Closed Loop Control with Jump Processes: Large-Scale Oil Production

Jad Soucar
Daniel J. Epstein Department of Industrial and Systems Engineering
University of Southern California
Los Angeles, California, USA

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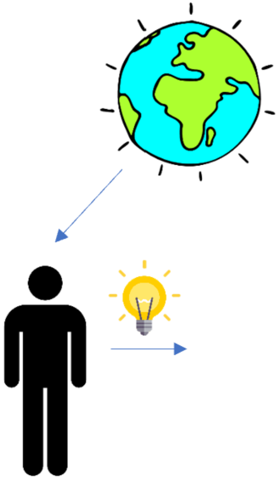
Outline

Open Loop Control

An Open Loop Control Process is Where ...

- **Day 1:** Actor Observes the Environment
- **Day 1:** Actor Makes a Decision

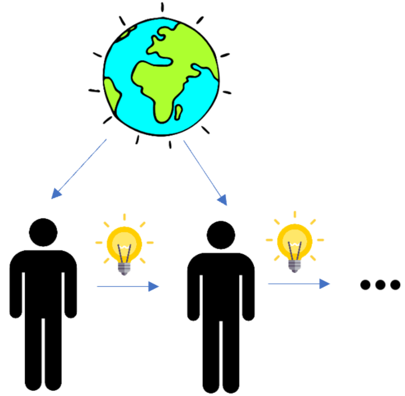


Open Loop Control

An Open Loop Control Process is Where ...

- **Day 1:** Actor Observes the Environment
- **Day 1:** Actor Makes a Decision
- **Day 2:** Actor Observes the Environment
- **Day 2:** Actor Makes a Decision

⋮



Open Loop Control

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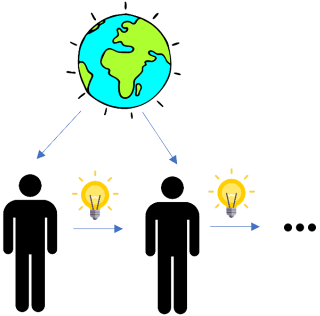
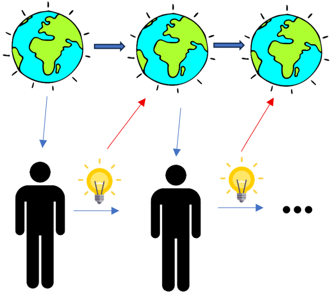


Key Take Away: In an open loop system, an actor's decisions **DO NOT** change the environment

A Closed Loop Control Process is Where ...

- **Day 1:** Actor Observes the Environment
- **Day 1:** Actor Makes a Decision
- **Decision Impacts Environment**
- **Day 2:** Actor Observes the NEW Environment
- **Day 2:** Actor Makes a Decision

⋮

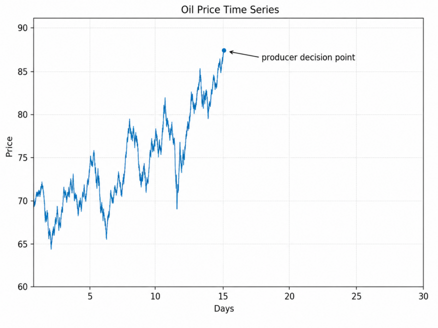


Key Take Away: In a closed loop system an actor's decision **DO** change the environment

Open Loop Systems in Oil Production

Up To 1 Gallon of Oil Production Per Day

- **Day 1:** Producer Observes Global Oil Prices
- **Day 1:** Producer Chooses to Produce $q \in [0, 1]$ Gallons of Oil



Open Loop Systems in Oil Production

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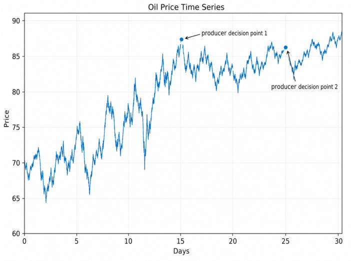
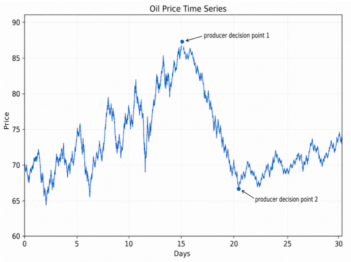


Selling 1 Gallon of Oil Does Not Effect Global Oil Prices → **Open Loop**

Up To 10 Million Gallons of Oil Production Per Day

- **Day 1:** Producer Observes Global Oil Prices
- **Day 1:** Producer Chooses to Produce $q = 10^6$ Gallons of Oil
- **Production Increases Global Supply Significantly $\rightarrow$ Price Drops**
- **Day 2:** Producer Observes Global Oil Prices
- **Day 2:** Producer Choose to Produce $q \in [0, 10^6]$ Gallons of Oil



Problem 1: Large Scale Oil Producer Must Contend with Closed Loop Price & Demand Effects When Choosing a Production Strategy

Oil Price and Demand Shocks

- **2026**, US-Iran War: Global Oil Prices Rose 7.84% in One Week
- **2022**, Russia-Ukraine War: Global Oil Prices Rose 34%

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UPDATED JAN 5, 2026

Oil Price and Demand Shocks

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- **2022**, Russia-Ukraine War: Global Oil Prices Rose 34%
- **2020**, COVID-19: Global Oil Demand Fell 29%
- **2008**, Great Recession: Global Oil Demand Fell 5.7%

Problem 2: Large Scale Oil Producers Must Content With Global Demand & Price Shocks When Choosing a Production Strategy

Primary Question

In the face of global price/demand shocks & closed loop price/demand effects,

What is the Optimal Production Strategy?

Outline

Modeling Price

- P_t: Price at time t
- D_t: Demand at time t
- q_t: Oil Production at time t.
- η: (Short-Run Price Elasticity) - Sensitivity of price to supply-demand imbalance.

$$dP_t = P_t \left[\underbrace{\eta \log\left(D_t/q_t\right) dt}_{\text{Relative Scarcity}} + \underbrace{\sigma_P dW_t^P}_{\text{Price Volatility}} \right]$$

- **Relative Scarcity**:
  - Shortages in Supply - ↑ Price
  - Shortages in Demand ↓ Price
  - *Unbounded* Non-linear price-response law [3, 4]
- **Price Volatility**: Price is subject to exogenous volatility

Modeling Demand

- α_D: Base level of demand growth
- β: (Long Run Elasticity) Demand Sensitivity to Price
- λ: Poisson Rate of Demand Shocks
- Y: Expected log Magnitude of Shock

$$dD_t = D_{t^-}[\underbrace{(\alpha_D - \beta P_t - \lambda k)dt}_{\text{Demand-Price Response}} + \underbrace{\sigma_D dW_t^D}_{\text{Demand Volatility}} + \underbrace{(e^Y - 1)dN_t}_{\text{Demand Shocks}}].$$

- **Demand-Price Response**:
  - Low Prices - $\uparrow$ Demand
  - High Prices $\uparrow$ Price
- **Demand Shocks**: Modeled with a Compound Poisson Shocks (Merton Jumps [5])

The Optimal Production Problem

- $[0, T]$: Time Horizon
- $C(q) = c_1 q_t + c_2 q_t^2$: Cost per barrel produced.
- ρ: Discount Rate (Risk Free Rate)

$$V(D, P, t) = \sup_{q_t} \mathbb{E}\left[\int_{s=t}^{T} e^{-\rho(T-s)} (\underbrace{\min\{q_s, D_s\} P_s}_{\text{Revenue}} - \underbrace{C(q_s)}_{\text{Production Cost}}) ds\right]$$

- $V(D, P, t)$ denotes the the value of the production strategy $\{q_s\}_{s=t}^{T}$ from time t to T.
- **Our task is to find the optimal production strategy**

Associated HJB Equation

The problem can be cast such that the optimal production strategy solves the a partial integro-differential equation

$$
\begin{aligned}
0 = {} & \partial_t V + \partial_D V D_t(\alpha_D - \beta P_t) + \frac{1}{2}\partial^2_{DD} V D_t^2 \sigma_D^2 + \frac{1}{2}\partial^2_{PP} V P_t^2 \sigma_P^2 + \partial^2_{DP} V D_t P_t \sigma_D \sigma_P \rho_{DP} \\
& + \lambda \left(\int_{-\infty}^{\infty} V(D_t e^y, P_t, t)\phi(y) dy - V(D_t, P_t, t) - \partial_D V D_t k \right) \\
& + \sup_{q_t} \left\{ (\min(q_t, D_t) P_t - C(q_t)) + \partial_P V P_t \eta \log\left(\frac{D_t + \epsilon}{q_t + \epsilon} \right) \right\} - \rho V,
\end{aligned}
$$

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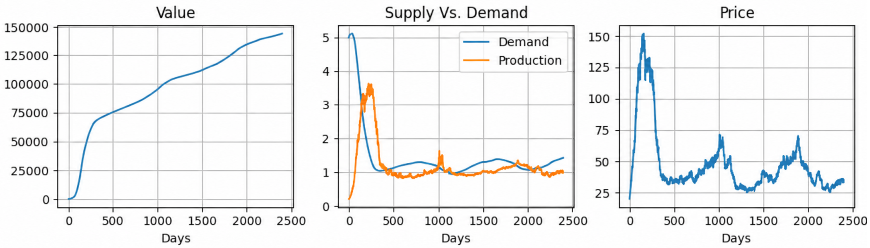
The solution can be approximated using a **Neural-Network Euler-Maruyama Scheme**

Outline

Boom-Bust Strategy



Dominant Strategy: Boom-Bust

1. Under Produce (Supply Drops)
2. Price Rises
3. Produce to Meet Demand at Hiked Price
4. Return to (1)

Boom Bust Strategy

THE OXFORD INSTITUTE FOR ENERGY STUDIES

"This leads us to the analysis of the price band mechanism which OPEC adopted in 2000 as a signalling mechanism. This mechanism set a target range for the OPEC basket price between US$22 and US$28 per barrel of oil. If prices are below the floor for ten consecutive days, OPEC will automatically cut production. If prices are above the upper band for twenty days, it will automatically increase production. Recently, various studies have examined OPEC pricing policies within a target price zone providing a rationale for the lower and upper bands (Tang and Hammoudeh, 2002; Chapman and Khanna, 2001; Horn, 2004)." [1]

Market Decoupling

Question 1: Does the Boom-Bust Strategy Persist in a Renewable Future?

Consumers have more flexibility to transition away from oil-based products.

↓

Consequently consumers react more aggressively to price increases.

↓

β Increases

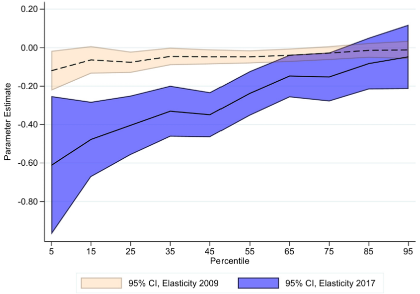


Fig. 3. Quantile estimates of the fuel price elasticity.

Figure: Long Run Elasticity (β) in 2009 vs. 2017 [2]

Market Decoupling

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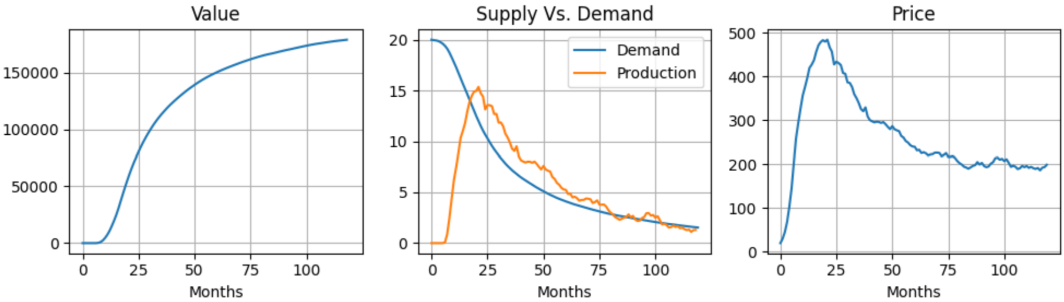

Boom-Bust Strategy Fails When Customers Have Choice, and Results in a Market Decoupling From Oil.

Inducing Consumer-Aligned Strategies

- Boom-bust production strategies can harm consumers by creating volatile and persistently elevated prices.
- The policy question is therefore not how to make producers less strategic, but ...

Question 2: Can we design a market environment where the optimal production strategy is more stable.

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March 16, 2026

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By Aimee Picchi

Updated on: May 11, 2026 / 7:37 PM EDT / CBS News

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Inducing Consumer-Aligned Strategies

Price-response policies correspond to bounded price-response laws

$$dP_t = P_t \left[\eta \underbrace{\cancel{\log(D_t/q_t)}}_{\tanh(D_t - q_t)} dt + \sigma_P dW_t^P \right].$$

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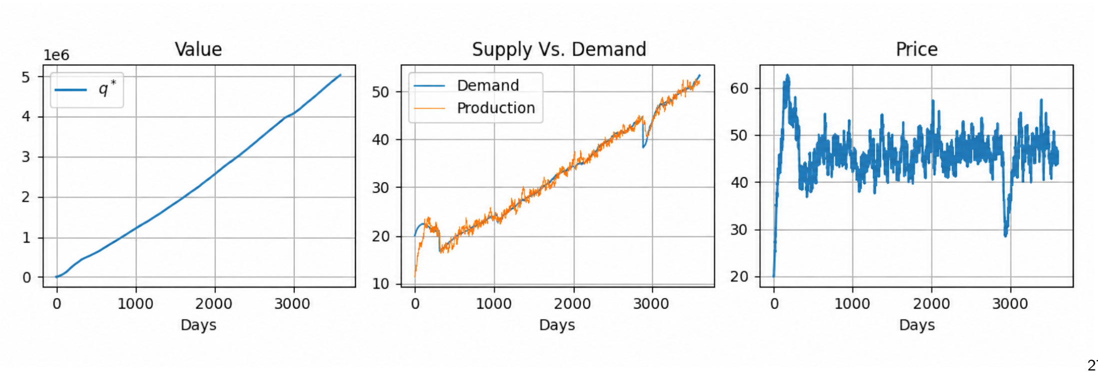

Summary

- Large oil producers operate in a **closed-loop market**: production decisions directly affect supply, prices, and future demand.
- In the baseline model, a **boom-bust strategy** emerge and reflect real-world decision making
- As consumers gain alternatives, demand becomes more elastic, making aggressive price manipulation less sustainable.
- Policy tools, such as bounded price-response mechanisms, can reshape incentives so that **stable production becomes optimal**.

Citations I

[1] Bassam Fattouh. OPEC Pricing Power: The Need for a New Perspective. Working Paper WPM 31. Oxford Institute for Energy Studies, Mar. 2007. URL: https://www.oxfordenergy.org/wpcms/wp-content/uploads/2010/11/WPM31-OPECPricingPowerTheNeedForANewPerspective-BassamFattouh-2007.pdf.

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[3] James D. Hamilton. "Causes and Consequences of the Oil Shock of 2007–08". In: Brookings Papers on Economic Activity 2009.1 (2009), pp. 215–261. URL: https://www.brookings.edu/wp-content/uploads/2016/07/2009a_bpea_hamilton-1.pdf.

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[5] Robert C. Merton. "Option pricing when underlying stock returns are discontinuous". In: Journal of Financial Economics 3.1-2 (1976), pp. 125–144.