The Future of Oil - Geology versus Technology

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Authors

Jaromir Benes, International Monetary Fund
Marcelle Chauvet, UC Riverside
Ondra Kamenik, Consultant
Michael Kumhof, International Monetary Fund
Douglas Laxton, International Monetary Fund
Susanna Mursula, International Monetary Fund
Jack Selody, Consultant

Disclaimer

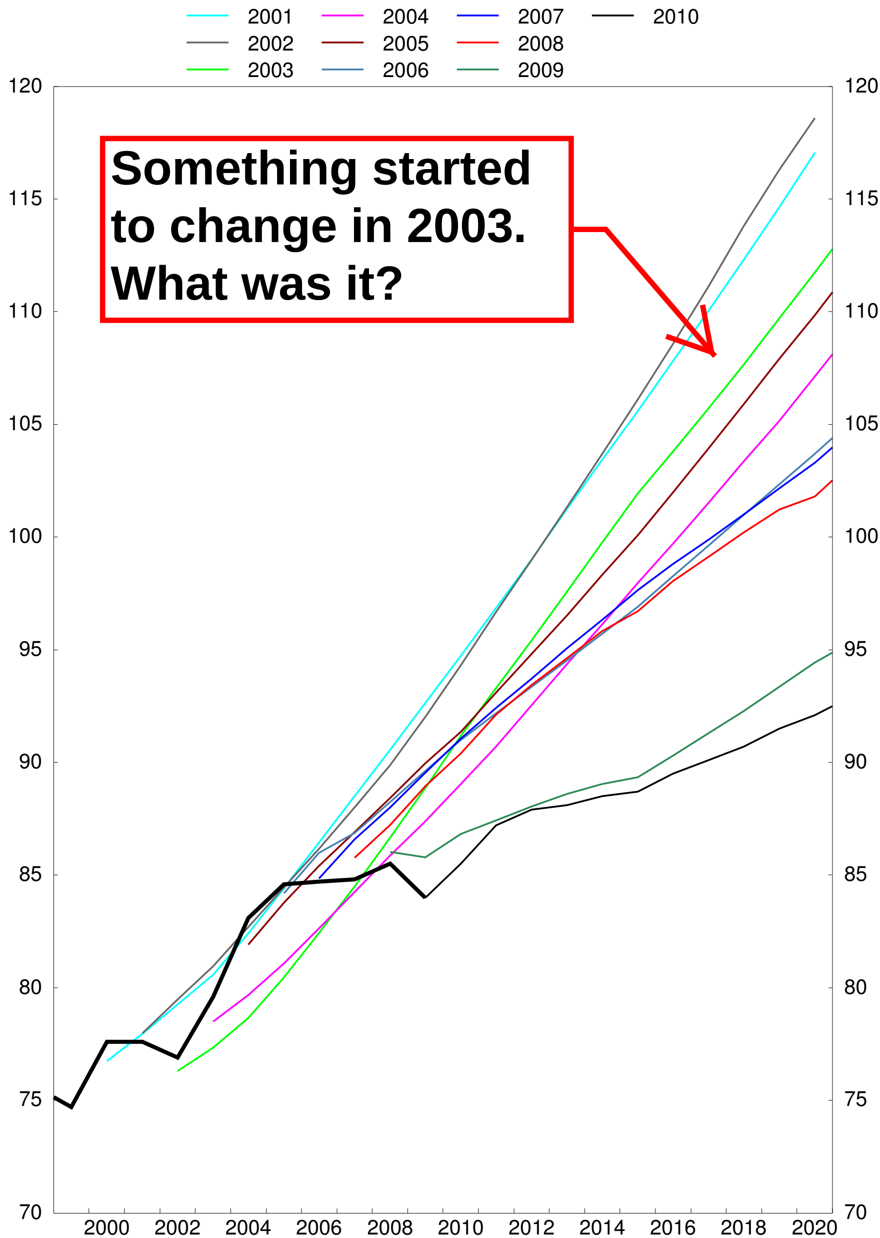
1 Introduction: Models of Oil

- **Demand-Side Approach - Conventional Economic Models**:
  - Models, surveys, futures cannot consistently beat a random-walk.
  - Econometric models pay very little attention to supply.
  - Problem: Cannot predict upward trend in oil price (models are mean-reverting).
- **Supply-Side Approach - Models with Hard Geological Limits:**
  - Oil supply constraints play a key role for oil production.
  - But in the pure geological model there is no role for oil prices.
  - This is not consistent with recent data.
- **Combined Approach - Model in this Paper:**
  - Geological limits are key for the upward trend in oil prices.
  - But demand shocks, through higher prices, can increase production.
  - Uncertainty about shocks and key parameters can be directly evaluated.
  - Model performs extremely well.

2 Historical Forecasts of World Oil Production

EIA Forecasts 2001-2010

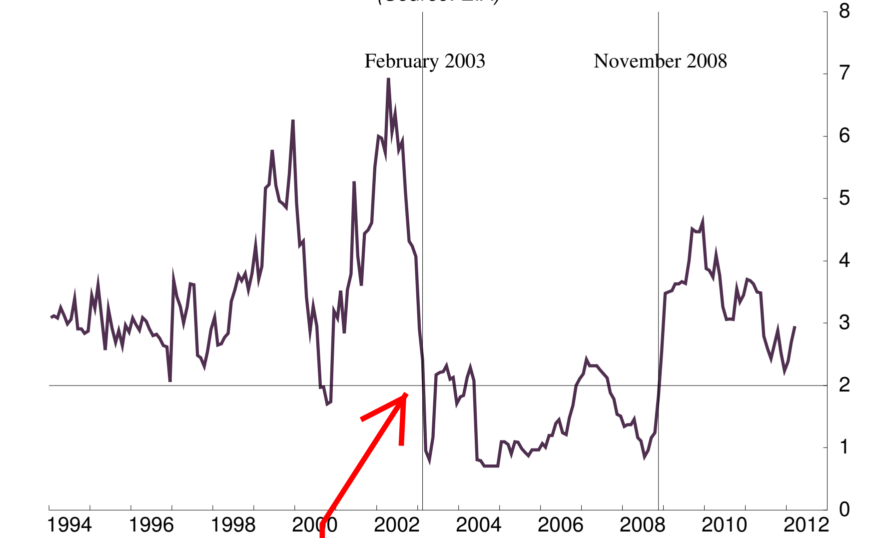
(EIA Definition of World Total Oil Supply, in Mbd)



World Real Oil Prices and Spare Capacity

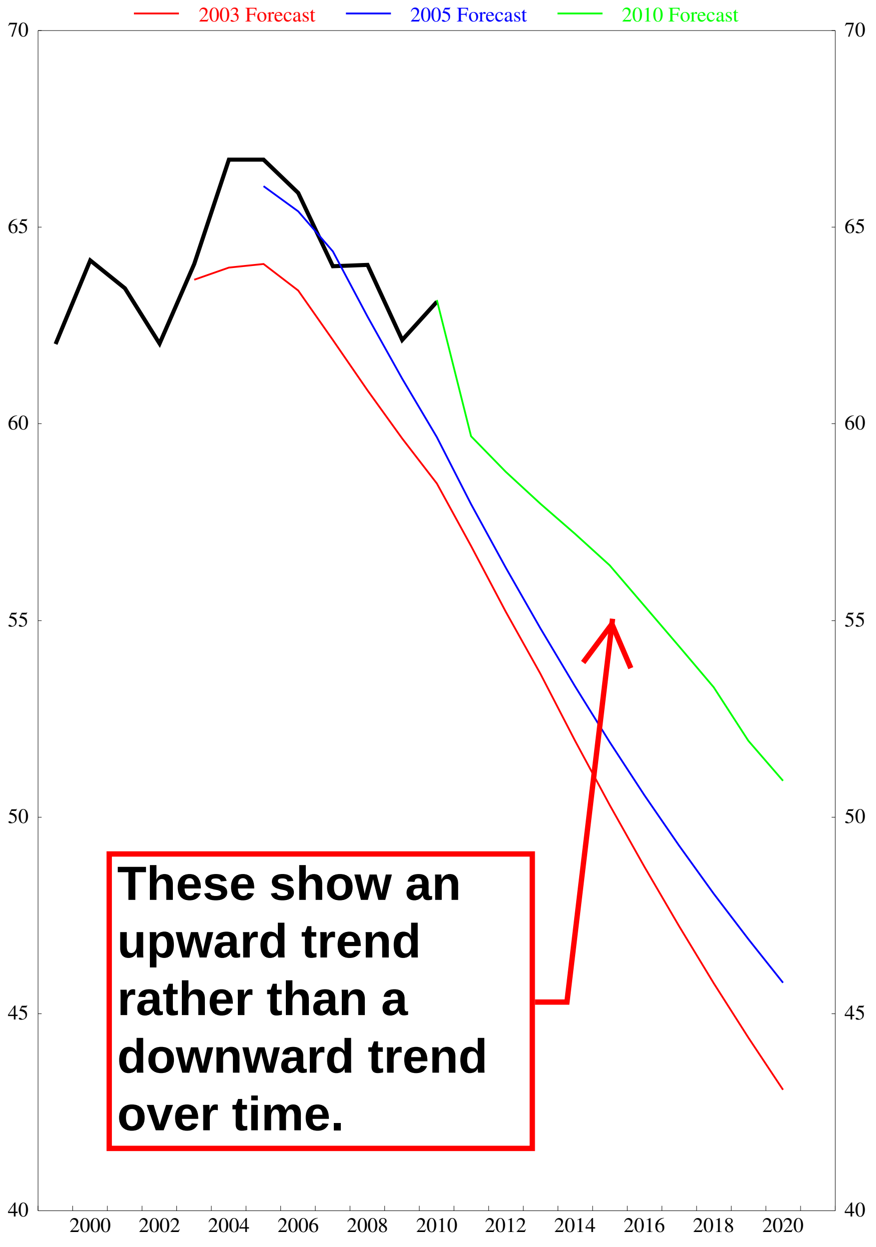
Oil Price (Average of UK Brent, Dubai, and West Texas)
(In U.S. dollars per barrel divided by U.S. CPI; 2011 CPI=1)

OPEC Spare Capacity (In millions of barrels per day)
(Source: EIA)



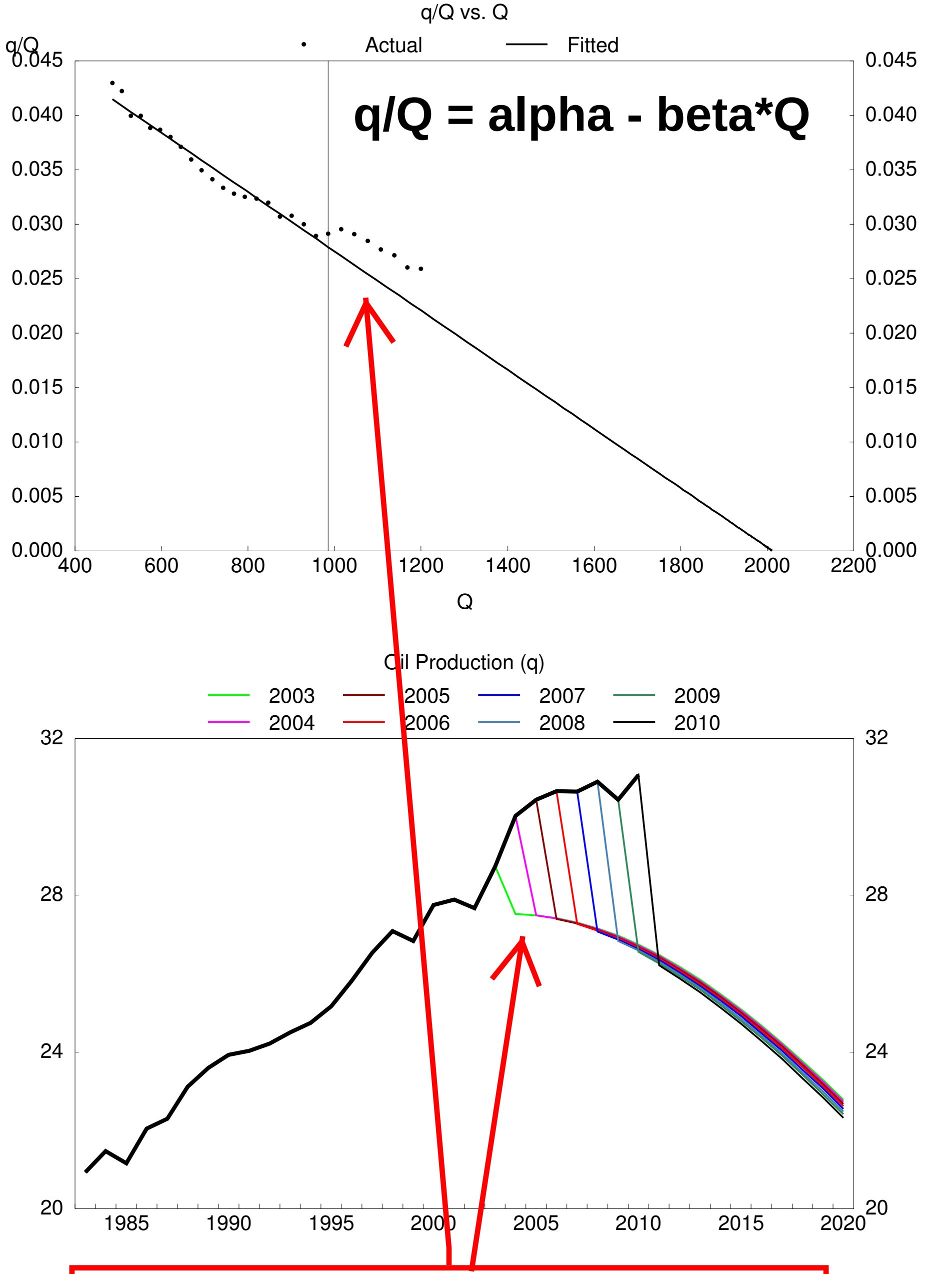
Answer: Drop in spare capacity triggered much higher prices.

Colin Campbell Forecasts 2003-2010
(Campbell Definition of Regular Conventional Oil, in Mbd)



Oil Production Forecasts in the Deffeyes (2005) Model

(Q in gigabarrels, q in gigabarrels per annum)



Sizeable positive deviations from the Hubbert line begin to appear after 2003.

3 The Model - Oil Supply

- Estimating Equation (loose uniform priors; posterior means in brackets):

$$\frac{q_t}{Q_t} = \alpha_s - \underset{(0.243)}{\beta_1} Q_t + \underset{(0.624)}{\beta_2} p_t + \underset{(0.056)}{\beta_3} \frac{1}{3} \sum_{k=4}^{6} p_{t-k}$$

- $\beta_1 = 0.243$: Significant role for the geological channel.
- β_2 and β_3 imply positive price elasticities:
  - Short-run: 0.05-0.15 (interpretation: using spare capacity).
  - Long-run: 0.005-0.02 (interpretation: building new capacity).
  - Prices delay and raise the peak of oil production.
  - But there is a big problem: Main price effect comes from using spare capacity, which in the future may not be available to the same extent.

4 The Model - Oil Demand

- Estimating Equation (fairly tight priors; posterior means in brackets):

$$\Delta \ln q_t = \alpha_d + \underset{(0.91)}{\gamma_1} \Delta \ln gdp_t - \underset{(0.02)}{\gamma_2} \ln \frac{p_t}{p_{t-1}} - \underset{(0.06)}{\gamma_3} \left(\ln \frac{p_{t-1}}{p_{t-10}} / 9 \right)$$

- $\gamma_1 = 0.91$: Consistent with previous studies.

- β_2 and β_3 imply negative price elasticities:
  - Short run: 0.02.
  - Long run (after 10 years): 0.08, and up to 0.3 at very high oil prices.

- The combination of low price elasticities of supply and demand implies that inadequate growth of supply must lead to either much higher oil prices or an economic contraction, or a combination of the two.

5 The Model - GDP

- GDP ($pot_t =$ potential, $y_t =$ gap):
$$gdp_t = pot_t * y_t$$

$$\Delta \ln pot_t = ... - \underset{(0.005)}{\lambda_2}\left(\Delta \ln p_t - \underset{(0.07)}{\rho}\right) - \underset{(0.005)}{\lambda_3}\left(\Delta \ln p_{t-1} - \underset{(0.07)}{\rho}\right)$$

$$\Delta \ln y_t = ... - \underset{(0.005)}{\phi_3}\left(\Delta \ln p_t - \underset{(0.07)}{\rho}\right) - \underset{(0.005)}{\phi_4}\left(\Delta \ln p_{t-1} - \underset{(0.07)}{\rho}\right)$$

- Results: High oil price growth has small but significant negative effect on
  - The growth rate of potential output.
  - The growth rate of excess demand.

6 Analysis

Forecasting Performance compared to Competing Models

Horizon	Real Price of Oil			Oil Production			GDP Level	
	Model	**Random Walk**		**Model**	**EIA**		**Model**	**WEO**
1 year	14.7	27.7		1.69	1.59		1.82	1.83
2 years	17.6	47.4		1.97	2.57		3.03	3.41
3 years	19.9	57.9		2.31	3.51		3.62	4.69
4 years	22.4	79.0		2.41	4.66		3.74	5.55
5 years	25.1	100.0		2.69	5.72		3.05	5.00

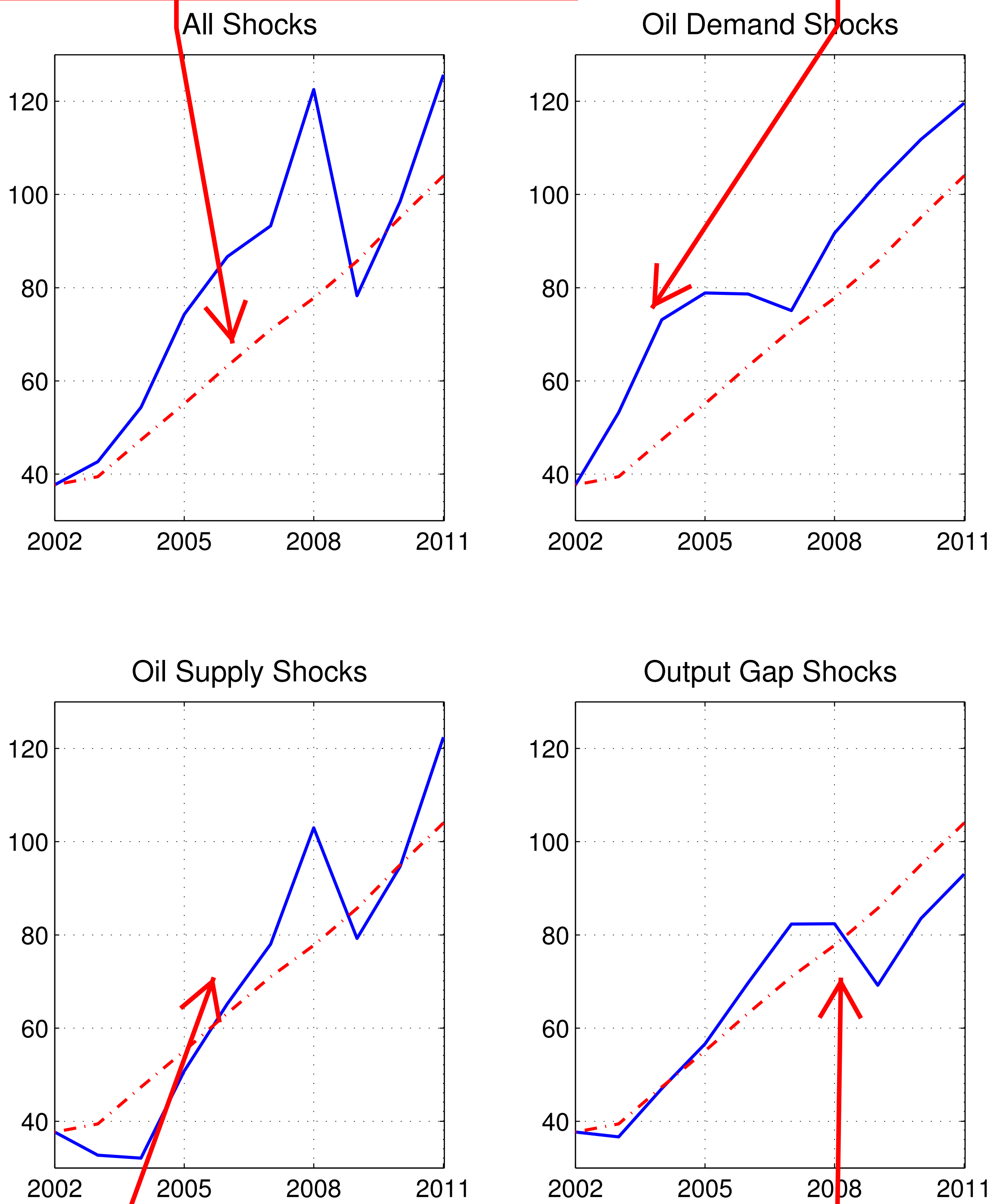
Our model's forecast errors for oil prices are far smaller than for a random walk forecast. Random walks are hard to beat by all current forecasting models for oil prices.

At horizons of four years or more, our forecast errors for oil production are at least 50% smaller than those of the EIA shown in the first figure above.

Interpretation of History - Oil Prices

This is the trend line without any shock realizations after 2002: Points up because of Hubbert feature.

Oil demand explains early 2000s deviations from trend.

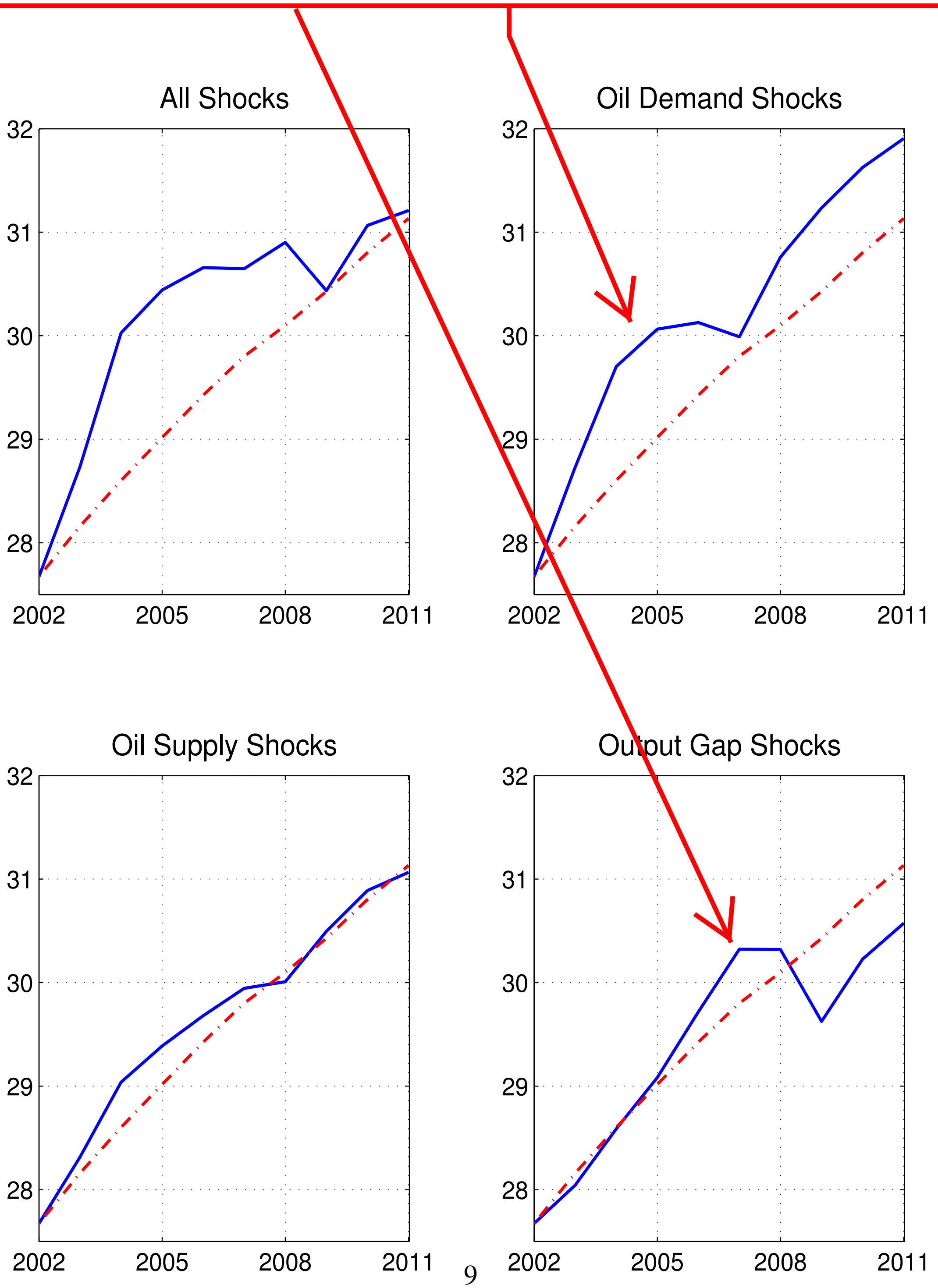


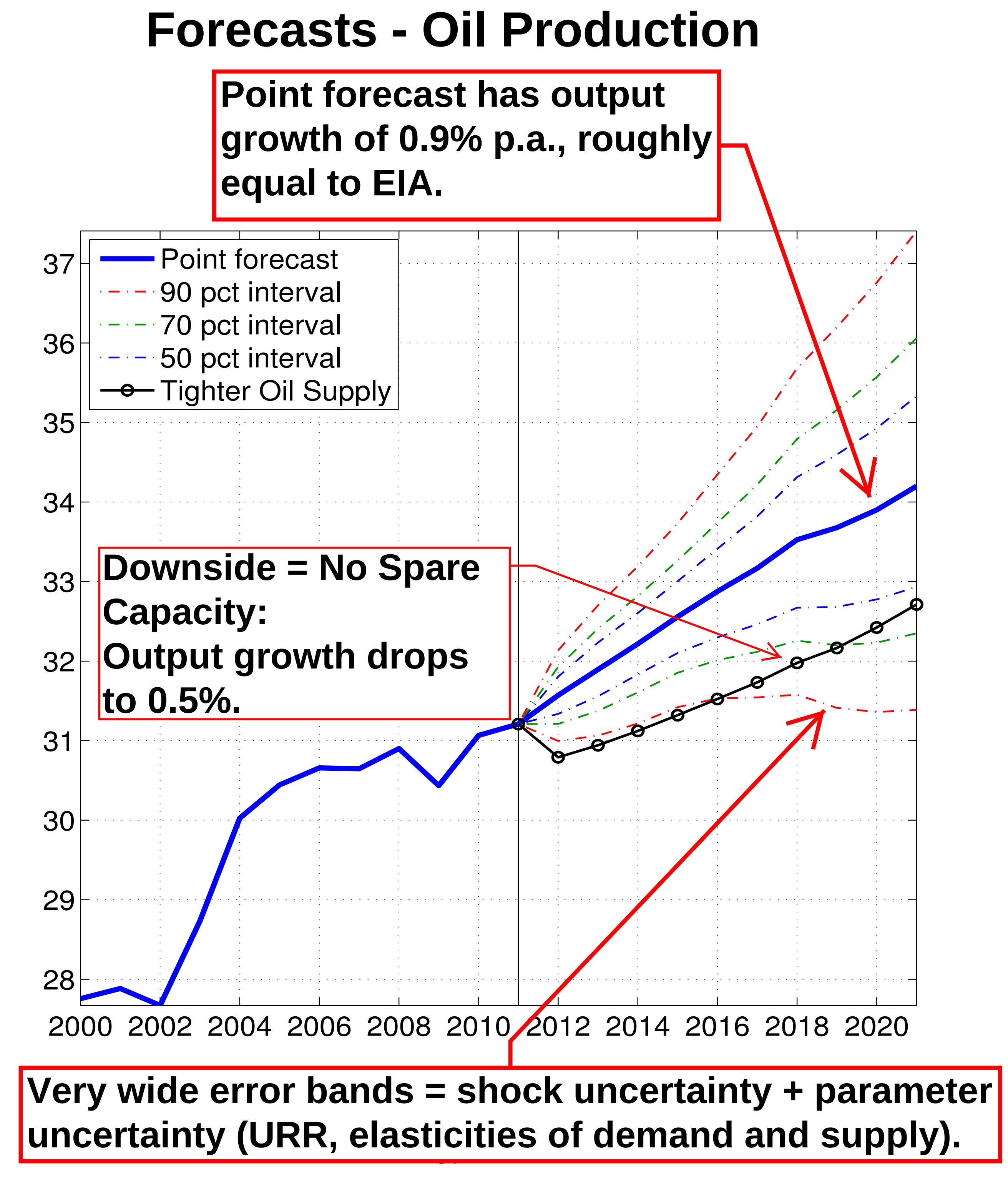
Oil supply explains 2005-2008 and recent deviations from trend: Effects of the plateau.

Output gaps explain price collapse in 2008/9.

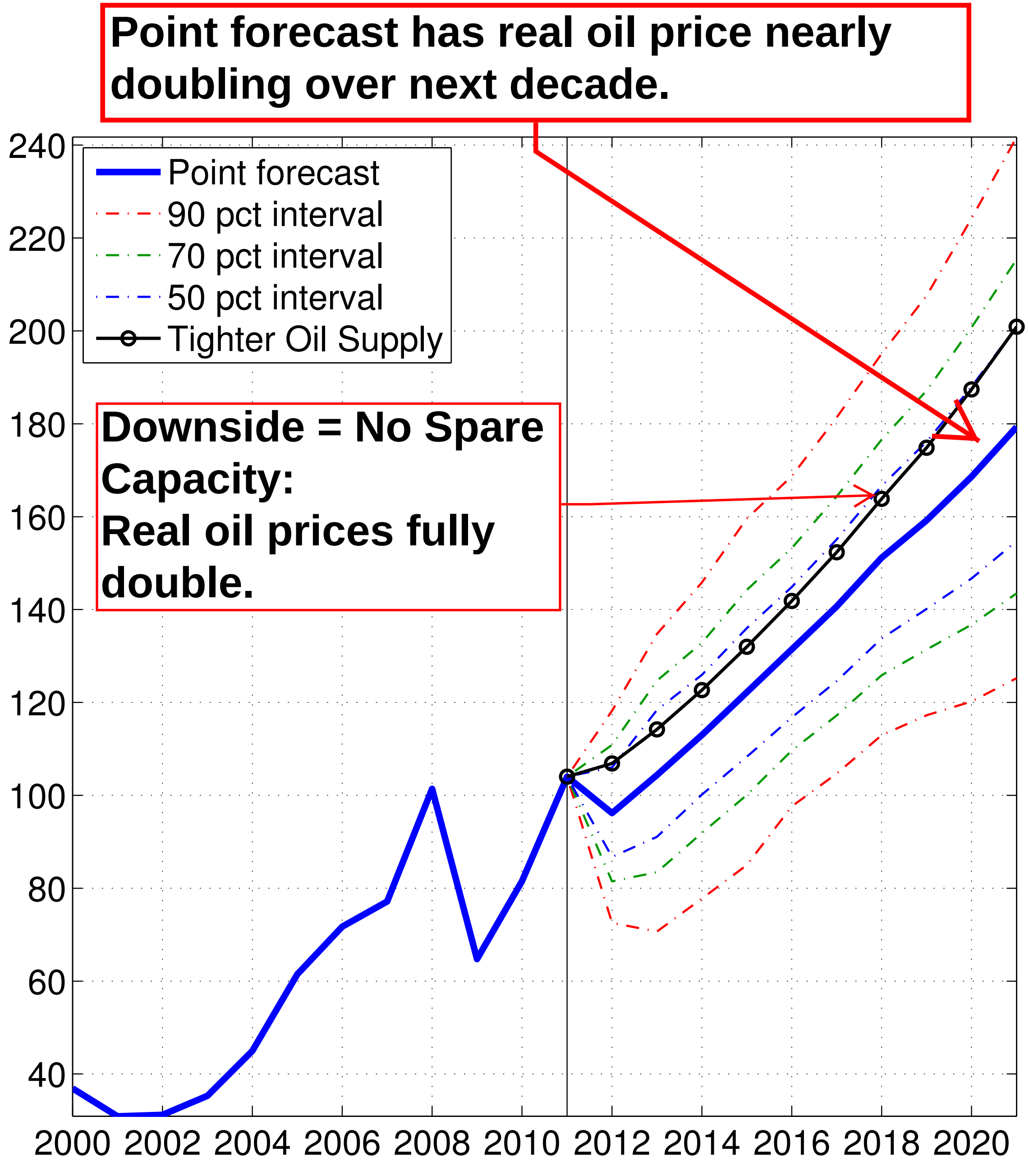
Interpretation of History - Oil Production

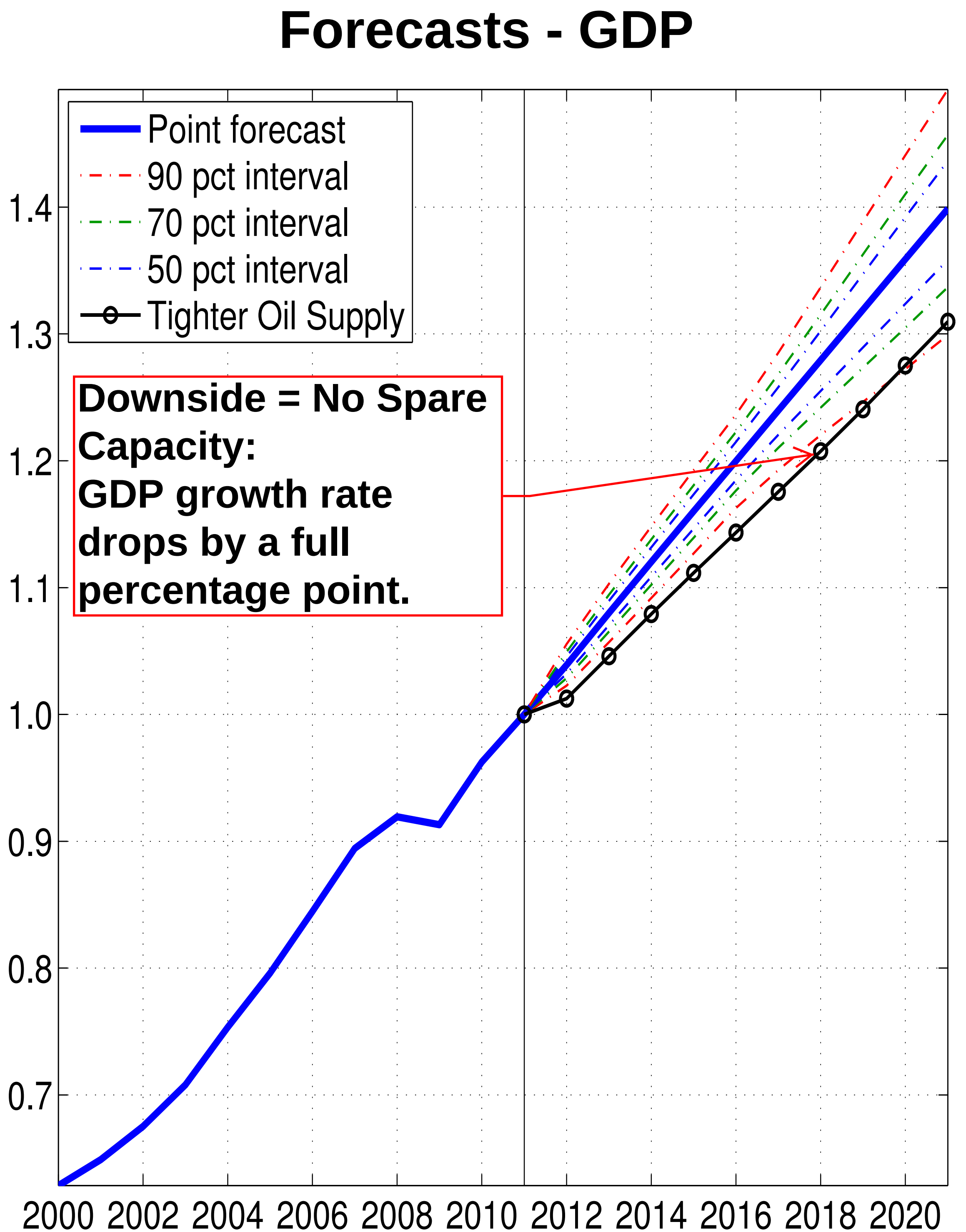
Demand shocks account for sizeable positive deviation from trend. Supply shocks do not contribute.




Forecasts - Oil Production
Point forecast has output growth of 0.9% p.a., roughly equal to EIA.
Point forecast
90 pct interval
70 pct interval
50 pct interval
Tighter Oil Supply
Downside = No Spare Capacity:
Output growth drops to 0.5%.
37
36
35
34
33
32
31
30
29
28
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Very wide error bands = shock uncertainty + parameter uncertainty (URR, elasticities of demand and supply).

Forecasts - Oil Prices




Forecasts - GDP
Point forecast
90 pct interval
70 pct interval
50 pct interval
Tighter Oil Supply
Downside = No Spare Capacity:
GDP growth rate drops by a full percentage point.
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020

7 Conclusions

- Objective = Evaluate a model that encompasses two diametrically opposite views of the world oil market:
  - Resource constraints are decisive: Hubbert linearization specification.
  - Prices are ultimately decisive: Prices-in-supply-curve specification.
- Model Performance:
  - History: Decomposition into trends and shocks is very plausible.
  - Forecasting: Far better performance than competing models.

- What Do The Forecasts Say?
  - EIA's latest forecasts of 0.9% annual supply growth may be feasible.
  - But real oil prices would have to nearly double over the next decade.
  - Large parameter uncertainty.
  - Effects on GDP, but not too dramatic: This requires further research into nonlinear responses of GDP beyond certain "pain barriers" for the oil price.
  - We have started to work on this using a structural model.

Oil and the World Economy: Some Possible Futures

November 20, 2012

Authors

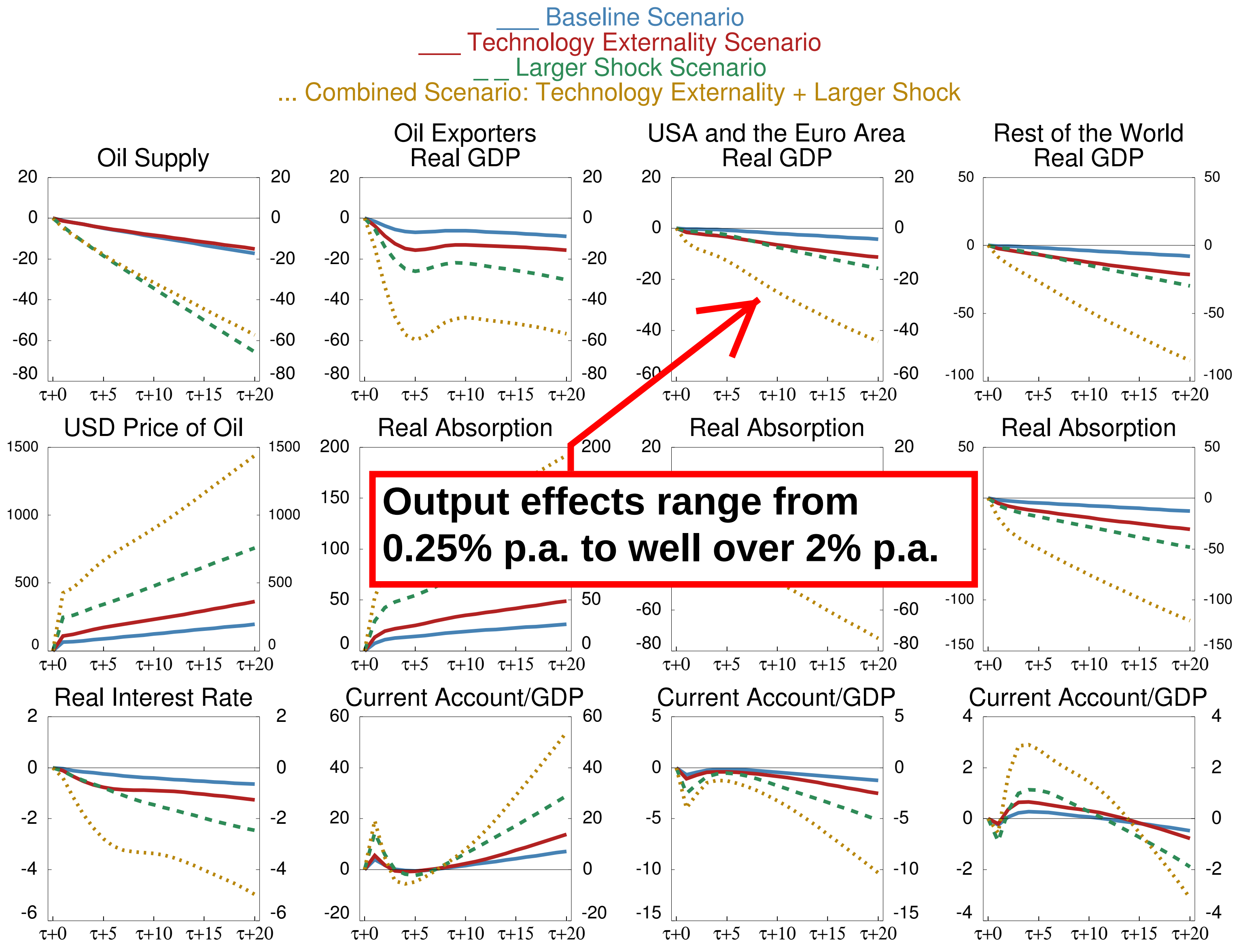
Michael Kumhof, International Monetary Fund

Dirk Muir, International Monetary Fund

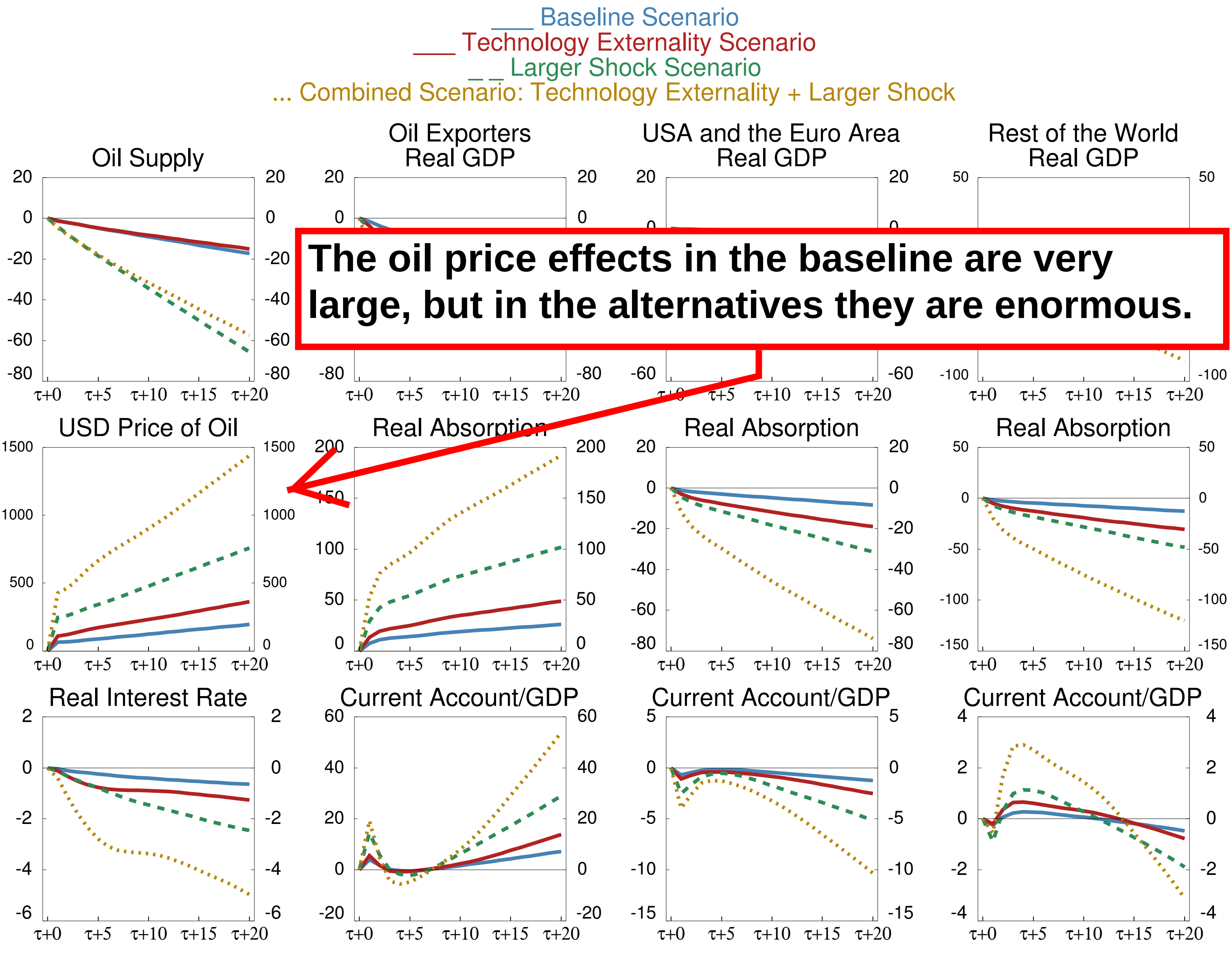
Disclaimer

- Hamilton (2009) and others focus on the **demand effects of high oil prices**.
- We emphasize the **supply effects of low oil quantities**:
  1. Energy/oil are key factors of production whose **output contribution** is grossly understated by historic cost shares.
     - Physicists and engineers have challenged the focus on cost shares.
     - I agree. They understand production far better than economists.
     - Their estimated output elasticities: Much greater than cost shares.
     - Our approach: Production function with oil as enabler of technology.
  2. The **substitutability** between energy/oil and other factors could be grossly overstated by ignoring entropy.
     - Again, physicists and engineers have challenged the assumption that elasticities of substitution can only increase over time.
     - There is a finite limit to the extent that machines (and labor) can substitute for energy.
     - Our approach: Production functions require a finite minimum of oil.

Large Shocks + Oil as a Key Enabler of Technology



Large Shocks + Oil as a Key Enabler of Technology



- The critical object for our analysis is the macroeconomic production function:

$$Z_t = \left((1-\eta)^{\frac{1}{\epsilon}} \left(K_t^{1-\alpha} L_t^{\alpha} \right)^{\frac{\epsilon-1}{\epsilon}} + \eta^{\frac{1}{\epsilon}} \left(\tilde{O}_t^{\xi} \left(O_t - \beta \frac{\bar{O}}{\bar{M}} \tilde{M}_t \right) \right)^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}}$$

  - $O_t =$ mostly exogenous production profile of oil or energy.
  - $\tilde{O}_t^{\xi} =$ technology enabled by oil availability.
  - $-\beta \frac{\bar{O}}{\bar{M}} \tilde{M}_t =$ entropy requiring a minimum oil use to produce any output.
  - $\epsilon =$ elasticity of substitution between oil/energy and other factors.

- This is where the work of geologists/engineers should overlap with that of economists.

- Fact-finding required to improve our specification of the production function:
  - Oil/Energy Flows: Supply Outlook
  - Technical Substitutability of Other Factors for Oil
  - Implementation Lags on Supply Side
  - Implementation Lags on Demand Side
  - Global Marginal Cost Curve for Production
  - Changes in Global Marginal Cost Curve Expected over Time
  - Game-Changing Exploration Technologies in the Pipeline
  - Game-Changing Recovery Technologies in the Pipeline
  - New Fields or Technologies: Cost Profiles
  - New Fields or Technologies: Energy Return Profiles
- This is where we need your help!