# Non-Price Material Scarcity Metrics:
## How Well, and Under What Conditions Is the Risk They Indicate Reflected by Material Price?

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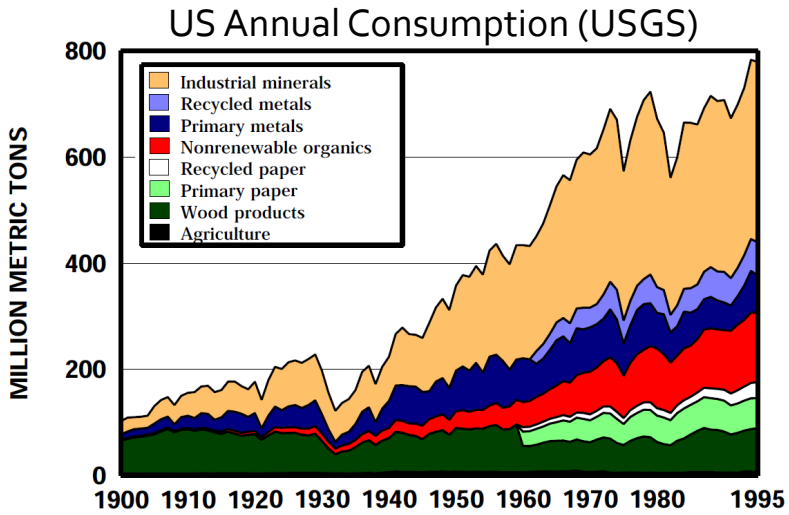
# Introduction / Problem Statement

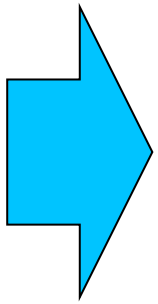
- Resource scarcity has increased notice:
  - Specific material concerns: rare earths, Lithium.
  - Sustainability problem: finite resource, growing use rate




- Scarcity is an abstract term—there is no definitive measure of scarcity.
- There are a number of technical measures of material scarcity.
- Material price is a measure of scarcity.
- How well do price and the other measures correlate?
  - Under what conditions?

# Scarcity Risk Metrics

| *Type* | *Metric* | *Units* |
|---|---|---|
| Institutional | Geographic Structure based on Supply | |
| Efficiency | Geographic Structure based on Production | |
| | Institutional Structure based on Production | |
| | Institutional Structure based on Consumption | |
| | Recycling rate | % |
| | Recycling Efficiency or Recovery Rate | % |
| | Market Price | $ |
| Physical | Static Index of Depletion | years |
| Constraint | Exponential Index of Depletion | years |
| | Relative Rate of Discovery and Extraction | |
| | Time to Peak Production | years |
| | Average Ore Grade | % |
| | Production Costs | $ |
| | Market Price | $ |



***Modeled Metrics***

Supply Herfindahl Index

Oxide Marginal Cost

Primary Marginal Cost

Oxide Price

Mining Acceleration

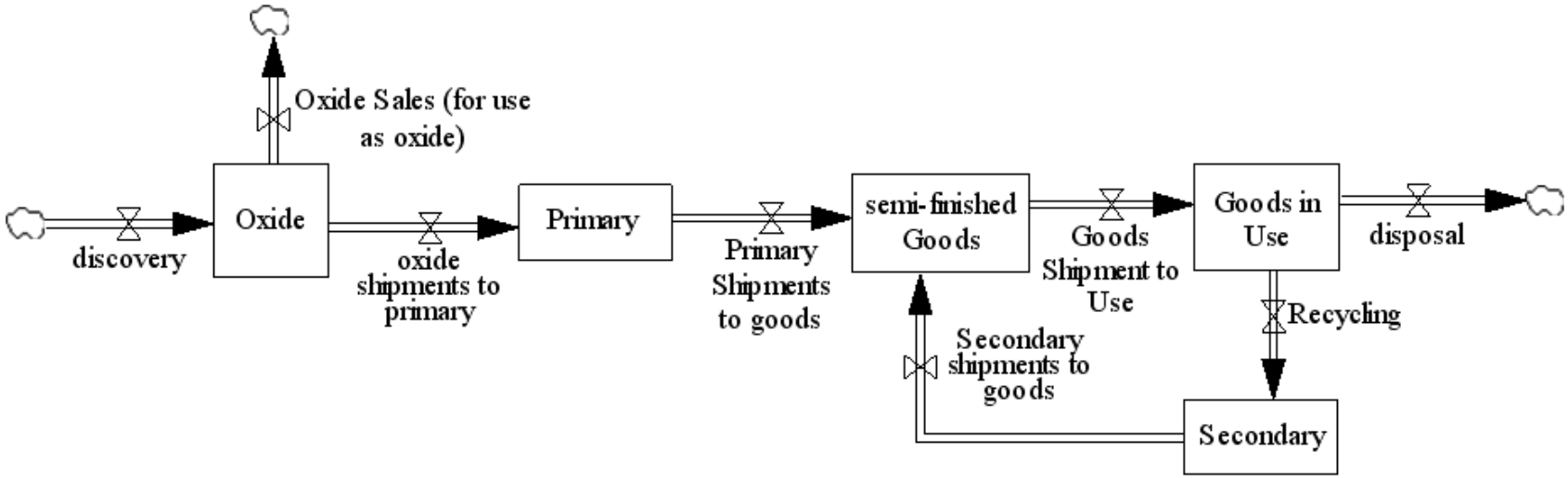
Recycling Rate

Recycling Efficiency

Static Depletion Index

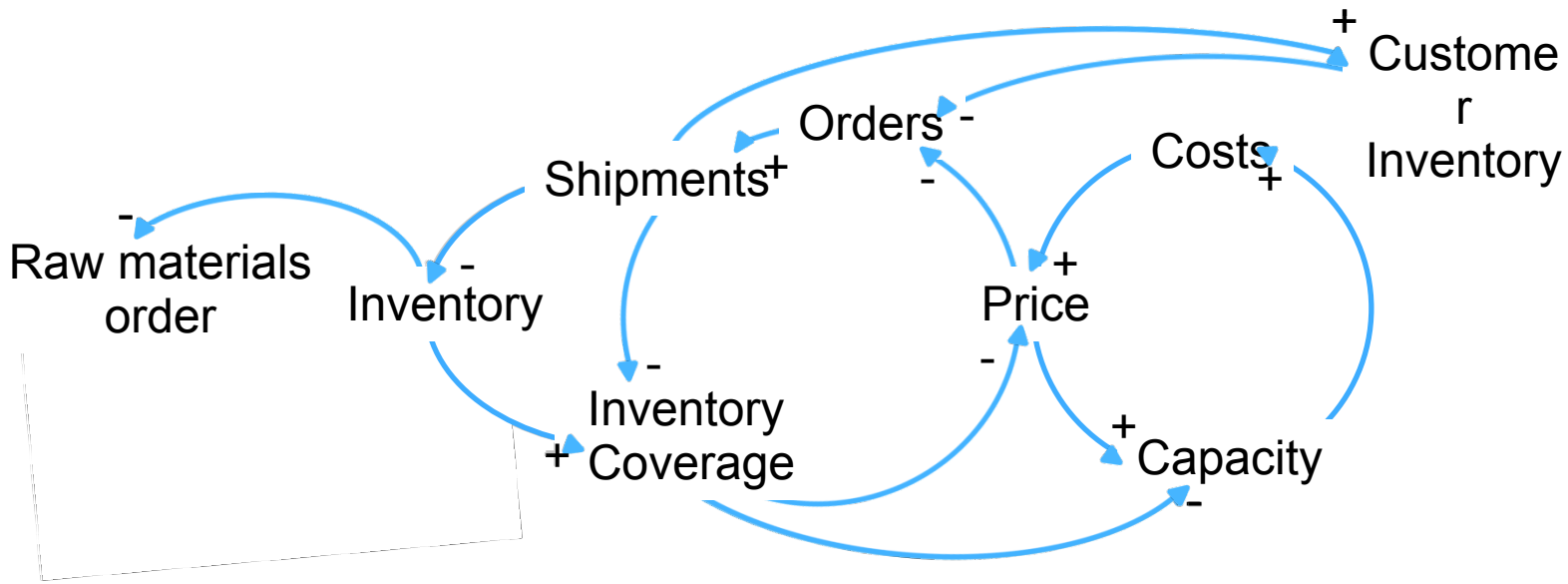
Source: Alonso, 2007

# System Dynamics Model: Stocks & Flows




- Model covers commodity metal material flows throughout supply chain – implemented in Aluminum—calibrated to historical data.
- Each 'module' includes measures of prices, inventories, capacities, orders and shipments.

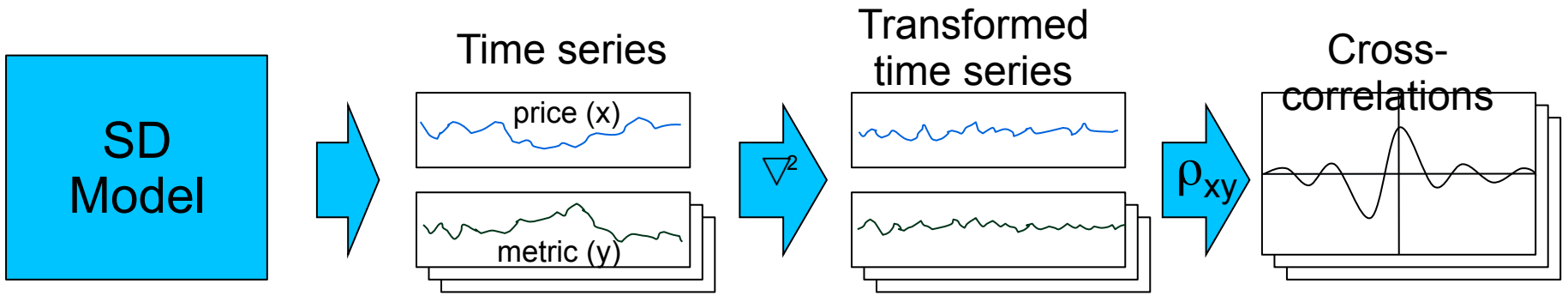
# Feedback loops to capture market behavior




Model function depends on interacting feedback loops:

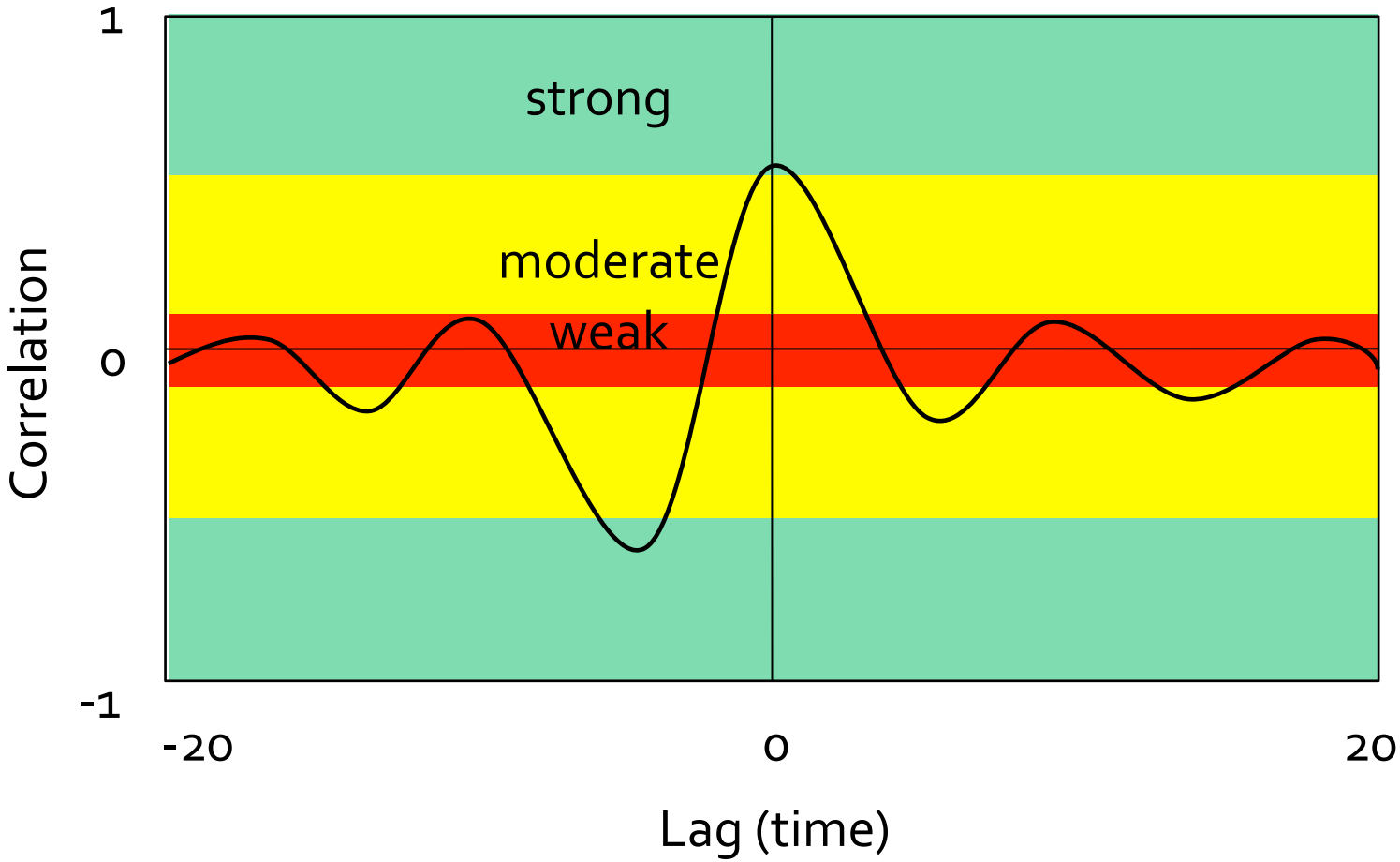
- price
- inventory
- capacity

# Experimental Setup

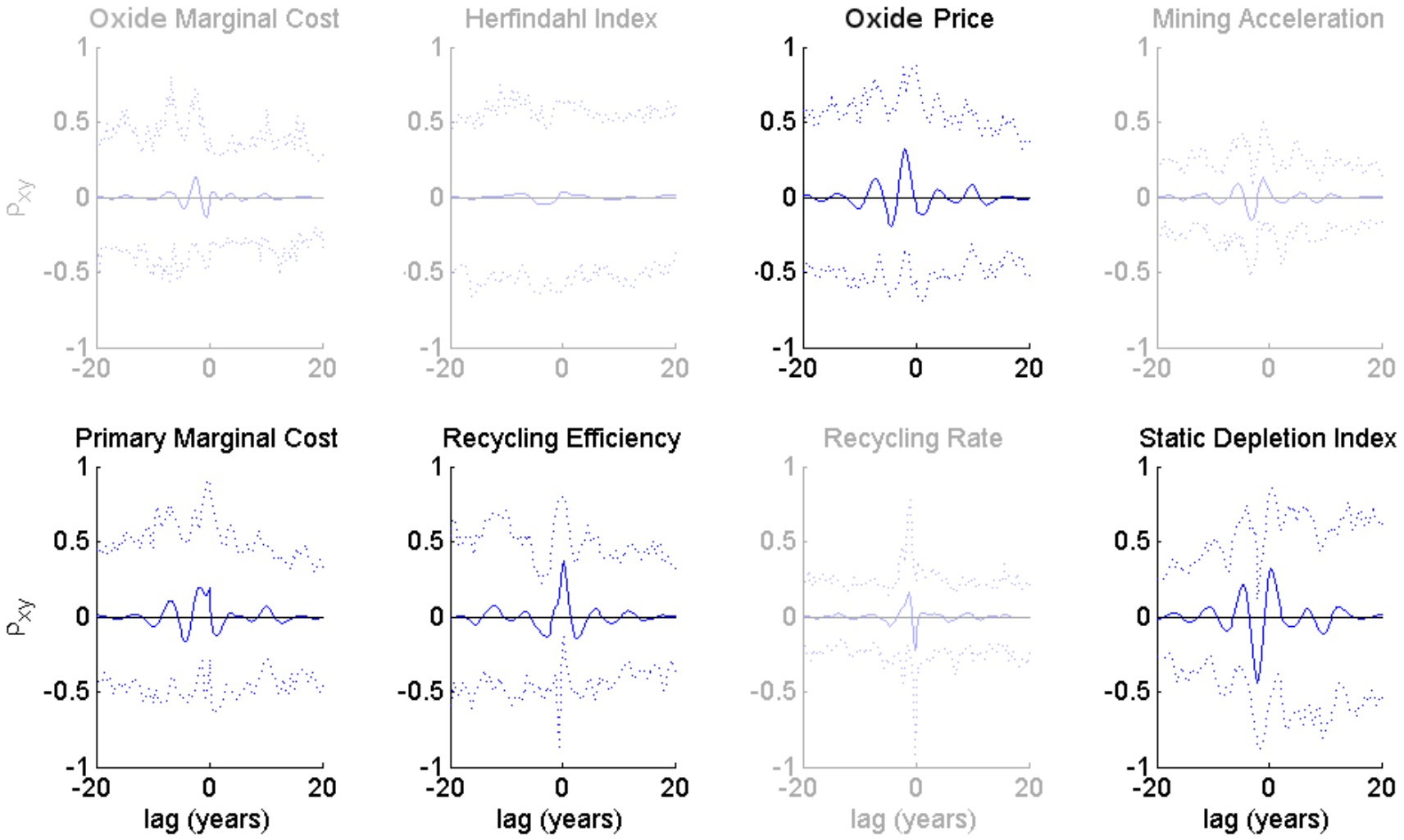



- Question: do changes in metrics show up as changes in price?
- Experiment repeated for 3-level of 4 market characteristics:
  - Oxide capacity acquisition delay
  - Primary capacity acquisition delay
  - Goods price elasticity of demand
  - Substitutability of secondary metal for primary
- This 81 ($3^4$) element full factorial experiment was replicated 25 times for a total of 2025 model runs

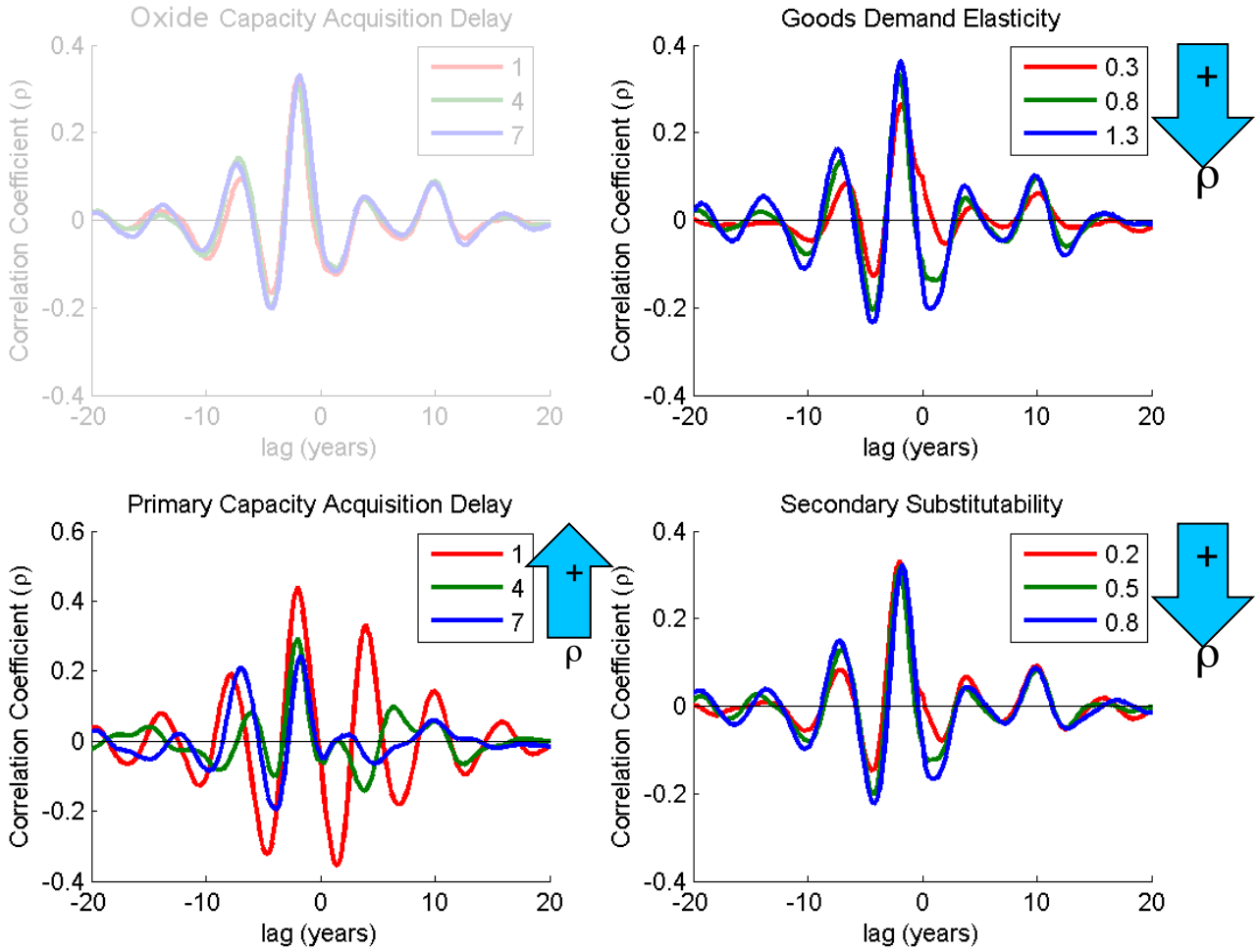
# How to Read a Correlogram



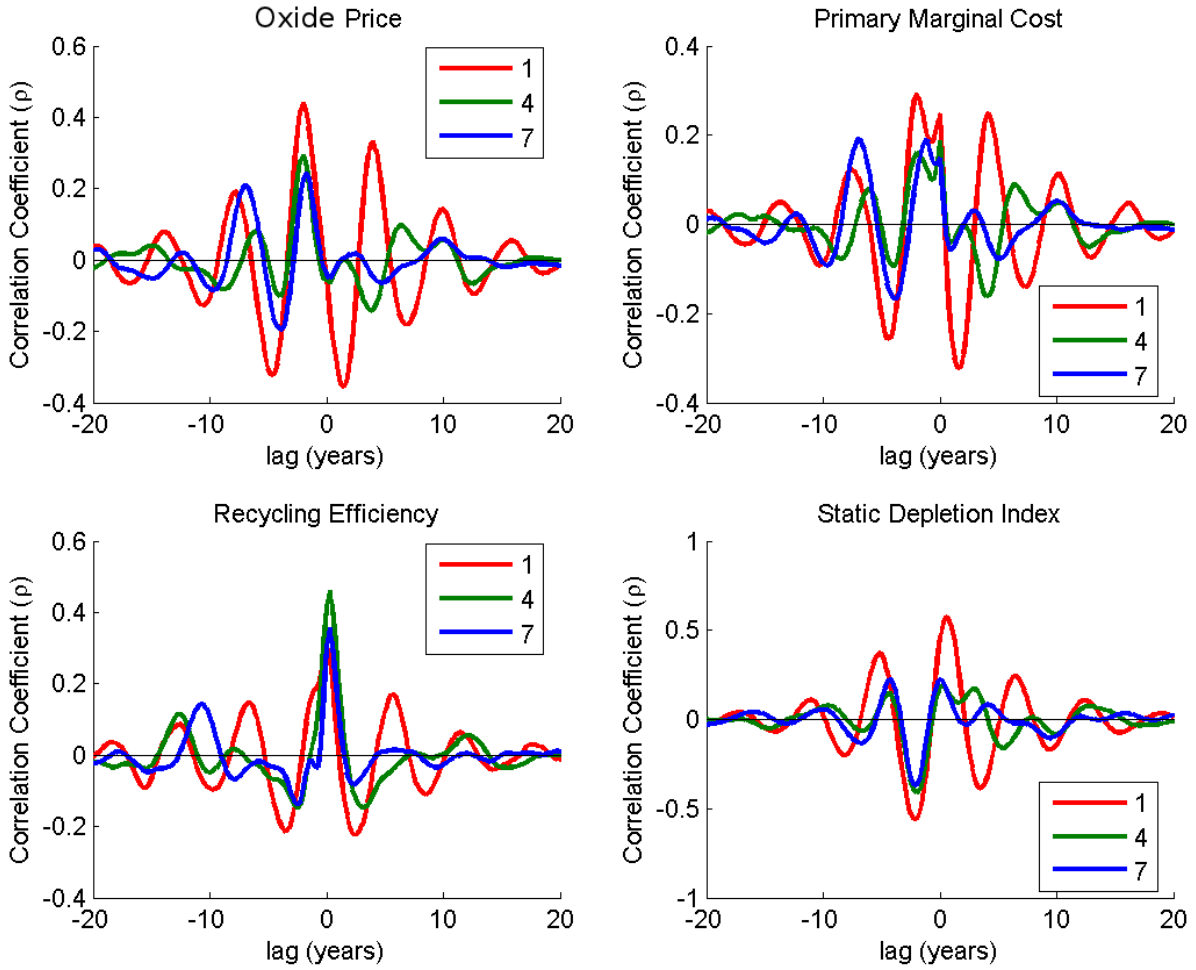
# Results: Correlograms



# Oxide Price: Broken down by Characteristics



# Metrics: Broken Down by Primary Delay



# Results Summary

- Price has a moderate correlation with some other scarcity risk metrics.
  - oxide price
  - primary marginal cost
  - recycling efficiency
  - and the static depletion index
- The correlations were weak for the remaining metrics.
- Correlations are stronger with:
  - Shorter primary capacity acquisition delays
  - Greater price elasticity of demand
  - Greater secondary substitutability

} *Increased responsiveness of material flows to price*

# Conclusions

- The modeled metrics with moderate correlations suggest that some metrics do provide relatively similar information to price. The remainder do not, because:
  1. Price is not reflecting the scarcity risk contained in the metrics
  3. Or, the metrics do no reflect the scarcity risk shown in price.
  4. Or, prices and metrics simply provide different information.
- However, there are conditions under which there is stronger correlation between price and metrics.
  - Markets in which material flows are more responsive to price show stronger correlations (high elasticity, low delays, high secondary substitutability.)