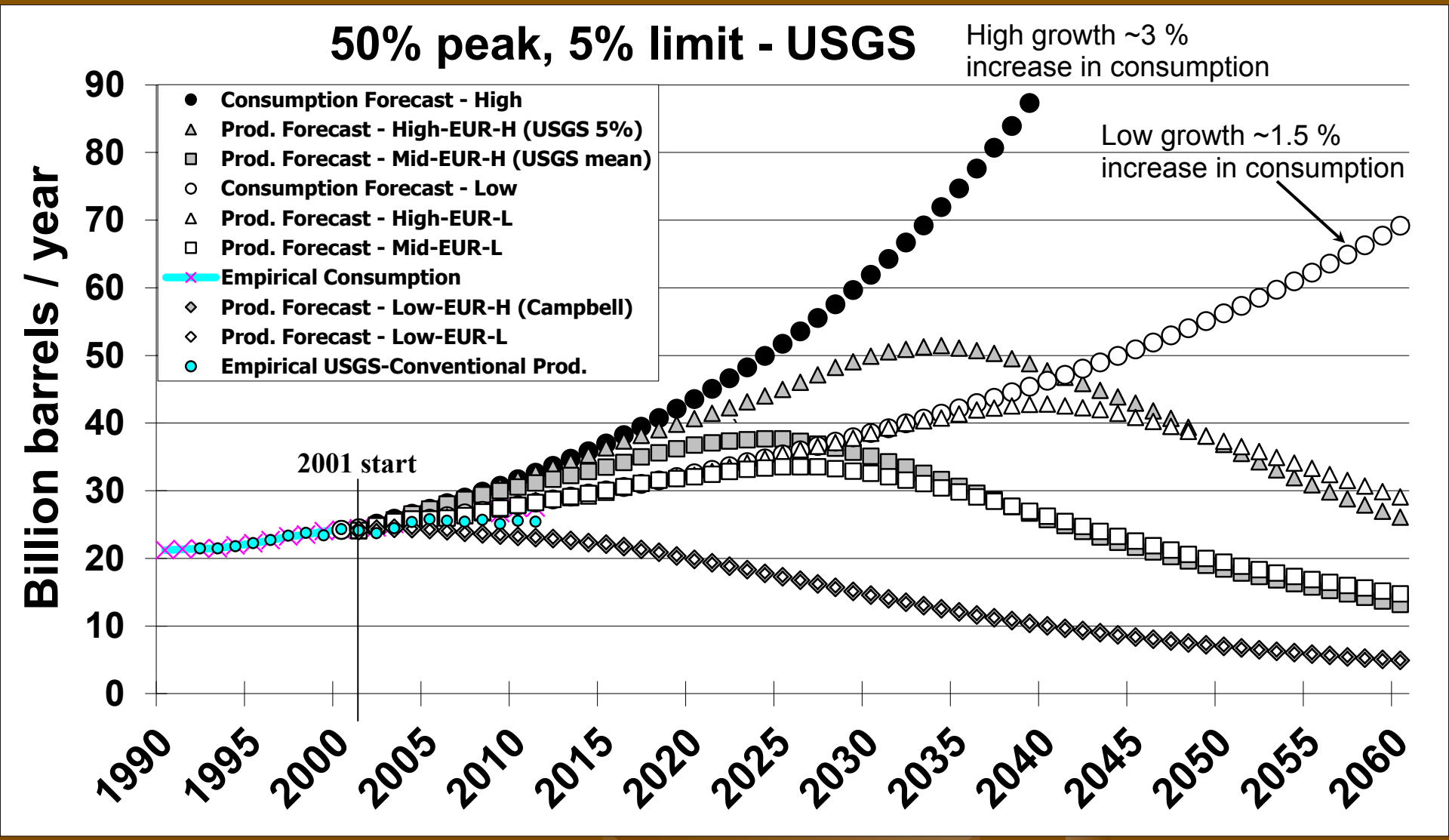
World USGS-Conventional Oil Production model scenarios vs. historical data



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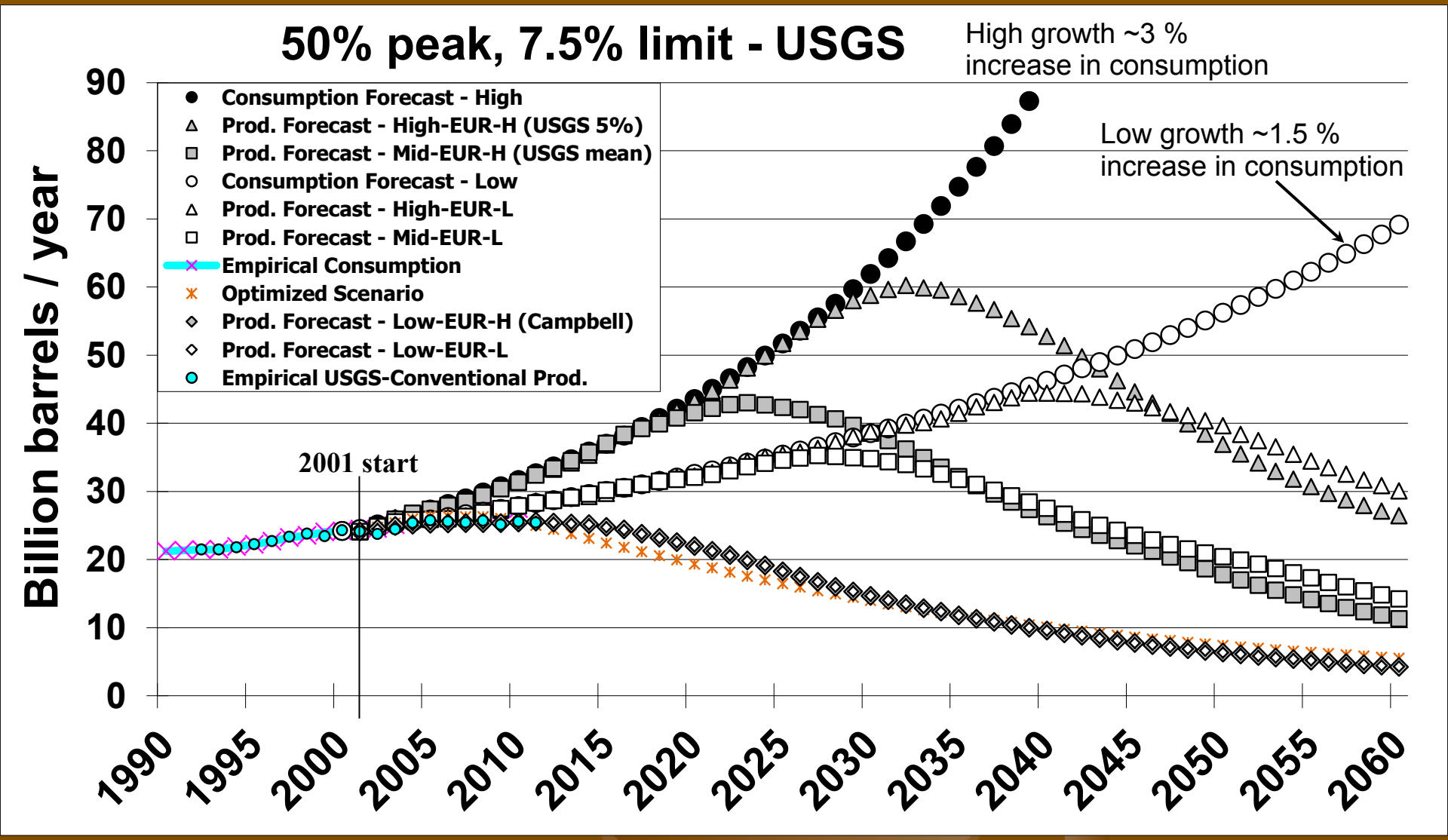

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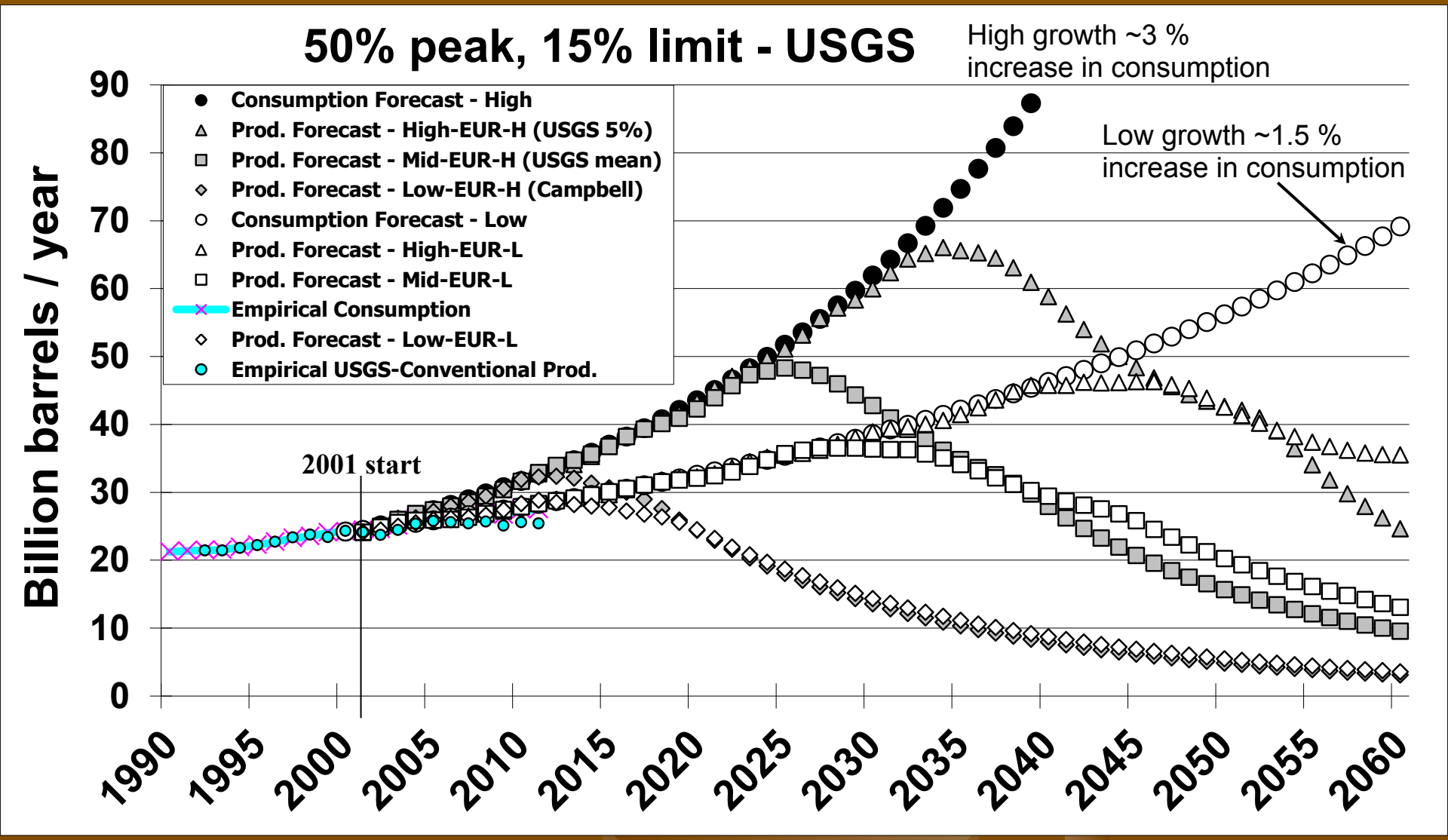

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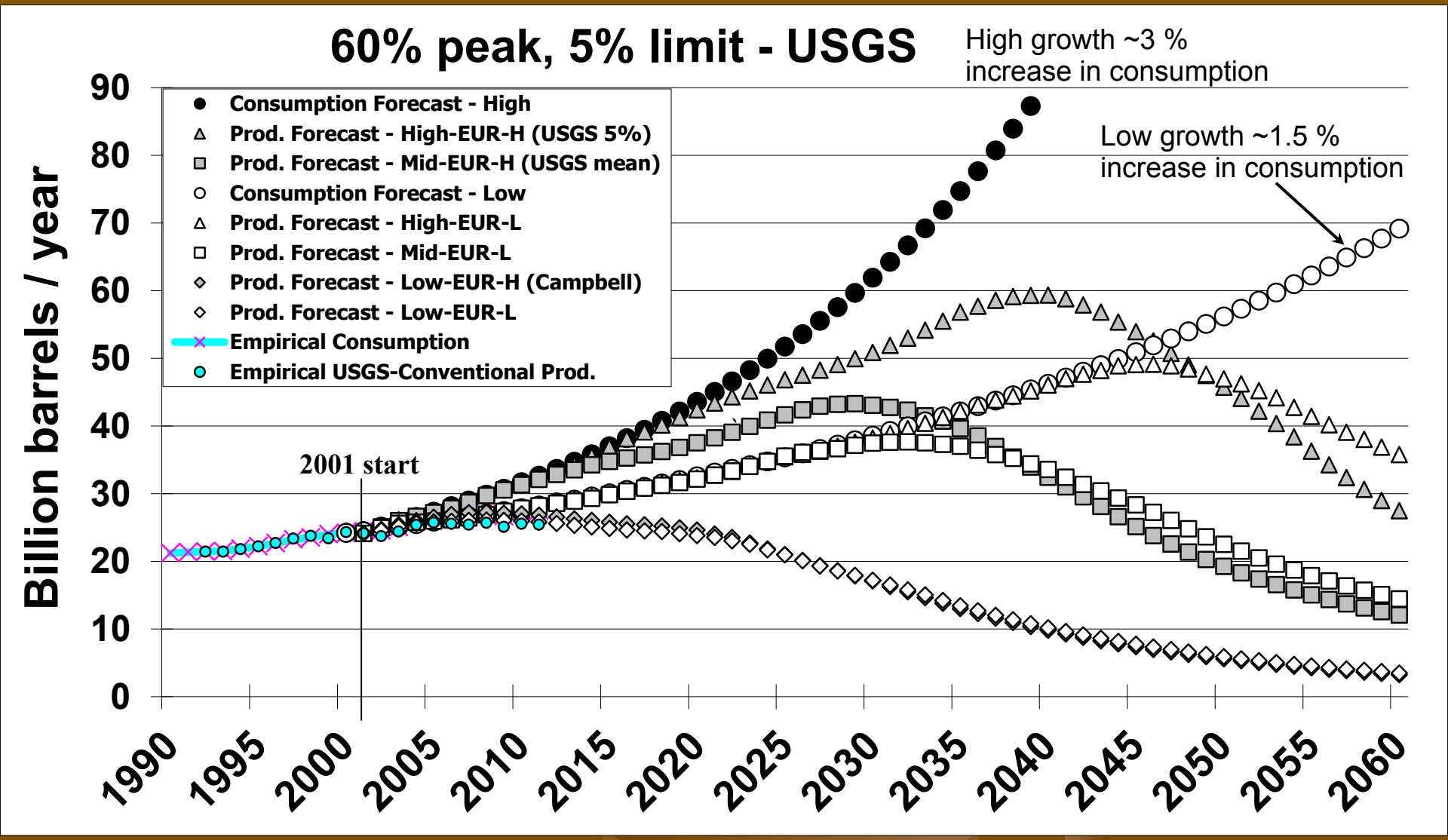

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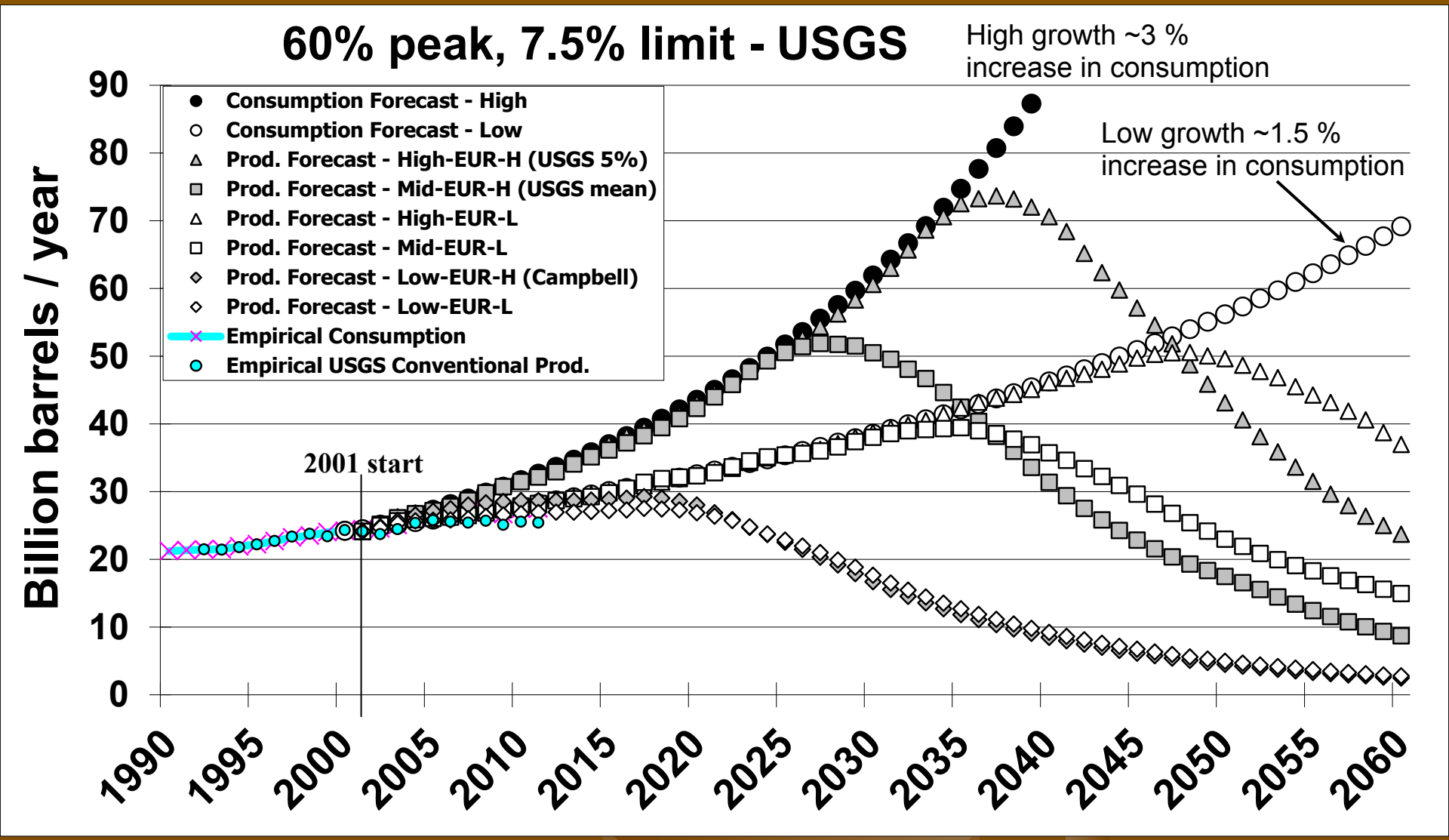

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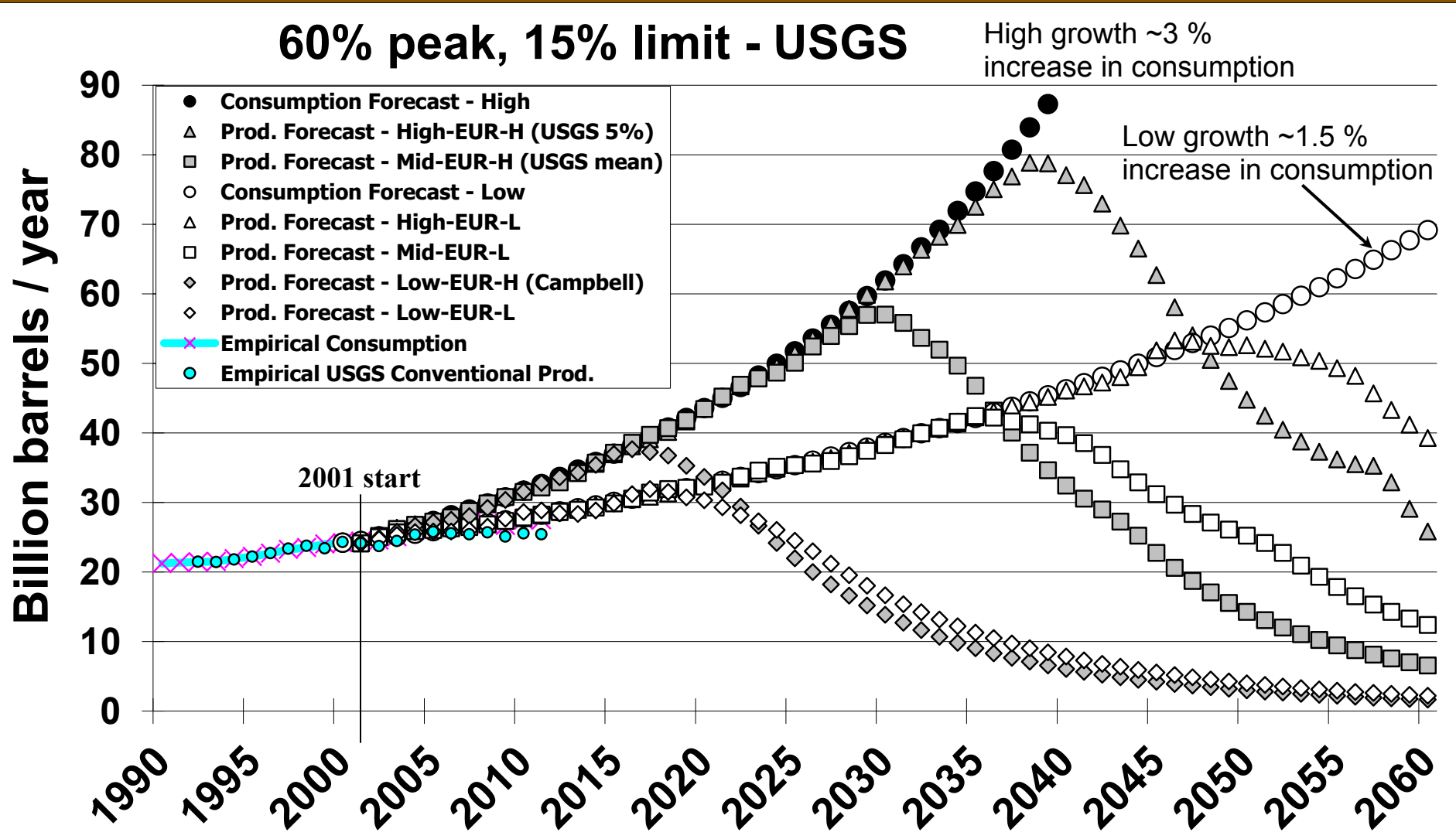

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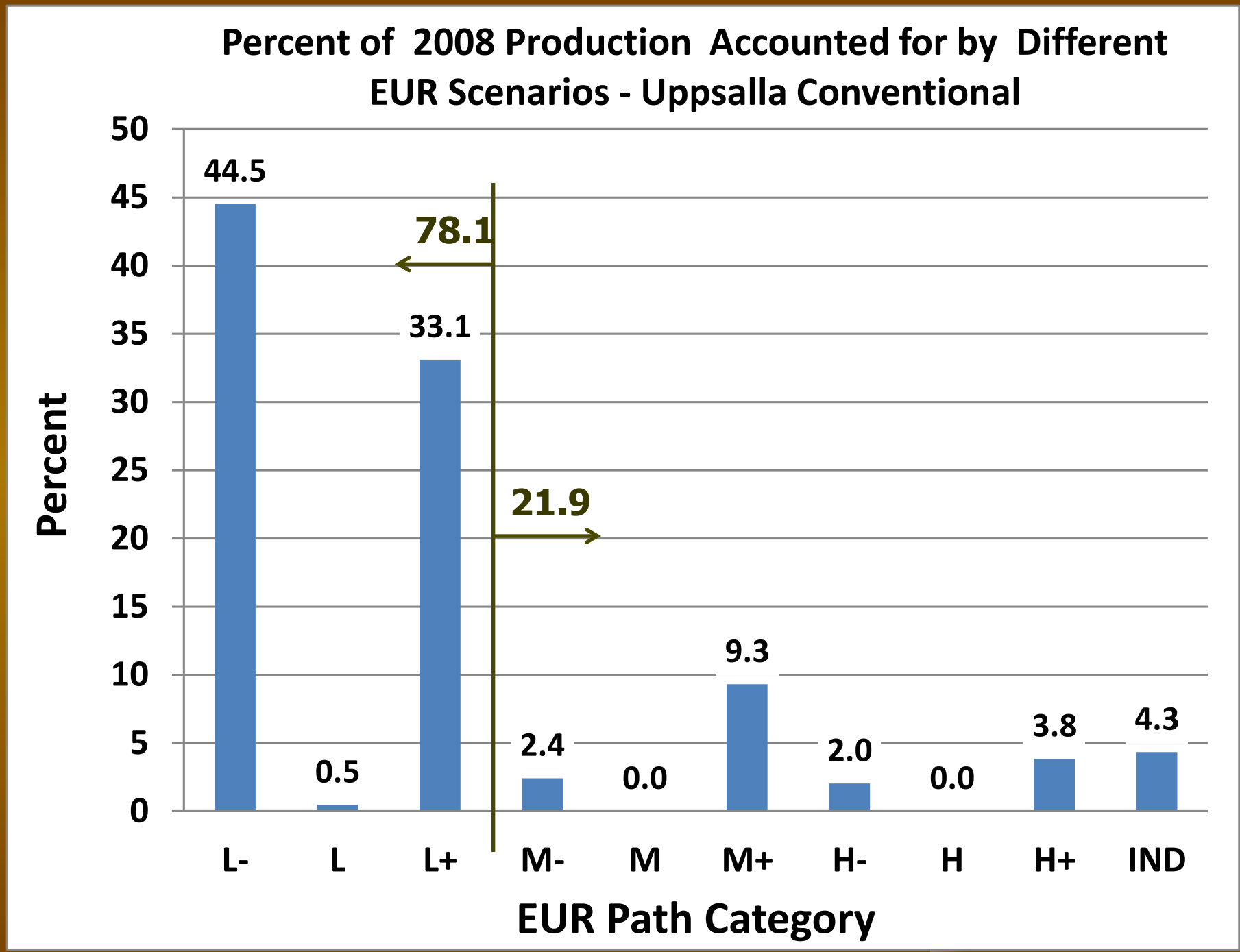
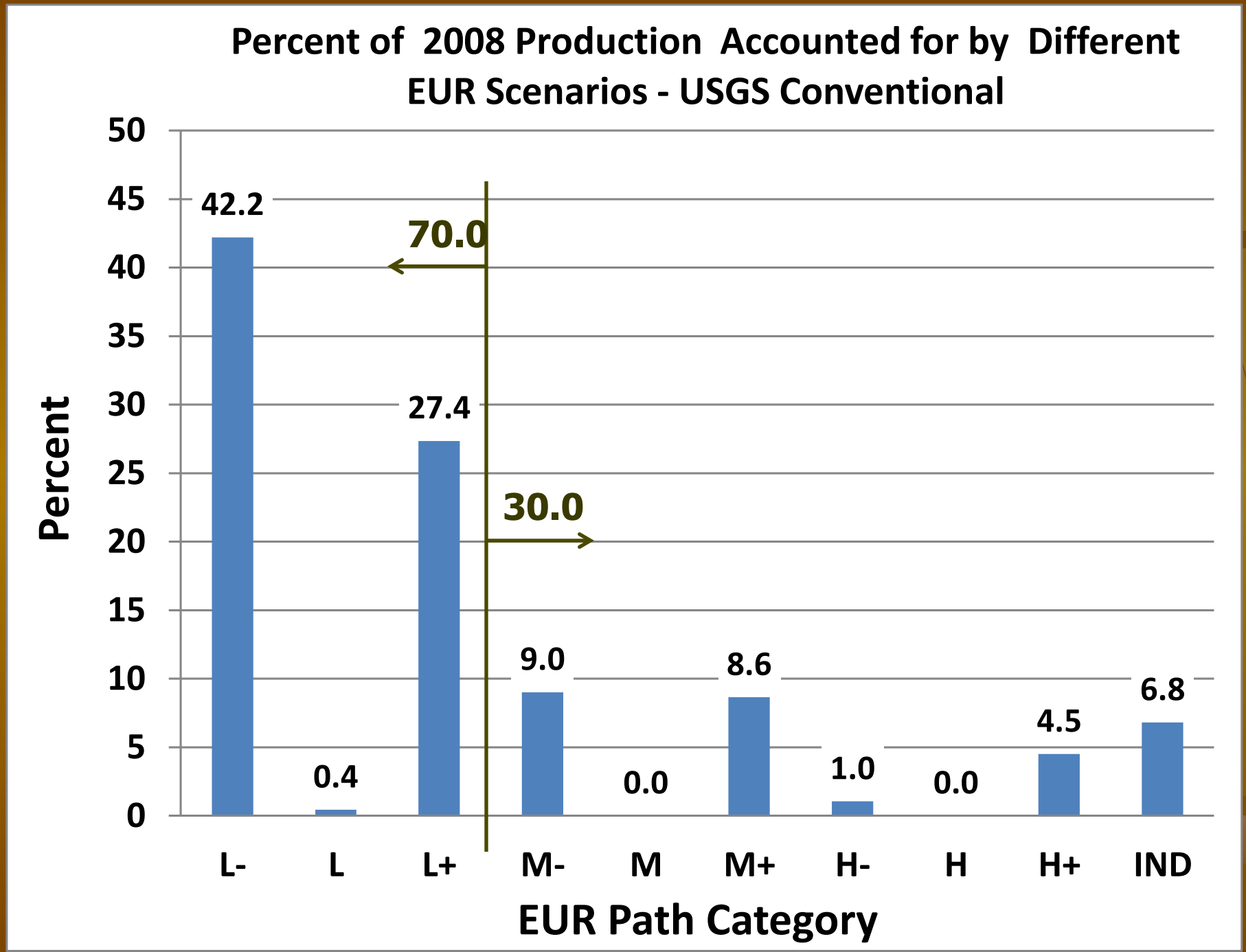
SIMILARITY INDEX BY MODEL SCENARIO – UC CONVENTIONAL

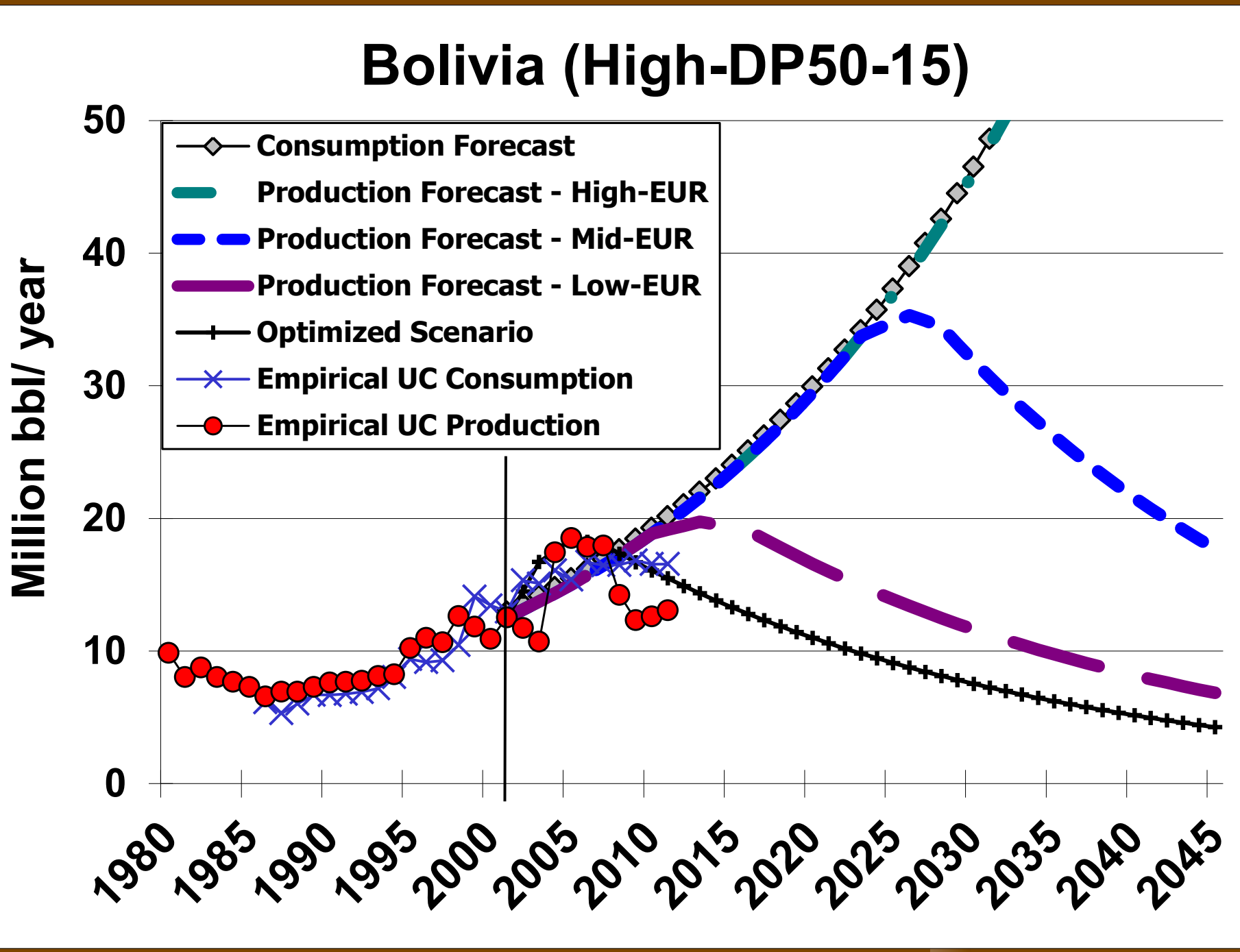
Scenario					Difference between scenario & empirical production data (Gbbl * yr.-1)					
EUR level	Demand growth	% EUR at decline	Max. production growth * yr.$^{-1}$(%)	EUR (TBO)	2002	2004	2006	2008	2010	Similarity Index
Low	Low	50	5	1.9	0.89	-0.28	-0.26	-0.37	0.07	0.6752
Low	High	50	5	1.9	0.90	-0.27	-0.25	-0.36	0.08	0.6754
Mid	Low	50	5	2.9	1.31	0.75	1.11	2.24	3.94	-0.4820
Mid	High	50	5	2.9	1.38	1.53	3.07	4.66	6.61	-0.7137
High	Low	50	5	4	1.46	0.76	1.31	2.13	4.05	-0.5016
High	High	50	5	4	1.55	1.48	2.72	4.93	7.60	-0.7329
Low	Low	50	7.5	1.9	0.99	0.29	0.80	1.16	2.08	-0.0998
Low	High	50	7.5	1.9	1.04	0.39	0.91	1.28	2.20	-0.1715
Mid	Low	50	7.5	2.9	1.34	0.77	1.14	2.25	3.98	-0.4888
Mid	High	50	7.5	2.9	1.46	1.69	2.99	4.78	7.44	-0.7338
High	Low	50	7.5	4	1.49	0.80	1.39	2.15	4.02	-0.5085
High	High	50	7.5	4	1.64	1.58	2.69	5.07	7.75	-0.7382
Low	Low	50	15	1.9	0.99	0.41	1.26	2.15	4.42	-0.4837
Low	High	50	15	1.9	1.06	1.17	3.13	4.70	7.82	-0.7251
Mid	Low	50	15	2.9	1.35	0.80	1.16	2.23	3.97	-0.4899
Mid	High	50	15	2.9	1.49	1.77	3.02	4.76	7.48	-0.7372
High	Low	50	15	4	1.50	0.85	1.45	2.17	3.95	-0.5120
High	High	50	15	4	1.67	1.66	2.79	5.06	7.81	-0.7420

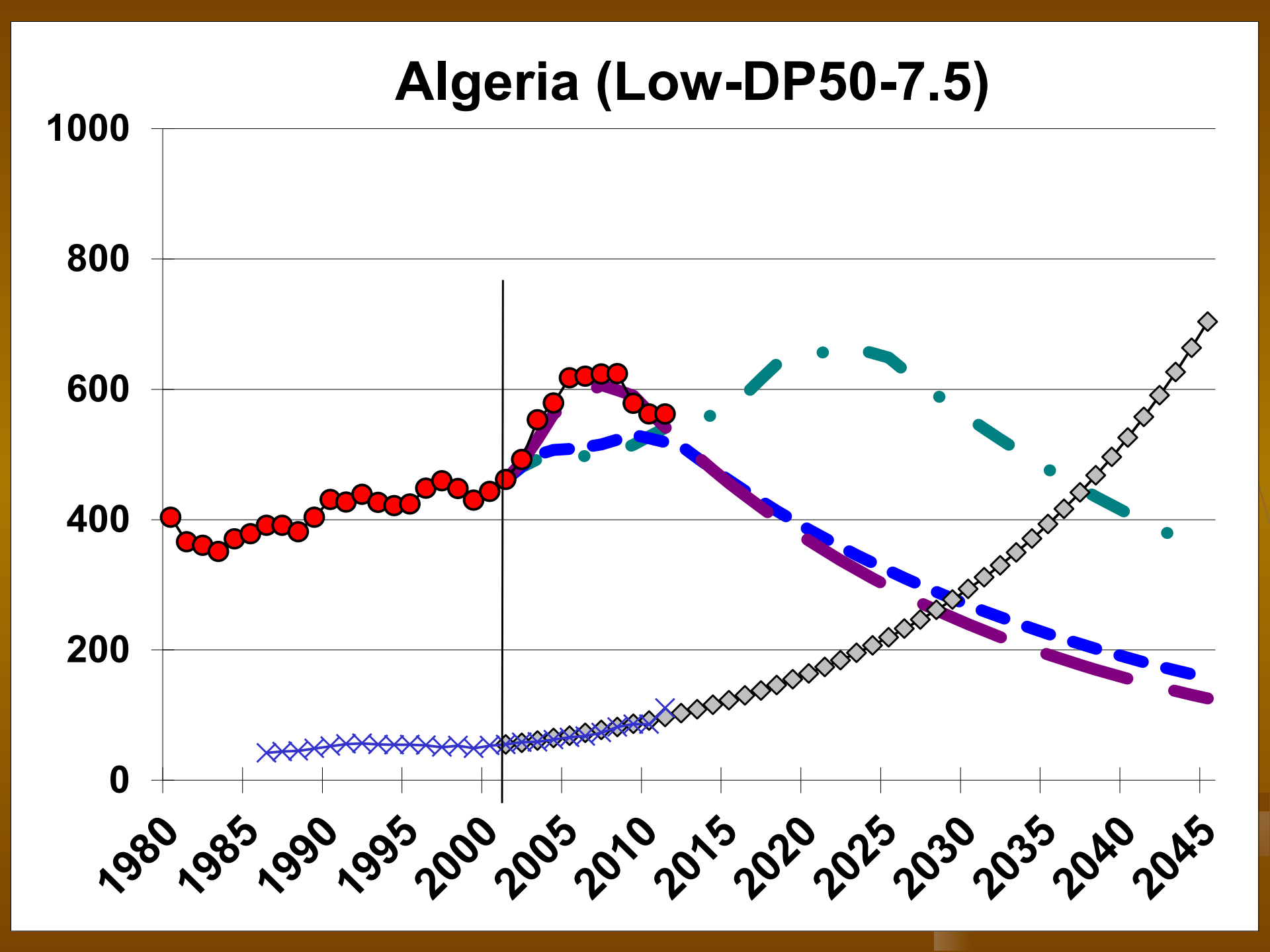
SIMILARITY INDEX BY MODEL SCENARIO – USGS CONVENTIONAL

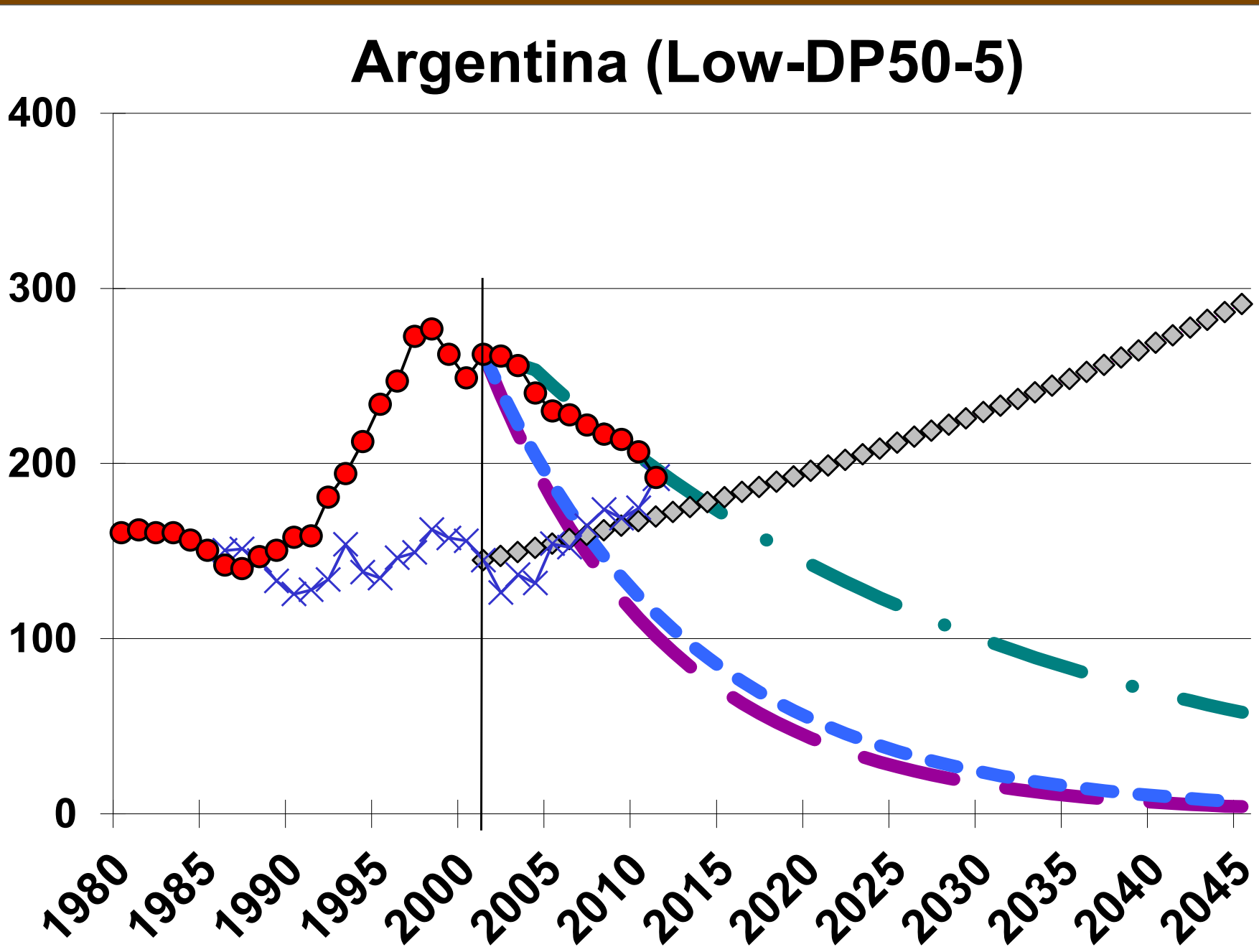
Scenario					Difference between scenario & empirical production data (Gbbl * yr.-1)					
EUR level	Demand growth	% EUR at decline	Max. production growth * yr.$^{-1}$(%)	EUR (TBO)	2002	2004	2006	2008	2010	Similarity Index
Low	Low	50	5	1.9	0.57	-0.97	-1.49	-2.07	-2.34	-0.1561
Low	High	50	5	1.9	0.58	-0.96	-1.48	-2.06	-2.33	-0.1530
Mid	Low	50	5	2.9	1.08	0.43	0.38	1.18	2.27	-0.0258
Mid	High	50	5	2.9	1.16	1.17	2.47	3.71	5.00	-0.5959
High	Low	50	5	4	1.27	0.43	0.59	1.04	2.43	-0.0933
High	High	50	5	4	1.37	1.20	2.04	3.94	6.14	-0.6339
Low	Low	50	7.5	1.9	0.72	-0.31	-0.33	-0.42	-0.22	0.7202
Low	High	50	7.5	1.9	0.77	-0.25	-0.28	-0.37	-0.16	0.7301
Mid	Low	50	7.5	2.9	1.10	0.45	0.40	1.20	2.33	-0.0497
Mid	High	50	7.5	2.9	1.24	1.42	2.38	3.72	5.80	-0.6301
High	Low	50	7.5	4	1.29	0.47	0.65	1.06	2.40	-0.1092
High	High	50	7.5	4	1.46	1.30	2.03	4.07	6.30	-0.6436
Low	Low	60	5	1.9	0.84	0.24	0.33	0.39	0.41	0.5887
Low	High	60	5	1.9	1.02	0.61	1.36	1.54	1.44	-0.0538
Mid	Low	60	5	2.9	1.24	0.42	0.58	1.18	2.29	-0.0767
Mid	High	60	5	2.9	1.36	1.29	2.29	4.01	5.78	-0.6317
High	Low	60	5	4	1.34	0.63	0.95	1.33	2.11	-0.1601
High	High	60	5	4	1.47	1.37	2.17	4.03	6.22	-0.6449


Percent of 2008 Production Accounted for by Different EUR Scenarios - Uppsalla Conventional
Percent
50
45
40
35
30
25
20
15
10
5
0
44.5
0.5
33.1
2.4
0.0
9.3
2.0
0.0
3.8
4.3
78.1
21.9
L-
L
L+
M-
M
M+
H-
H
H+
IND
EUR Path Category


Percent of 2008 Production Accounted for by Different EUR Scenarios - USGS Conventional
Percent
50
45
40
35
30
25
20
15
10
5
0
42.2
0.4
27.4
9.0
0.0
8.6
1.0
0.0
4.5
6.8
70.0
30.0
L-
L
L+
M-
M
M+
H-
H
H+
IND
EUR Path Category


Bolivia (High-DP50-15)
Million bbl/ year
50
40
30
20
10
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
Consumption Forecast
Production Forecast - High-EUR
Production Forecast - Mid-EUR
Production Forecast - Low-EUR
Optimized Scenario
Empirical UC Consumption
Empirical UC Production


Algeria (Low-DP50-7.5)
1000
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045


Argentina (Low-DP50-5)
400
300
200
100
0
1980
1985
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2035
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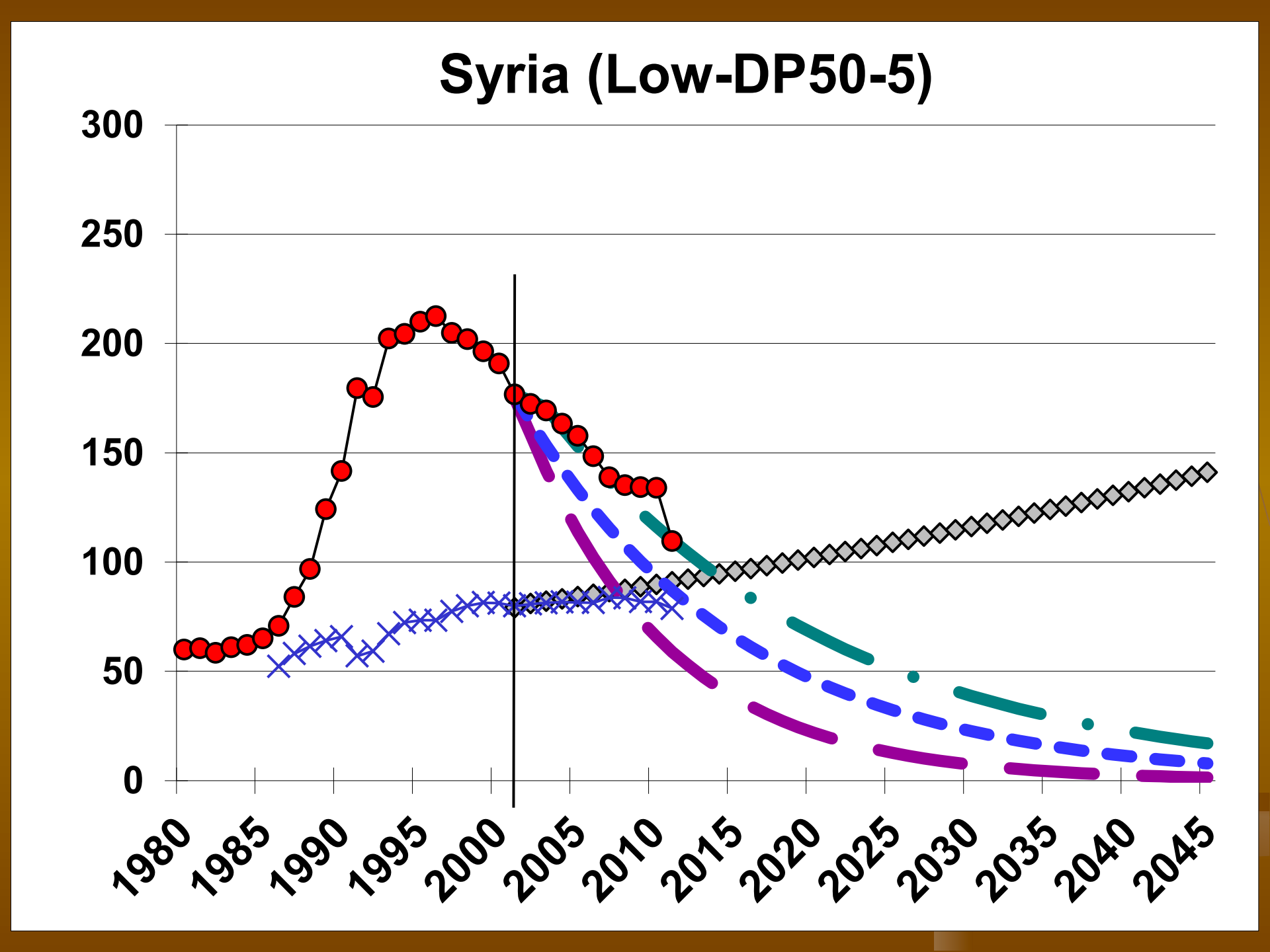
2045


Syria (Low-DP50-5)
300
250
200
150
100
50
0
1980
1985
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1995
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2020
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2030
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2040
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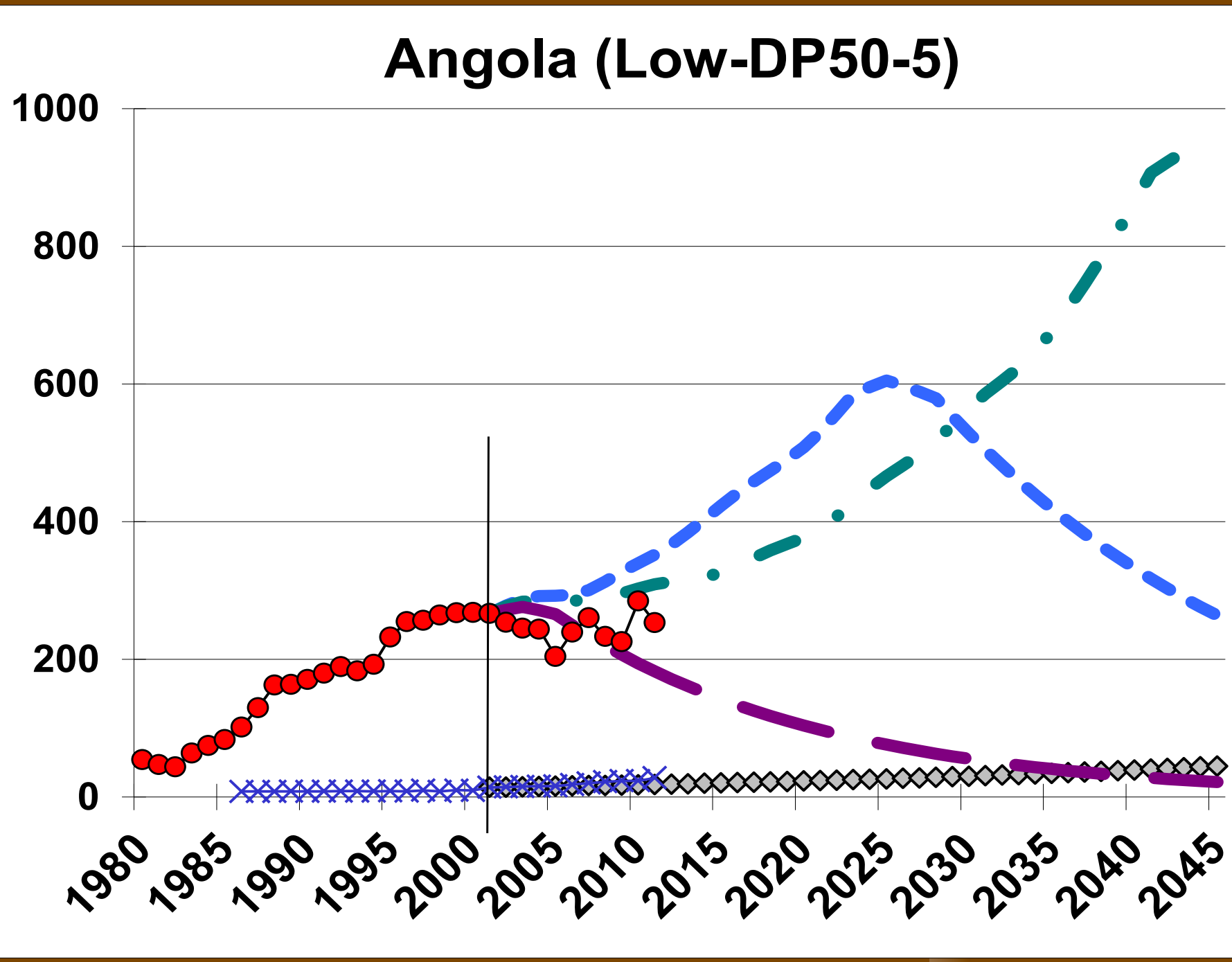
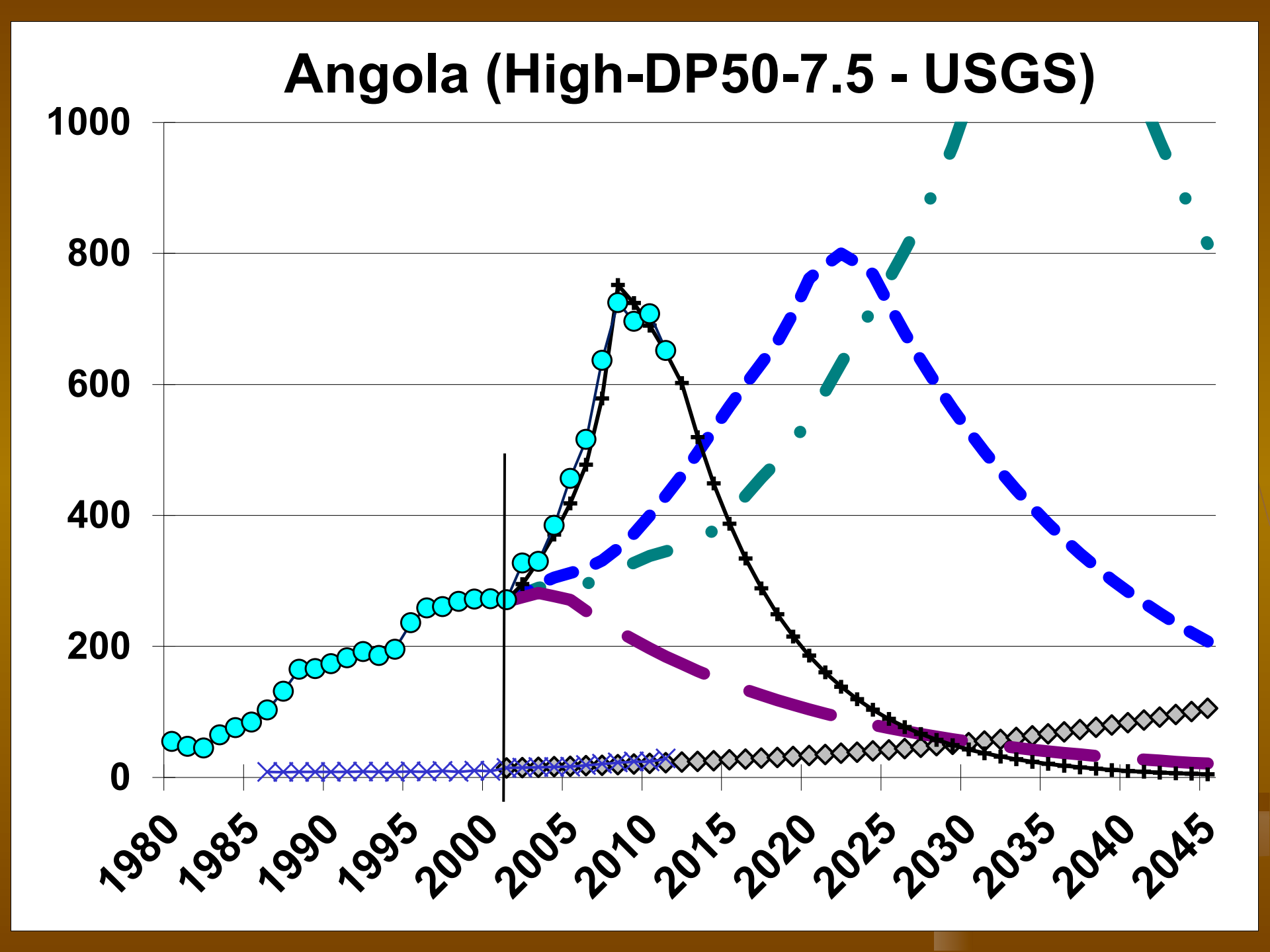
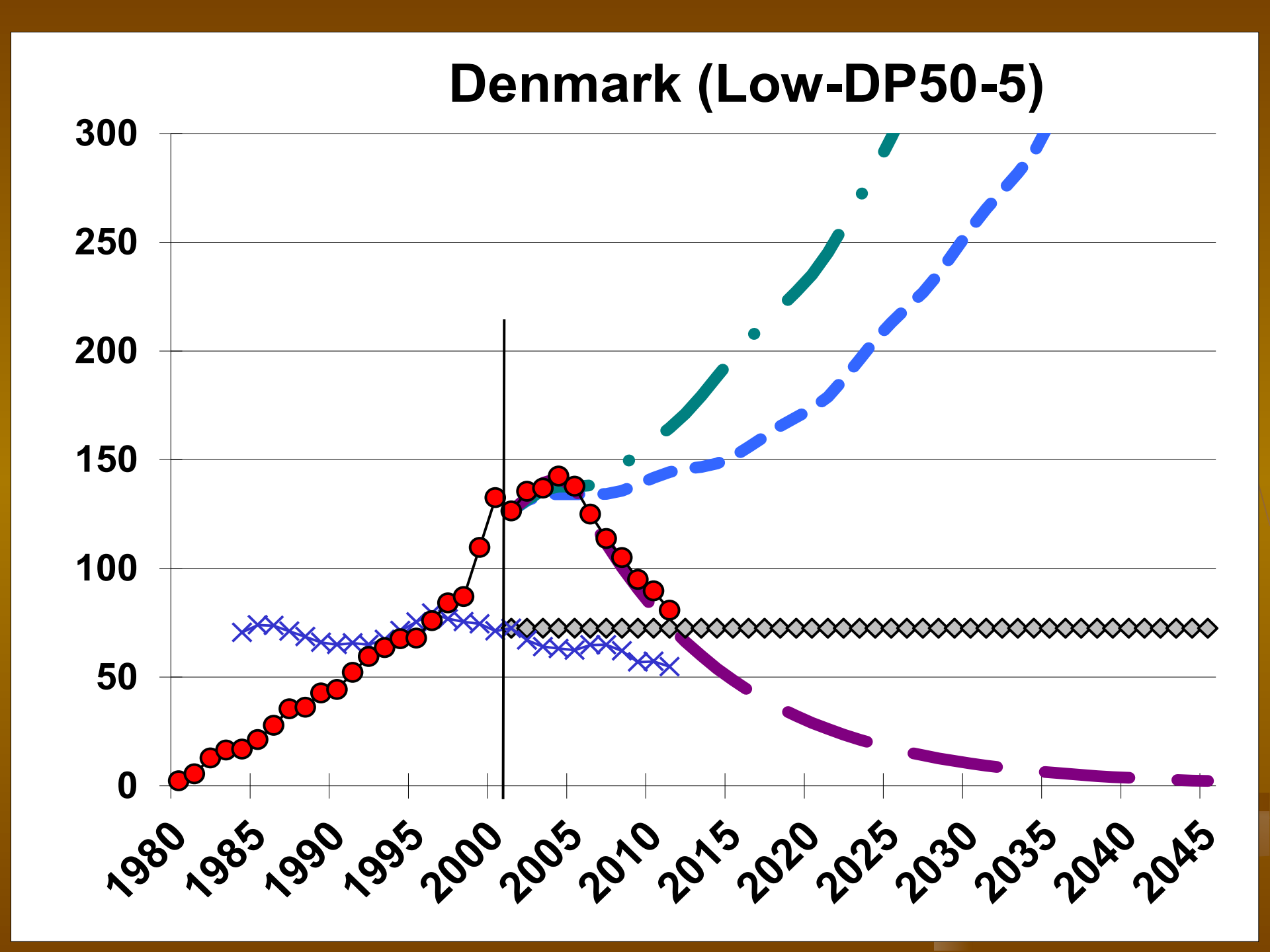
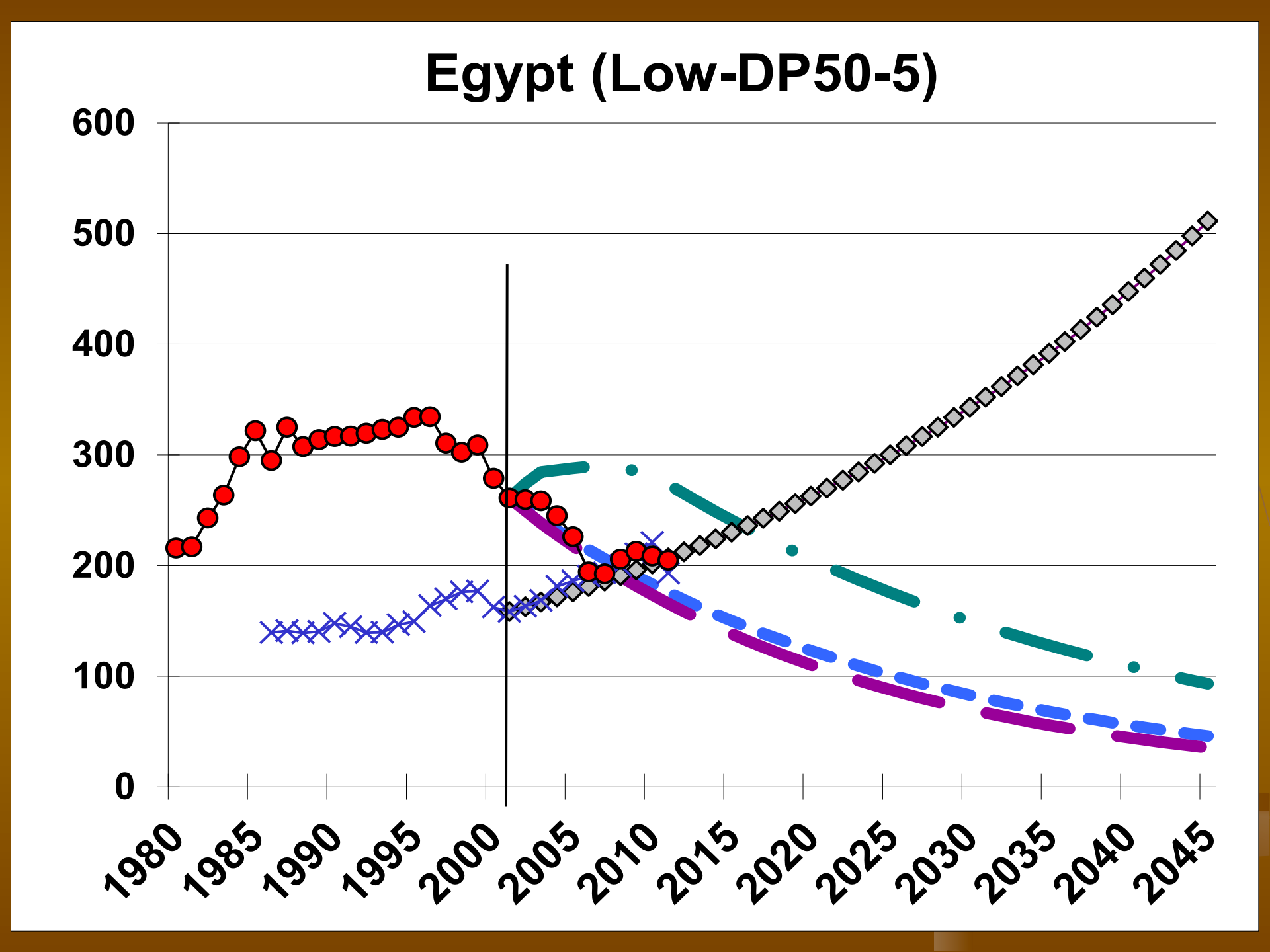
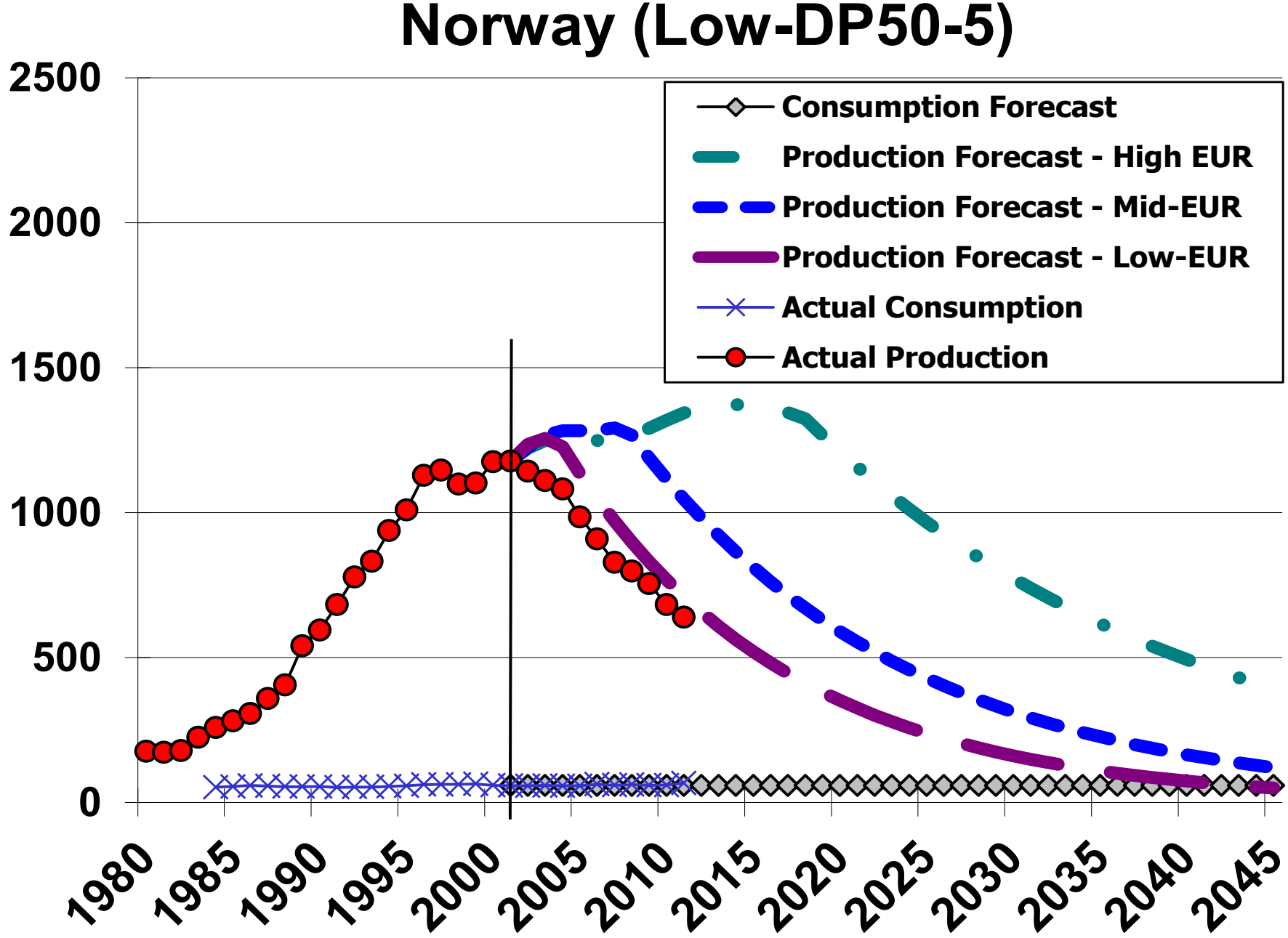
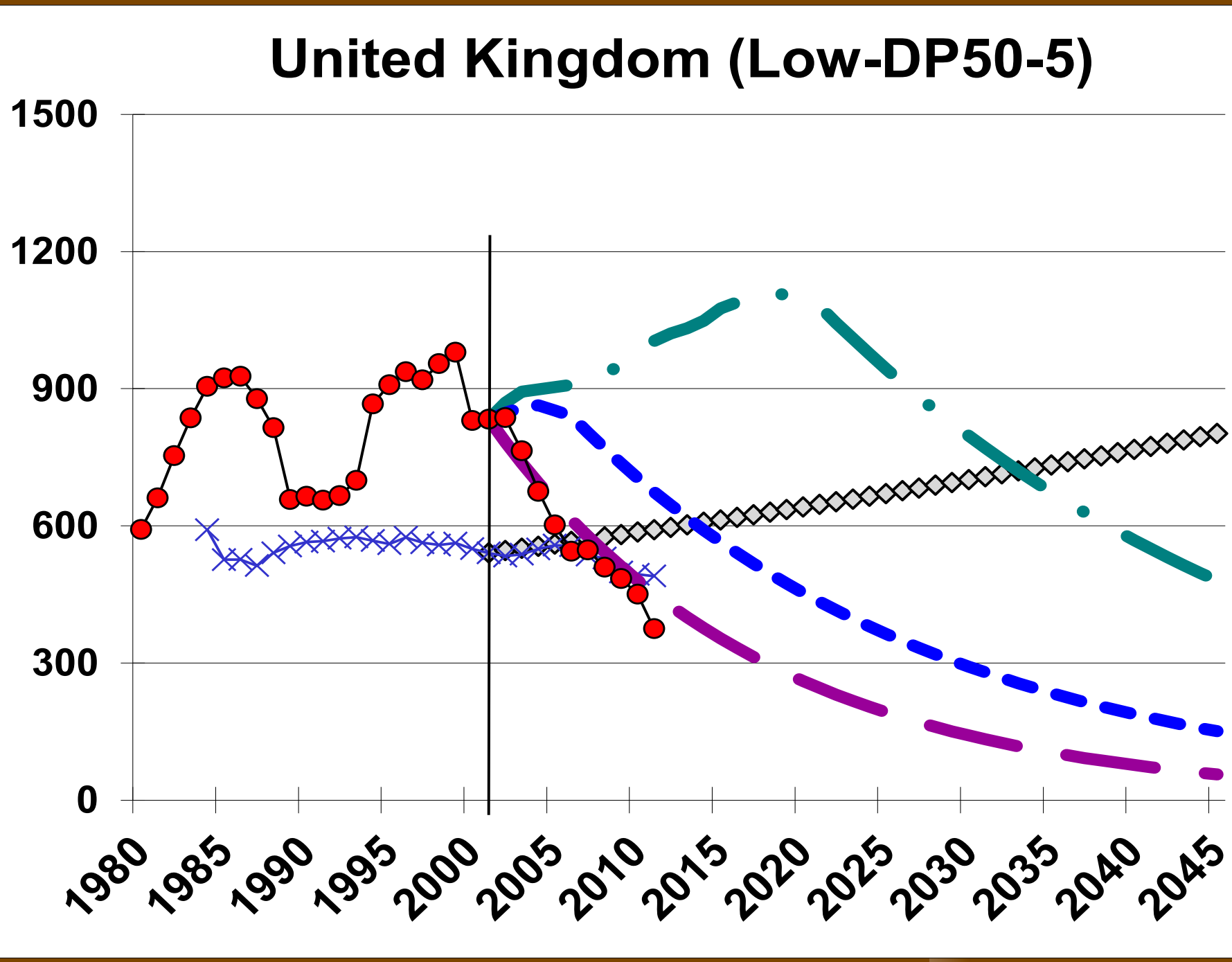

Angola (Low-DP50-5)
1000
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045

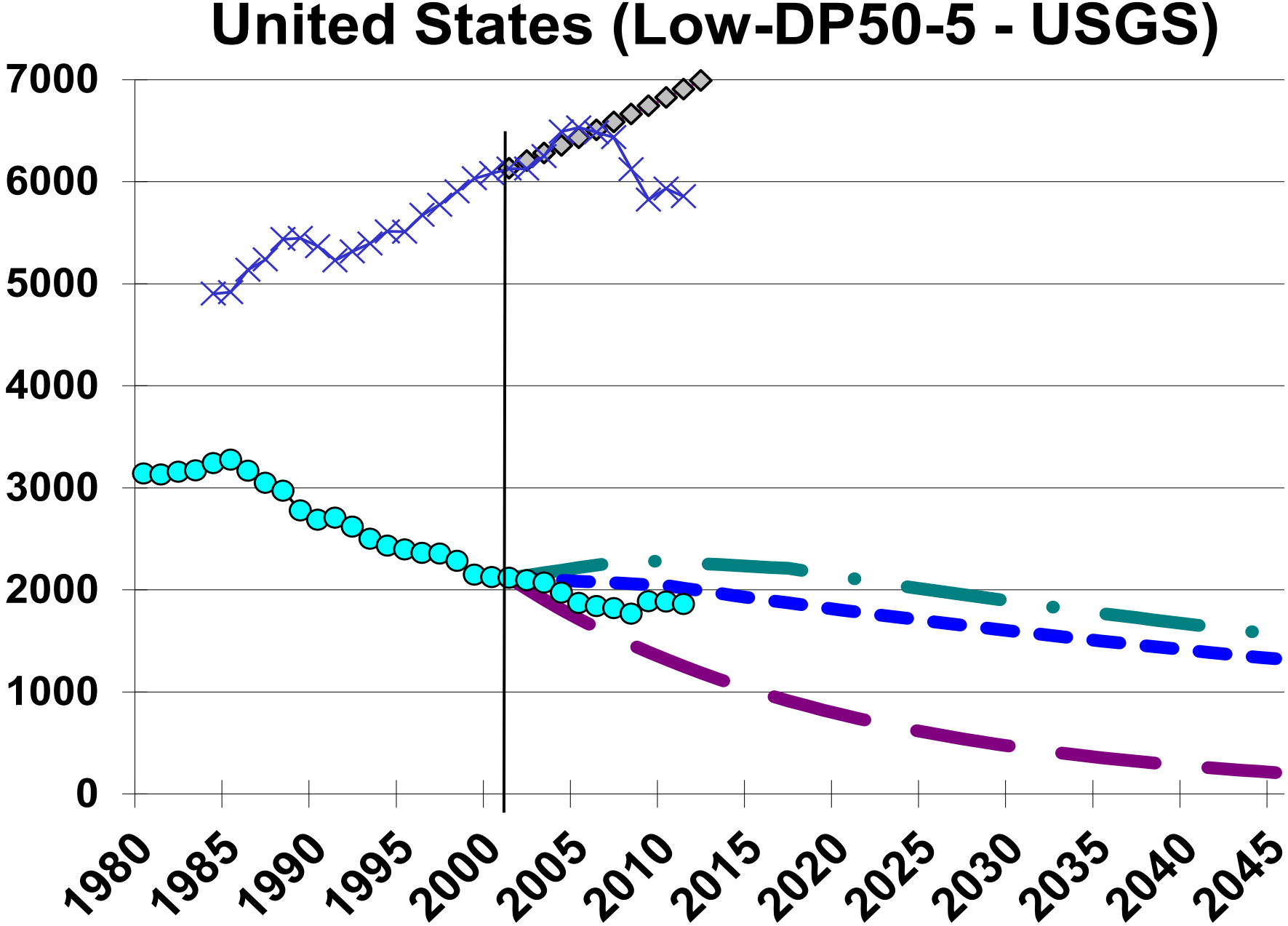

Angola (High-DP50-7.5 - USGS)
1000
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045

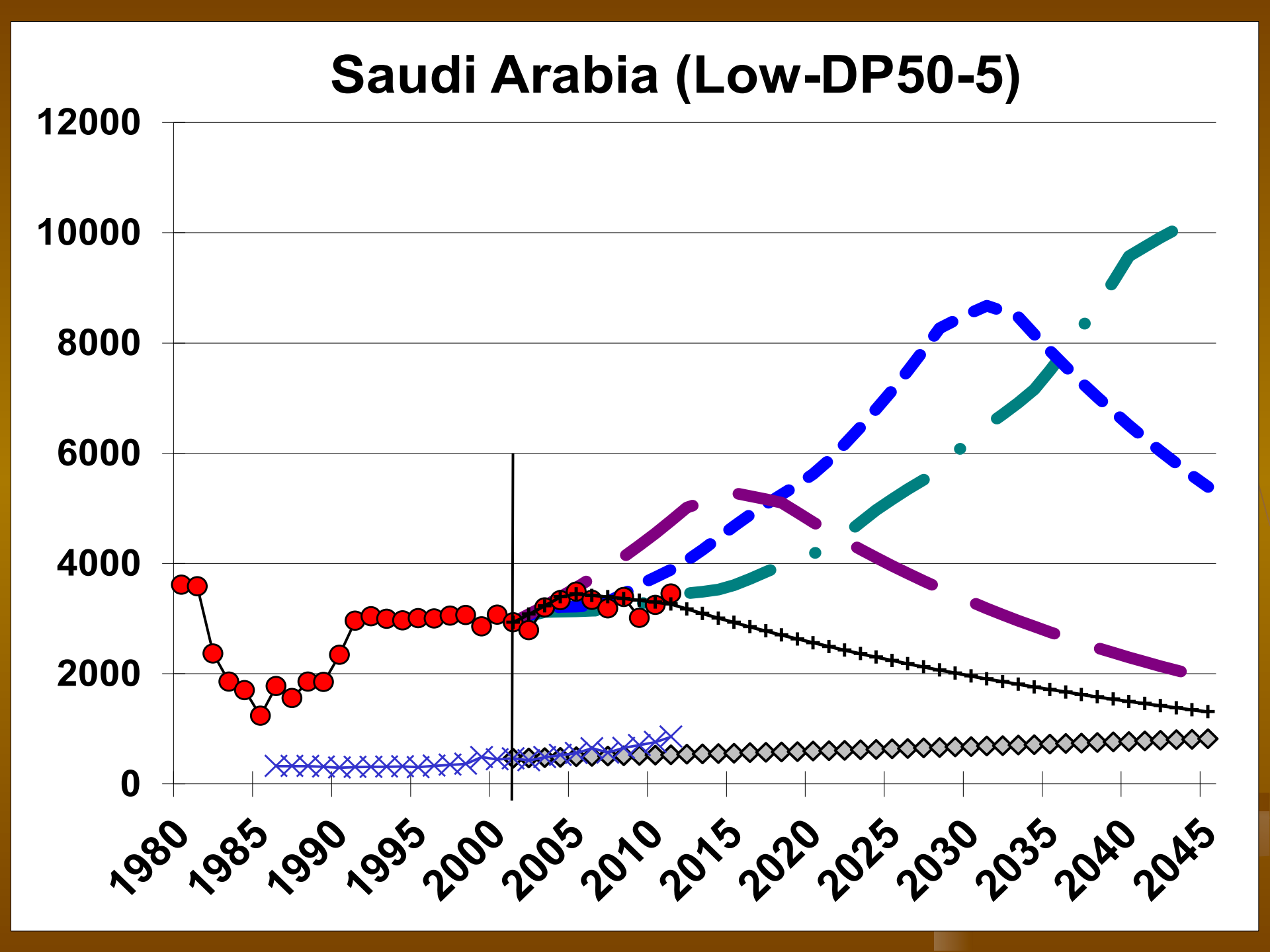

Denmark (Low-DP50-5)
300
250
200
150
100
50
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045

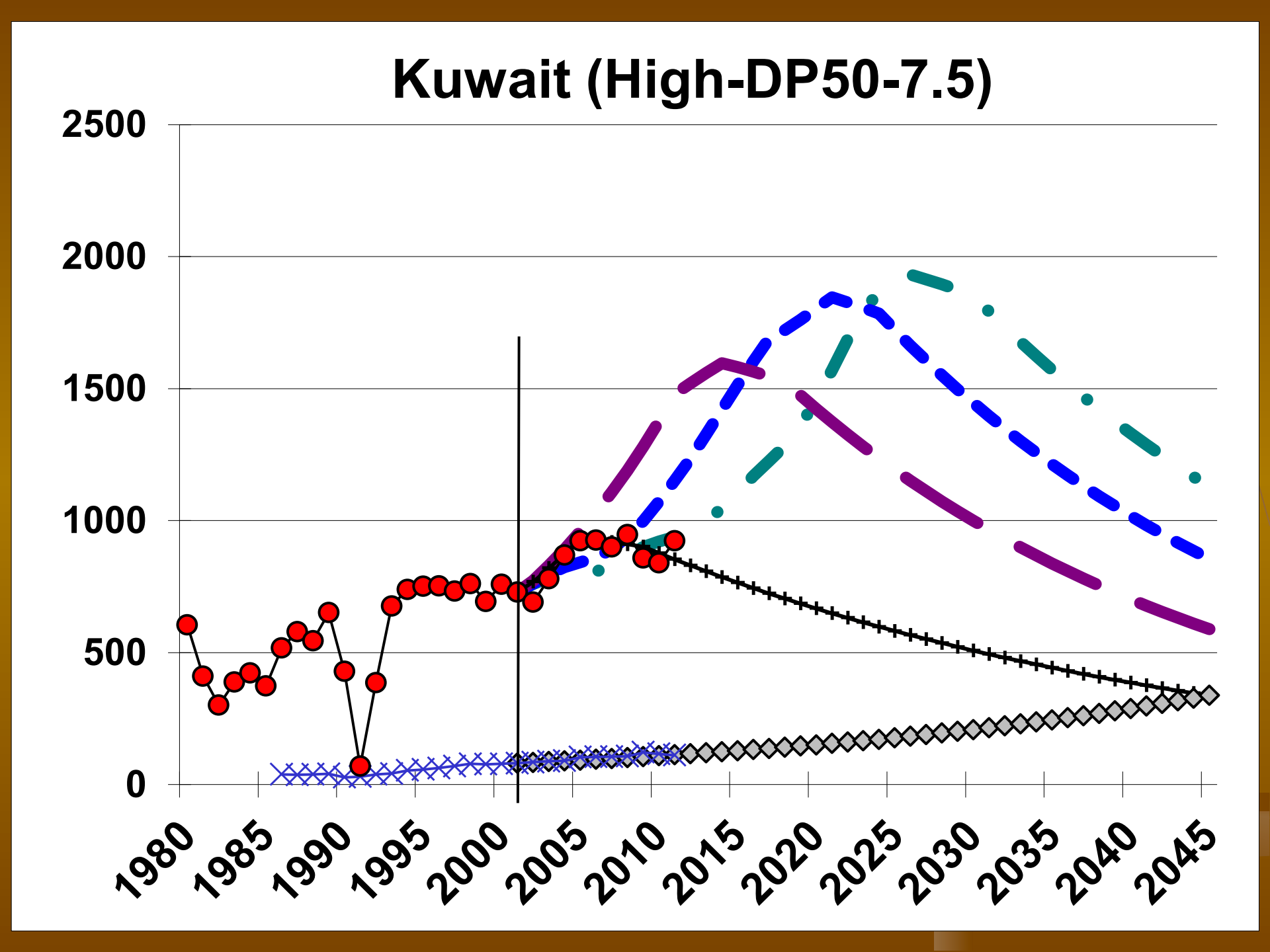

Egypt (Low-DP50-5)
600
500
400
300
200
100
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045


Norway (Low-DP50-5)
2500
2000
1500
1000
500
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
Consumption Forecast
Production Forecast - High EUR
Production Forecast - Mid-EUR
Production Forecast - Low-EUR
Actual Consumption
Actual Production

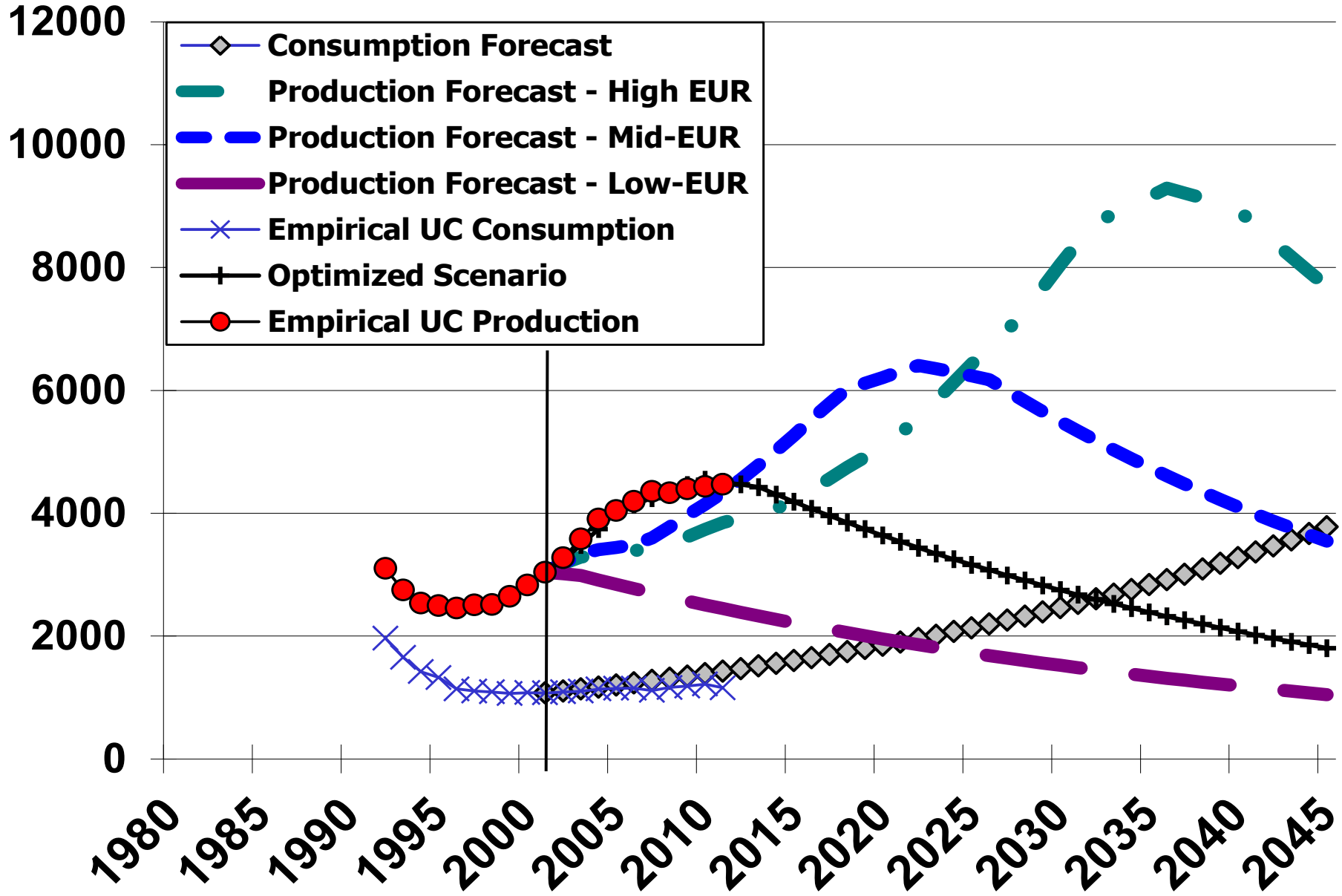

United Kingdom (Low-DP50-5)
1500
1200
900
600
300
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045

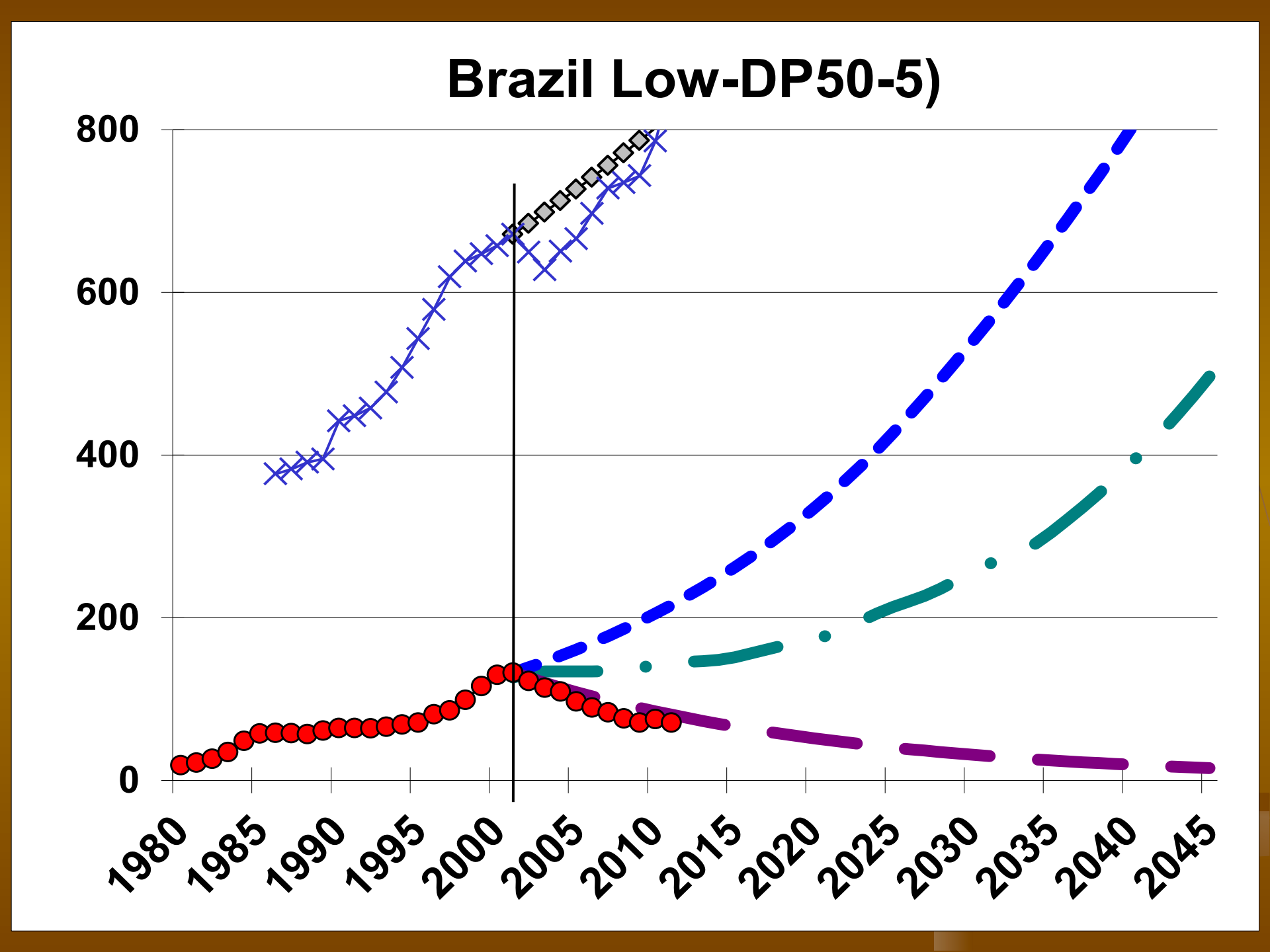

United States (Low-DP50-5 - USGS)
7000
6000
5000
4000
3000
2000
1000
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045

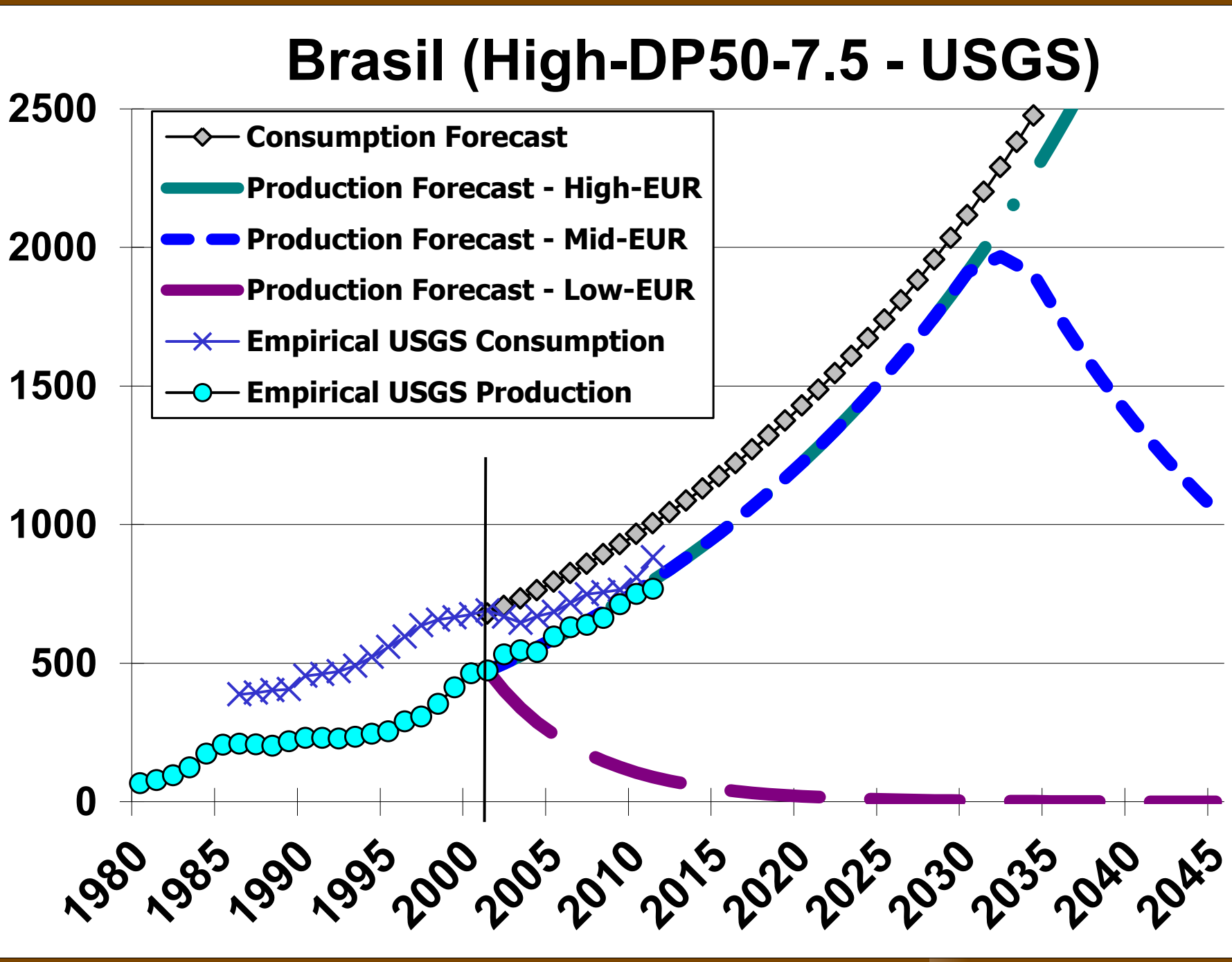

Saudi Arabia (Low-DP50-5)
12000
10000
8000
6000
4000
2000
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045

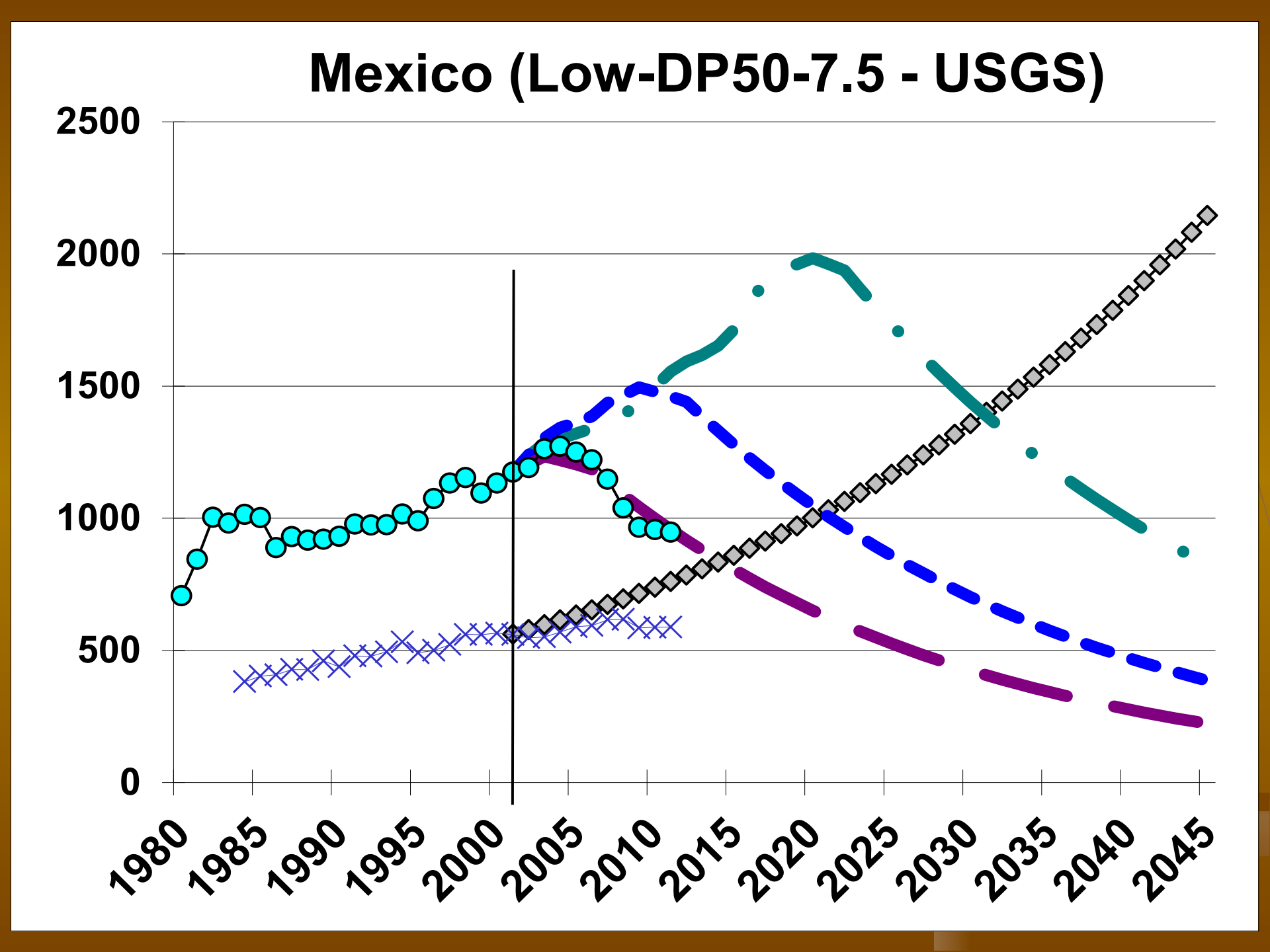

Kuwait (High-DP50-7.5)
2500
2000
1500
1000
500
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045

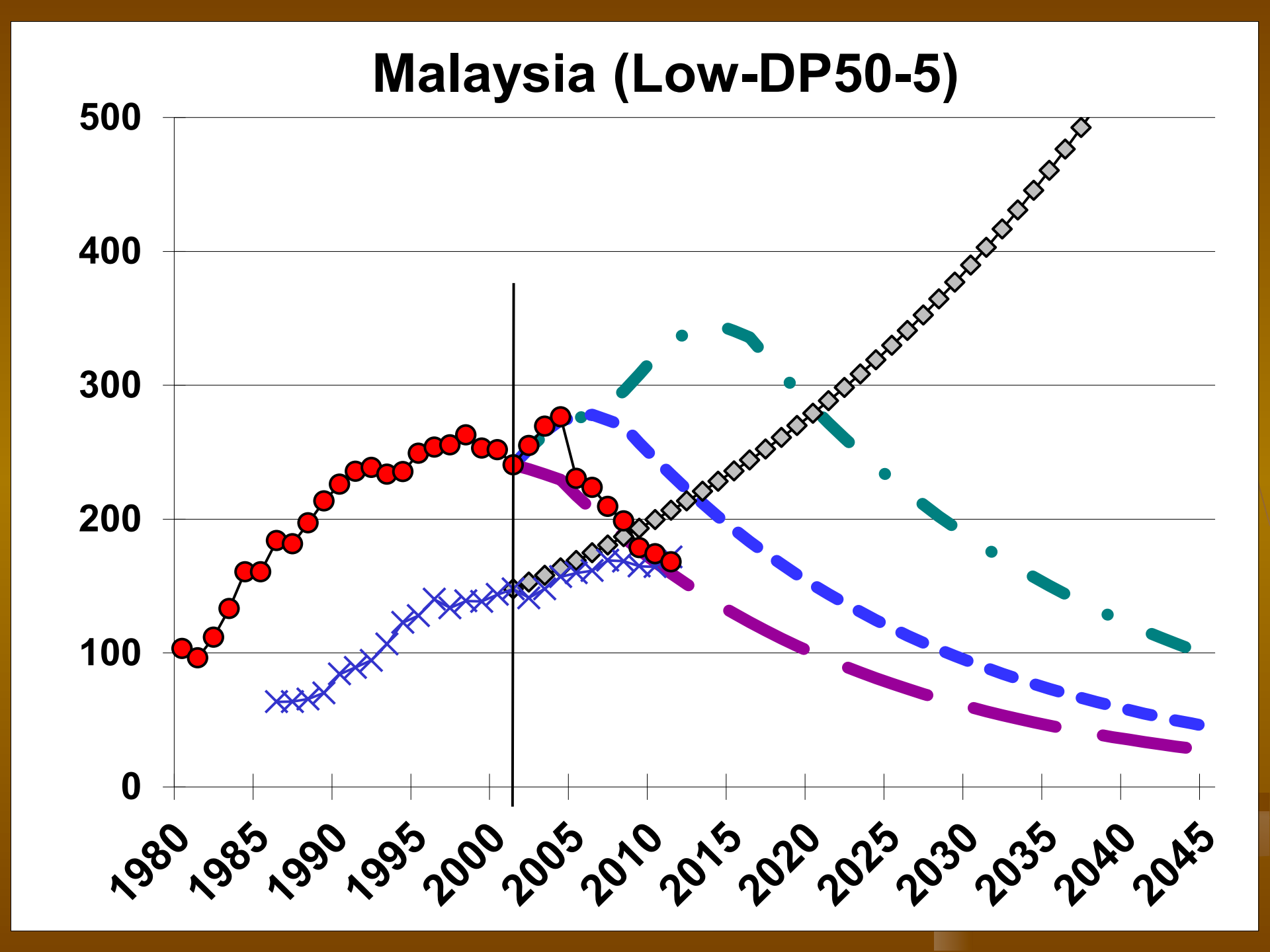
Russia/FSU (Low- DP50-5)

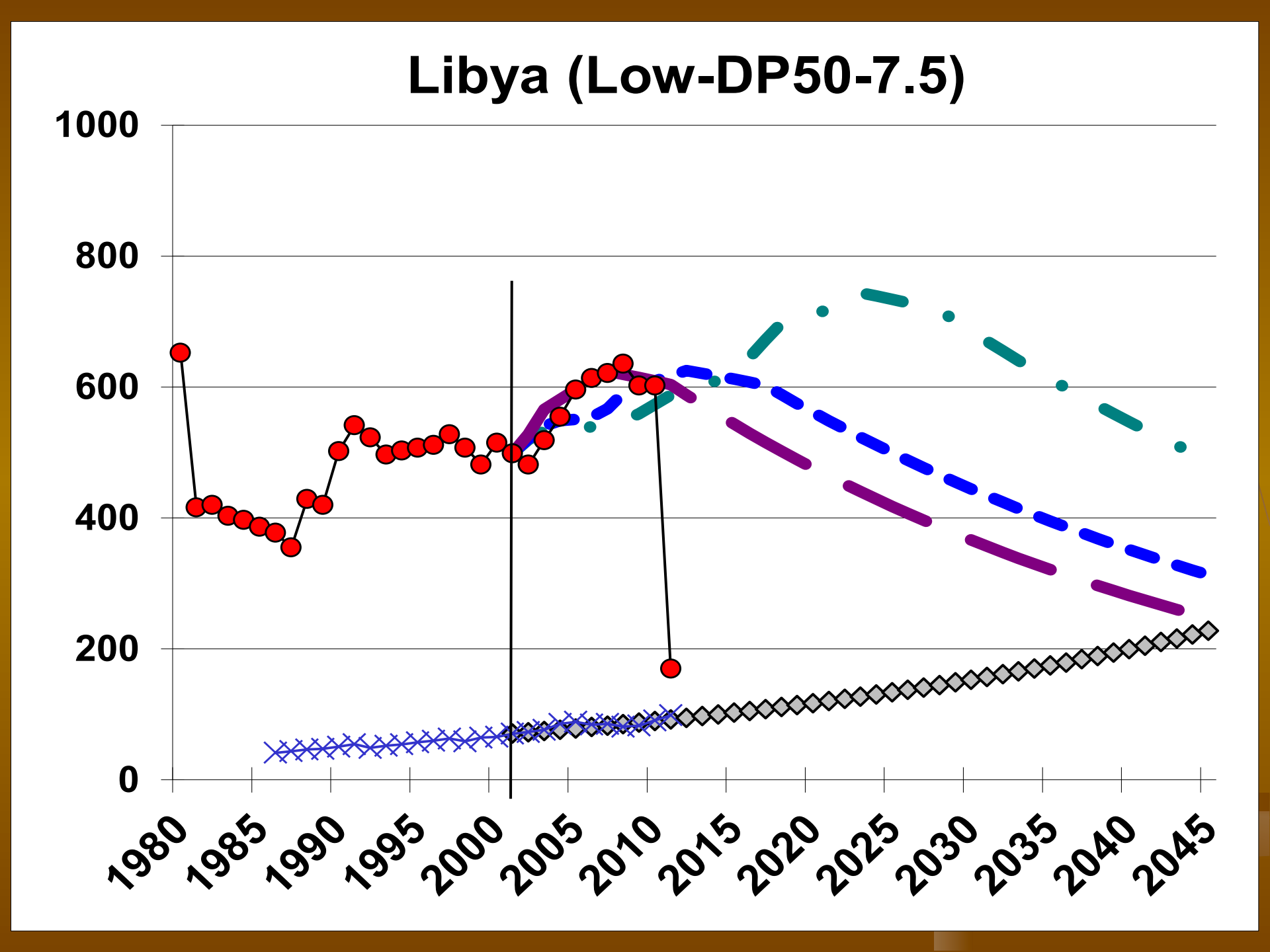



Brazil Low-DP50-5)
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045


Brasil (High-DP50-7.5 - USGS)
Consumption Forecast
Production Forecast - High-EUR
Production Forecast - Mid-EUR
Production Forecast - Low-EUR
Empirical USGS Consumption
Empirical USGS Production
2500
2000
1500
1000
500
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045


Mexico (Low-DP50-7.5 - USGS)
2500
2000
1500
1000
500
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045


Malaysia (Low-DP50-5)
500
400
300
200
100
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045

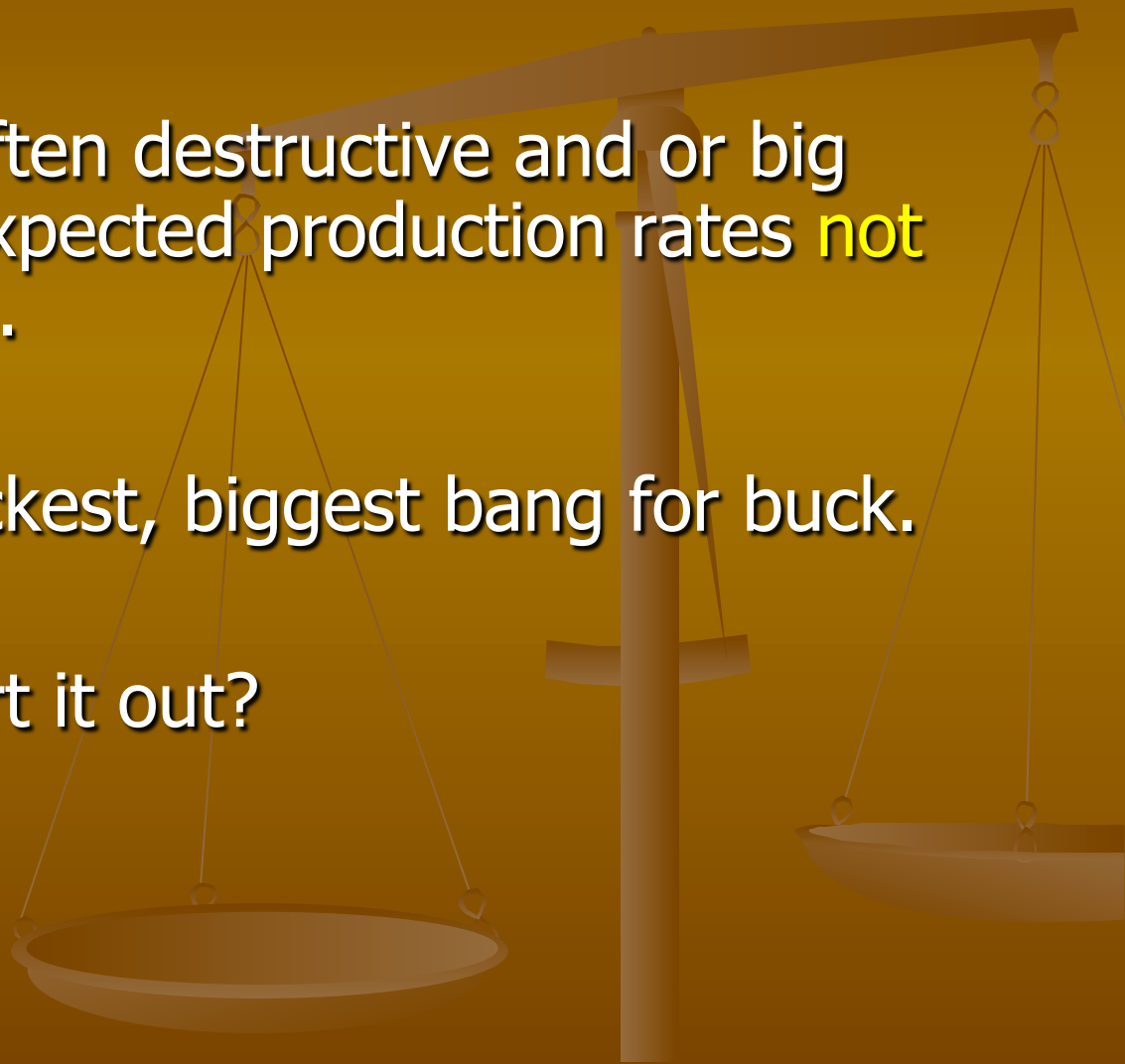

Libya (Low-DP50-7.5)
1000
800
600
400
200
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045

Summary of Empirical Comparison

- Low EUR scenarios only ones consistent with Empirical data at global level
- USGS medium and high estimates of conventional oil EUR look practically implausible now.
- Models performed well when right input used
- UC Conventional oil – the cheapest stuff – appears to have peaked in 2005.
- USGS Conventional on track to decline within a few years if close match to scenario continues.
- Only addition of lower EROI oils has enabled TPL.
- New conventional production will occur – but…
- Plans and policies based on continuing to increase conventional oil production contain a high degree of risk.

Mitigation Possibilities

- Non-conventional oil will and is offsetting some decline of conventional oil.
- But – Expensive, often destructive and or big increase in GHG, expected production rates not necessarily enough.
- Conservation - quickest, biggest bang for buck.
- Let the Markets sort it out?



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CERA's Record of Oil Price Forecasts