Revisiting “The Long-Run Evolution of Energy Prices”

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Background

- Robert Pindyck’s seminal article (1999) in the Energy Journal on the long-run evolution of energy prices has been cited in numerous studies. His work spanned up to 127 years of prices of oil, coal, and natural gas.

- He raised questions on how to model the dynamics and long-run path of energy prices.
Price Dynamics and Evolution

- Two Main Characteristics

1. Reversion to Unobservable long-run total marginal cost which follows quadratic trend.

2. Stochastic Level and Slope in the Trend
Price Dynamics and Evolution

• The focus of his research appears to be an analysis of the long-run price of oil/energy.
• This approach is primarily focused on explaining the price path through the lens of non-renewable resource economics.
• Quadratic Price trend is an outcome of this approach.
• Stochastic Trend influence - Technological changes can improve the resource picture and costs of production.
• Stochastic Level - due to geopolitical shocks and business cycles.
• An alternative view considers thinking in terms of the price of oil/energy services.
Does Resource Scarcity Explain the Long-run Path of Real Oil Prices

The Quadratic Trend Model Through 1996 and 2012
Price Dynamics and Evolution

• Mu and Ye (2012) adopt Pindyck's framework and allow for structural breaks in the process. They specify the (univariate) unobserved components model for the log of the real oil price as a function of a time trend, two cyclical components, structural break(s) or shift(s), and the innovation or disturbance term.

• The second cycle incorporates hypotheses concerning: a) long-run commodity prices and b) the Singer relative terms of trade.
Price Dynamics and Evolution

- Adelman (1995) studied the prices of oil to consumers and crude prices over 80 and 130 year periods respectively. He concluded that the hypothesis that oil is a limited resource could not be supported.

- This can be explained incomplete information about the resource constraint. Perhaps analysts have been too optimisitic.

- Technological change can reduce costs and make non-economic reserves viable.

- Production techniques and management of resource base.

- An alternative view considers thinking in terms of the price of oil/energy services.
The Price of Energy Services

• Nordhaus (1997) discussed the importance of distinguishing between the price of energy services not the price of energy itself.

• Consumption or the demand side depends on the former which drives the demand for oil and price is a function of sources of supply. His example was lighting and the declining costs due to major technological improvements. Both contributed to important welfare gains to consumers. Efficiency improvements affect the price of services and types of services, but may not impact the price of energy.
The Price of Energy Services Model

Our model incorporates the Pindyck and Mu & Ye Models of deterministic and stochastic levels and trends with cyclical components.

1. We allow for the possibility of quadratic trends.
2. The cyclical component is specified as an AR(2) – higher orders did not provide significant information.
3. We use a model selection procedure known as Autometrics.
4. This approach can capture shocks on supply from producer behavior and geopolitical factors.
5. It allows for the impact of transitions in the services from oil/energy services.

Yergin (2011) and Hamilton (2011) discuss the shocks and changing structure of oil markets from the demand supply perspective.

Light, Heat, Power, Transportation, Regulation

Our approach attempts bring in these factors through the estimation techniques.
Autometrics and Impulse Indicator Saturation – General to specific modeling algorithm

Hendry and Krollzig (2001) There are five basic steps:

1. Specification of the GUM (General Unrestricted Model) by the empirical modeler.
2. Tests for mis-specification usually through residual diagnostics.
4. Test terminal models or paths for congruency.
5. Evaluate terminal models for final model(s) through encompassing tests.

End Result: **Retain only Variables in GUM that Matter!!**
Impulse and Step Indicator Saturation

- IIS and SIS provides a general procedure for analyzing a model’s constancy. Specifically, IIS is a generic test for:
  - an unknown number of breaks,
  - occurring at unknown times,
  - with unknown duration and magnitude and functional form,
  - anywhere in the sample.

- IIS is a powerful empirical tool for both evaluating and improving existing empirical models.

- See Doornik(2009a), Johansen and Nielsen(2009,2011), and Castle, Doornik, Hendry, and Pretis(2013) for further discussion and recent developments
STEP Indicator Saturation

• Super saturation searches across all possible one-off step functions, in addition to.

• Step functions are of economic interest because they may capture permanent or long-lasting changes that are not otherwise incorporated into a specific empirical model.

• A step function is a partial sum of impulse indicators; equivalently, it is a parsimonious representation of a sequential subset of impulse indicators that have equal coefficients.
Comparison of Oil Price Approach to Price of Oil Service Approach

Estimated Residuals AR2 with Quadratic Trend vs. Autometrics Model

-0.4 -0.2 0.0 0.2 0.4

1880 1900 1920 1940 1960 1980 2000 2020
## The Price of Energy Services Model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>Services</th>
</tr>
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<tbody>
<tr>
<td>S1:1877</td>
<td>0.344</td>
<td>0.073</td>
<td></td>
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<tr>
<td>S1:1891</td>
<td>-0.226</td>
<td>0.045</td>
<td>Lighting and Supply Expansions</td>
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<td>S1:1904</td>
<td>0.265</td>
<td>0.049</td>
<td>Transitions Lighting Transportation and Supply Growth</td>
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<tr>
<td>S1:1915</td>
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<td>0.039</td>
<td>Global and US Production Surges</td>
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<td>S1:1969</td>
<td>-0.104</td>
<td>0.027</td>
<td>Power, Heating, and Transportation Transition with Regulation by States to Manage Production</td>
</tr>
<tr>
<td>S1:2003</td>
<td>-0.444</td>
<td>0.052</td>
<td>Power and Transportation Transition with Regulation Manage Production</td>
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<tr>
<td>Constant</td>
<td>1.044</td>
<td>0.101</td>
<td>Current &quot;Level&quot; Geographic and Transportation Transitions</td>
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The Price of Energy Services Model Dynamic Level
### The Price of Energy Services Model Fit

<table>
<thead>
<tr>
<th>Variable</th>
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<th>Std. Error</th>
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<tbody>
<tr>
<td>LRPOIL_1</td>
<td>0.630</td>
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<tr>
<td>I:1873</td>
<td>-0.543</td>
<td>0.124</td>
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<td>I:1874</td>
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<td>I:1876</td>
<td>0.516</td>
<td>0.125</td>
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<td>I:1883</td>
<td>0.365</td>
<td>0.112</td>
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<td>I:1892</td>
<td>-0.332</td>
<td>0.113</td>
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<tr>
<td>I:1895</td>
<td>0.315</td>
<td>0.112</td>
</tr>
<tr>
<td>I:1897</td>
<td>-0.342</td>
<td>0.112</td>
</tr>
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<td>I:1913</td>
<td>0.344</td>
<td>0.112</td>
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<td>I:1920</td>
<td>0.333</td>
<td>0.108</td>
</tr>
<tr>
<td>I:1931</td>
<td>-0.405</td>
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<td>I:1980</td>
<td>0.425</td>
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<tr>
<td>I:2000</td>
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<td>0.109</td>
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<tr>
<td>I:2009</td>
<td>-0.426</td>
<td>0.114</td>
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</table>
The Price of Energy Services Model Fit
Thank you

- We have and are considering an alternative model of understanding long-run oil price dynamics that is one that considers the price of oil services.
- Factors that determine oil price now include the types of services provided by oil not (just) natural resource scarcity with upward increasing marginal cost trends, technology impacts, business cycles, and geopolitical shocks.
- We do not find evidence nor believe in long-run oil commodity cycles under the price of oil services view.
The Price of Energy Services Model Fit
The Price of Energy Services Model Fit
The Price of Energy Services Model Fit
Pindyck’s Model

This produces a three equation discrete time system with a measurement equation and two state equations.

\[ p_t = b_0 + b_1 t + b_2 t^2 + \rho p_{t-1} + \phi_{1,t} + \phi_{2,t} + \epsilon_t \]

\[ \phi_{1,t} = c_1 \phi_{1,t-1} + \nu_{1,t} \]

\[ \phi_{2,t} = c_2 \phi_{2,t-1} + \nu_{2,t} \]

A starting assumption could be that \( \epsilon_t, \nu_{1,t}, \text{and} \nu_{2,t} \) are multivariate normal (assumptions for general distribution are possible). The measurement innovation is uncorrelated with the state innovations. Unobserved components and the Kalman Filter are the procedure for the obtaining the maximum likelihood estimates for the parameters and mean squared error estimates of the state variables.
Mu and Ye’ Model

They specify the (univariate) unobserved components model for the log of the real oil price as a function of a time trend, two cyclical components, structural break(s) or shift(s), and the innovation or disturbance term.

\[ p_t = \mu_t + \gamma_t + \phi_t + \delta w_t + \epsilon_t ; \text{ where } \epsilon_t : NID(0, \sigma^2) \]

The trend component is given by \( \mu_t \). Two cycles are considered - one might be a transitory or short cycle, \( \gamma_t \) caused by temporary bottlenecks or economic disruptions. The second more persistent one, \( \phi_t \), may be due to prolonged pressure from rapid economic growth and or investment cycles in the resource. The structural break, \( \delta w_t \), is a fundamental shift in the level of the trend. Shifts in the slope of the trend are possible as well, but not tested for here in part due to the sample.

The unobserved trend components in the model are given by

\[ \mu_t = \mu_{t-1} + \beta + \eta_t ; \eta_t : NID(0, \sigma^2) \]

\[ \Delta^d \beta_t = \xi_t ; \xi_t : NID(0, \sigma^2) \]

Cyclical behavior in the price may have two stochastic components. these are expressed as a mixture of sine and cosine functions.

\[
\begin{bmatrix}
\phi_t \\
\phi^*_t
\end{bmatrix} = \rho \begin{bmatrix}
\cos \lambda \phi \\
-\sin \lambda \phi
\end{bmatrix} \begin{bmatrix}
\phi_{t-1} \\
\phi^*_{t-1}
\end{bmatrix} + \begin{bmatrix}
\kappa_t \\
\kappa^*_t
\end{bmatrix}
\]
Objective

- Robert Pindyck’s seminal article (1999) in the Energy Journal on the long-run evolution of energy prices has been cited in numerous studies. His work spanned up to 127 years of prices of oil, coal, and natural gas.

- He raised questions on how to model the dynamics and long-run path of energy prices.

- Our objective is to examine how well his models and projections captured the movements in prices for oil, coal, and natural gas since then. We begin by attempting to replicate his earlier study using the data from 1870-1996 and then update the data through 2011. This has been a period of structural changes with greater impact from natural gas.

- price deregulation and production techniques, changes in global demand, geopolitical strife, and the role of commodities as an asset class in financial markets. Then we will use the updated models to make projections to
Multivariate Ornstein-Uhlenbeck Process

\[ d\tilde{p} = -\gamma \tilde{p} dt + \sigma dz, \quad (10) \]

where \( \tilde{p} = p - \alpha_0 - \alpha_1 t - \alpha_2 t^2 \) is the detrended price. In terms of the price level itself, this is equivalent to:

\[ dp = [-\gamma (p - \alpha_0 - \alpha_1 t - \alpha_2 t^2) + \alpha_1 + 2\alpha_2 t] dt + \sigma dz. \quad (11) \]

Note that the parameter \( \gamma \) describes the rate of reversion to the (fixed) trend line. If \( \gamma = 0 \), the log price follows an arithmetic Brownian motion (so price is a geometric Brownian motion), and the variance ratio would approach 1.

The multivariate Ornstein-Uhlenbeck process is a simple generalization of eqn. (10). In the bivariate case, we could write the process as:

\[ d\tilde{p} = (-\gamma \tilde{p} + \lambda x) dt + \sigma dz, \quad (12) \]

where \( x \) is itself an OU process:

\[ dx = -\delta x dt + \sigma_x dz, \quad (13) \]
Unobserved Components Model for Price Dynamics

\[ \begin{align*}
    p_t &= c_1 + c_2 p_{t-1} + \phi_{1t} + \phi_{2t} t + \epsilon_t \\
    \phi_{1t} &= c_3 \phi_{1, t-1} + \nu_{1t} \\
    \phi_{2t} &= c_4 \phi_{2, t-1} + \nu_{2t}
\end{align*} \]
<table>
<thead>
<tr>
<th></th>
<th>Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_1$</td>
<td>-0.7771</td>
</tr>
<tr>
<td></td>
<td>(0.0568)</td>
</tr>
<tr>
<td>$c_2$</td>
<td>0.8041</td>
</tr>
<tr>
<td></td>
<td>(0.0528)</td>
</tr>
<tr>
<td>$c_3$</td>
<td>1.0009</td>
</tr>
<tr>
<td></td>
<td>(0.0008)</td>
</tr>
<tr>
<td>$c_4$</td>
<td>0.5418</td>
</tr>
<tr>
<td></td>
<td>(1.833)</td>
</tr>
<tr>
<td>$\phi_{1T}$</td>
<td>1.1075</td>
</tr>
<tr>
<td></td>
<td>(0.0155)</td>
</tr>
<tr>
<td>$\phi_{2T}$</td>
<td>$2.96 \times 10^{-9}$</td>
</tr>
<tr>
<td></td>
<td>($3.65 \times 10^{-6}$)</td>
</tr>
</tbody>
</table>
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• Doornik, Hendry, and Pretis (2013) and Castle, Doornik, Hendry, and Pretis (2013) investigate the statistical properties of a closely related saturation estimator – step indicator saturation (SIS) – which searches among only the step indicator variables.