What is the value of flexibility in a product supply chain?

- **Base Design**: Produce everything before the start of the season at low-cost, long lead-time facilities.

- **Flexible Design**: Produce some additional units in high-cost, short lead-time facilities.

![Diagram showing production, sale, and demand over time for base and flexible designs.](image)
The key uncertainty is the demand for each product...

- Non-negative
- Long right-hand tails
- Learning
**Decision rules are designed to determine optimal production quantities...**

<table>
<thead>
<tr>
<th></th>
<th><strong>Before Season</strong></th>
<th><strong>During Season</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base Design</strong></td>
<td><img src="image" alt="Base Design Before Season" /></td>
<td>Q*</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Base Design During Season" /></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Flexible Design</strong></td>
<td><img src="image" alt="Flexible Design Before Season" /></td>
<td>Q*</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Flexible Design During Season" /></td>
<td>Q**</td>
</tr>
</tbody>
</table>

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Determining the optimal quantity for each case is a classic newsvendor problem...

**Profit Function:**

\[ \Pi = \begin{cases} 
q(r - p) & \text{if } d > q \\
q(r - p) + (q - d)(s - p) & \text{if } d \leq q'
\end{cases} \]

**Marginal Profit:**

\[
\frac{\partial \Pi}{\partial q} = P(d > q)(r - p) + P(d \leq q)(s - p) = 0
\]

\[
(1 - P(d \leq q))(r - p) + P(d \leq q)(s - p) = 0
\]

\[
P(d \leq q)((s - p) - (r - p)) = -(r - p)
\]

**Optimal Quantity:**

\[
P(d \leq q) = \frac{r - p}{(r - p) - (s - p)} = \frac{c}{c + h'}
\]
SIMULATION used 1M trials for each set of product, system design and decision rule…

- Base Design:

\[
NPV_{\text{Base}} = \left( \frac{\min(D, Q/T)}{r} \right) \left( 1 - \frac{1}{(1+r)^T} \right) - Q^{PL},
\]

- Flexible Design:

\[
NPV_{\text{Flexible}} = \left( \frac{\min\left( \frac{D}{T(1-E)}, \frac{Q}{T(1-E)} \right)}{r} \right) \left( 1 - \frac{1}{(1+r)^{(1-E)}} \right) - Q^{PL} + \left( \frac{\min\left( \frac{\hat{D}, Q^s + \hat{Q}}{TE} \right)}{r(1+r)^{(1-E)}} \right) \left( 1 - \frac{1}{(1+r)^{TE}} \right) - \frac{Q^{PS}}{(1+r)^{(1-E)}},
\]
The results show that the flexible design outperforms the base design...

<table>
<thead>
<tr>
<th></th>
<th>E[NPV]</th>
<th>STD[NPV]</th>
<th>CAPEX</th>
<th>E[NPV]/CAPEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Design</td>
<td>$313,085.60</td>
<td>$219,461.20</td>
<td>$265,680.00</td>
<td>1.18</td>
</tr>
<tr>
<td>(Inflexible)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexible Design</td>
<td>$325,979.20</td>
<td>$270,032.50</td>
<td>$185,976.00</td>
<td>1.75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>P5</th>
<th>P95</th>
<th>Min(NPV)</th>
<th>Max(NPV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Design (Inflexible)</td>
<td>$(91,701.71)</td>
<td>$504,191.10</td>
<td>$(258,937.60)</td>
<td>$504,191.10</td>
</tr>
<tr>
<td>Flexible Design</td>
<td>$(50,923.83)</td>
<td>$722,381.20</td>
<td>$(181,233.00)</td>
<td>$13,056,468.70</td>
</tr>
</tbody>
</table>
The results show that the flexible design outperforms the base design...
THE VALUE OF FLEXIBILITY DEPENDS ON THE UNCERTAINTY AND THE PRODUCTION COSTS...
The value of flexibility increases with the number of products...

5 Products

- Coefficient of Variation = 0.5
- Coefficient of Variation = 1
- Coefficient of Variation = 1.5
- Coefficient of Variation = 2

10 Products

- Coefficient of Variation = 0.5
- Coefficient of Variation = 1
- Coefficient of Variation = 1.5
- Coefficient of Variation = 2

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SUMMARY OF FINDINGS…

- The flexible design reduced the potential losses, significantly improved the potential gains, and had an average net present value increase of over 4% for a typical set of operating conditions.

- The benefit of the flexibility increases dramatically as the cost of short lead-time production goes down or the demand uncertainty goes up.

- As the number of products increases, the flexible design becomes progressively more attractive.