Sustainability Issues and Some Research Questions

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Waste tracked in US

Municipal solid waste - Waste discarded by households, hotels/motels, and commercial, institutional, and industrial sources. Consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. In 2000, the U.S. generated approximately 232 million tons of MSW.

Hazardous waste – waste that is ignitable, corrosive, reactive, or toxic. 40 million tons of RCRA hazardous waste by top 2000 businesses in 2000.

Radioactive waste – In 2000, approximately 600,000 cubic meters

Other types of waste

- Extraction waste
- Industrial non-hazardous waste
- Household hazardous waste
- Agricultural waste
- Construction and demolition waste
- Medical waste
- Oil and gas waste
- Sludge
- Energy inefficiencies


Focus on Energy – Good News

- Between 1973 and 1986 the U.S. economy grew by 36 percent with no increase in energy use. If Americans had not become more energy efficient, annual energy bills would have been $150 billion higher.

In 1994, the United States imported more than 50 percent of its petroleum. America still wastes upwards of $300 billion a year worth of energy: more than the entire military budget, far more than the federal budget deficit, and enough to increase personal wealth by more than $1,000 per American per year.

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The US economy is not even 10% energy efficient as the laws of physics allow. Just the energy thrown off as waste heat by US power stations equals the total energy use of Japan. Energy production and use account for nearly 80 percent of air pollution, more than 88 percent of heat-trapping greenhouse gas emissions, and more environmental damage than any other human activity.
Resource Inefficiencies

- Only 1% of the energy consumed by today’s cars is actually used to move the driver: only 15-20% of the power generated by burning gasoline reaches the wheels (the rest is lost in the engine and drive train) and 95% of the resulting propulsion moves the car, not the driver.

- Only about 1% of all the materials (220 billion tons) mobilized to serve America is actually made into products and is still in use 6 months after sale.


What Can You Do?

- If over the next 15 years everyone were to buy only those energy-efficient products marked in stores with EPA's distinctive ENERGY STAR label, we could shrink our energy bills by a total of about $100 billion over the next 15 years and dramatically cut greenhouse gas emissions.

- Producing aluminum from recycled aluminum consumes 90 percent less energy than producing it from raw materials and generates 95 percent less air pollution.

What Can You Do?

- Each ton of glass produced from raw materials generates about 385 pounds of mining waste; using 50 percent recycled glass reduces this waste by almost 80 percent.
- One gallon of used motor oil when recycled yields the same amount of refined lubricating oil—2.5 quarts—as 42 gallons of crude oil. If America refined the billion gallons of motor oil they use every year, we would save 1.3 million barrels of oil every day, which represents half the daily output of the Alaska Pipeline. Recycle your used motor oil!!!

http://energy.navymil/awareness/tools/tools_10.html

What Can You Do?

- It is estimated that 50 percent to 80 percent of the tires rolling on U.S. roads are underinflated. Driving with tires that are underinflated increases "rolling resistance," wasting up to 5% percent of a car's fuel. We could save up to 2 billion gallons of gasoline annually simply by properly inflating our tires.

http://energy.navymil/awareness/tools/tools_10.html
Increasing Efficiency

- Adding low-emissivity (low-E) coatings to all windows in the United States would save the equivalent of 500,000 barrels of oil per day—one-third the amount of oil we import from the Persian Gulf.

- Boosting the fuel efficiency of cars in the United States by a mere 1.5 miles-per-gallon would save more oil than is estimated to lie under the Arctic National Wildlife Refuge.

The EPA Advocates Source Reduction

- **Source Reduction** refers to any change in the design, manufacture, purchase, or use of materials or products (including packaging) to reduce their amount or toxicity before they become municipal solid waste. Source reduction also refers to the reuse of products or materials.
Industry and the Environment

- Typical framing: Inherent and fixed trade-off: ecology versus the economy.

Social benefits from strict environmental standards versus Industry’s private costs for prevention and clean-up Costs that lead to higher prices and reduced competitiveness.

Industry and the Environment

Properly designed environmental standards

Innovations that lower the total cost of a product or improve its value

Resource productivity

Increased competitiveness
Parallel to TQM

- Initial reaction: “Higher quality means more inspection and rework or inevitable defects from the production line → $$$”

- TQM approach: “Defects are a sign of inefficient product and process design.”

- Redesign the process, build quality into the process (source reduction) instead of inspection and redesign (identification and processing of waste).

Examples

- 1991 law on benzene emissions
  - Opposed by coal tar distillers
  - Only way was to add costly gas blankets
  - One firm found a way of removing benzene from tar in the first processing step
  - Saved 3.3 million

Examples

- Reducing solvent emissions by 90%
  - 3M avoided solvents by using water-based solutions
  - Shortened time to market
  - Competitive advantage due to moving early


Examples

- Electronics companies to eliminate CFCs
  - Raytheon found alternate cleaning agent to be used in closed-loop system
  - Improved product quality
  - Reduced operating costs

Innovation-Friendly Regulation

- Focus on outcomes, not technologies.
- Enact strict rather than lax legislation
- Regulate close to the end-user and encourage upstream solutions
- Use phase-in periods
- Use market incentives
- Develop regulations in sync or slightly ahead of them.


Examples

- WEEE Directive of the European Union
  - Stipulates producer responsibility for recovery
  - Is expected to encourage innovations for ease of recovery, reduction of hazardous materials, information availability, etc.
  - All firms selling in Europe are affected
Challenges in Designing Closed-Loop Supply Chains

Inventory Management for Remanufacturable Products

- Issue: In the procurement of new components for remanufacturable products,
  - delay in procurement
  - products in field unobservable
  - return flows unpredictable

IMRT – Research Question

- Develop an ordering policy for new component procurement
- How much is it worth tracking products in the field?


IMRT - Approach

- Statistical estimation methods for censored data
- Closed-queuing network modeling
- Developed several policies for adaptive estimation and control
- Simulation-based comparison using disguised data from Kodak

Market Segmentation and Remanufacturing Technology Selection

Issues:
- Retreaded tires are valued less than new tires ⇒ market segmentation
- Not all used tires are retreadable ⇒ technology selection

Tire = Tread + Casing
Retreading = Replace + Reuse

Debo, Toktay and Van Wassenhove, INSEAD Working Paper

MSRTS - Research Questions

- What are the key profitability drivers in a product portfolio consisting of a new and a remanufactured product? How do they interact?

- What pricing strategy and production technology choice best fit the target market?

- What is the impact of a change in remanufacturing cost and other parameters?

Debo, Toktay and Van Wassenhove, INSEAD Working Paper
**MSRTS - Approach**

- Develop multi-period optimization model with
  - Heterogeneous customers
  - Lower valuation of remanufactured product
  - Production and remanufacturing cost as a function of remanufacturability level
  - Volume dependence over time
  - Prices and remanufacturability level as decision variables
  - Characterize optimal solution and do sensitivity analysis

Debo, Toktay and Van Wassenhove, INSEAD Working Paper

**MSRTS - One Result**

- It may be optimal to price new product at a low margin or even at a loss
  - Why? Creates opportunity for future remanufactured product sales, where most of the profit is made.

**Implication:**

Single profit center may dominate two separate profit centers.

Debo, Toktay and Van Wassenhove, INSEAD Working Paper
Internal Transfer Pricing

Computer industry
- Separate remarketing organization
- Sales org. buys from manufacturing at SC and sells returns to remarketing at same SC

Telecommunications
- Separate remarketing organization
- Sales org. buys from manufacturing at SC and sells returns to remarketing at 0 transfer price

Internal Transfer Pricing

Copier/printing solutions (Oce*)
- Manufacturing sells to OpCo’s at standard cost
- There is an Asset Recovery department
- Asset Recovery posts internal transfer price to OpCo for ‘purchasing’ used products

* “Managing Asset Recovery at Océ N.V.,” A Business View on Closed Loop Supply Chains, REVLOG Group
ITP - Research Question

- Under a decentralized structure, what is the appropriate cost allocation mechanism that aligns division incentives with those of the firm?

ITP - Approach

- Develop two-division decentralized model, D1 manufactures and sells first, D2 remanufactures and sells later (Stackelberg Game)
- Solve centralized benchmark, quantify level of inefficiency from Stackelberg equilibrium
- Develop cost allocation mechanism to achieve centralized benchmark profit
Model: Company Structure

Decisions
new product price $p_n$
remanufactured product price $p_r$

Decisions
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new product price $p_n$
remanufactured product price $p_r$

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Model: Company Structure

Decisions
- new product price $p_n$
- remanufactured product price $p_r$

Demand model

$$d_n = 1 - p_n$$

- Consumer has lower willingness-to-pay for a remanufactured product

$$d_r = 1 - \frac{p_r}{1 - \delta}$$

“perceived depreciation”
**Model: Decisions and cash flows**

- Produce and sell new prod. \( s_n = d_n(p_n) \)
- Dispose \( 1-q \)
- Returned & reusable \( q s_n \)
- Salvage
- Remanufacture and sell \( s_r = d_r(p_r) \leq q s_n \)

\[ pn \quad c \quad D1 \quad Period \ 1 \quad D2 \quad Period \ 2 \quad cr \quad v \quad time \]

**First-Best Solution**

\[
\max_{s_n, s_r} s_n p_n(s_n) - c s_n + \beta (s_r p_r(s_r) - c_r s_r + v(q s_n - s_r))
\]

\[ s_r \leq q s_n \]

**Proposition:**

- \( s_r^* < q s_n^* \) (unconstr.) if \( c_r + v \geq (1 - q(1 + c + \beta v q))(1 - \delta) \)
- \( s_r^* = q s_n^* \) (constr.) o/w
Decentralized Scenario ($\alpha = 1$)

\[
\max_{s_n} s_n p_n(s_n) - c s_n \quad \max_{s_r} s_r p_r(s_r) - c_r s_r + v(q\tilde{s}_n - s_r)
\]

\[
\begin{align*}
\downarrow & \quad \tilde{s}_n \\
\downarrow & \quad \tilde{s}_r
\end{align*}
\]

Proposition: If $v > 0$, then $\tilde{s}_n < \tilde{s}_n^*$ and $\tilde{s}_r \leq s_r^*$.

Proportional Cost Allocation $\alpha c$

D1: \[
\max_{s_n} s_n p_n(s_n) - \alpha c s_n \quad \longrightarrow \quad \tilde{s}_n
\]

D2: \[
\begin{align*}
\max_{s_r} (1 - \alpha) c \tilde{s}_n + s_r p_r(s_r) - c_r s_r + v(q\tilde{s}_n - s_r) \\
\downarrow & \quad q\tilde{s}_n \\
\downarrow & \quad \tilde{s}_r
\end{align*}
\]
Optimal Cost Allocation

Proposition: An \((\alpha^*, 1-\alpha^*)\) cost allocation scheme achieves the first-best solution with

\[
\alpha^* = \begin{cases} 
\frac{c - \beta v q}{c} & \text{if unconstrained} \\
\frac{c + \beta q (c + (1-\delta)(q-1))}{c(1 + \beta q^2(1-\delta))} & \text{if constrained}
\end{cases}
\]

Interpretation of \(\alpha^*\)

Proposition: \(\alpha^* = \frac{C'_N(s^*_n)}{c} \quad \Rightarrow \quad \text{Firm’s marginal cost}
\)

\[
\text{D1: max}_{s_n} s_n p_n(s_n) - \alpha c s_n
\]

\[
\text{max}_{s_n} R_N(s_n) - C'_N(s^*_n) s_n
\]

FOC: \(R'_N(s_n) - C''_N(s^*_n) = 0\)

\(\Rightarrow \quad \text{D1 chooses } s_n^*\)
Interpretation of $\alpha^*$

1. Unconstrained case: 
   \[ \alpha^* = \frac{c - \beta vq}{c} \]
   FOC: \[ R'_N(s_n) - \left( c - \beta vq \right) = 0 \]
   - marginal revenue to D1
   - life-cycle marginal cost to firm (when next unit is salvaged)

2. Constrained case: 
   \[ \alpha^* = \frac{c + \beta q(c_r + (1-q)(q-1))}{c(1+\beta q^2(1-\delta))} \]
   FOC: \[ R'_N(s_n) - \frac{c + \beta q c_r + \beta q ((1-\delta)(q-1))}{1+\beta q^2(1-\delta)} = 0 \]
   - marginal revenue to D1
   - life-cycle marginal cost to firm (when next unit is remanufactured)

Conclusions

- Cost allocation should be such that the marginal revenue from making one more new product = the marginal cost to the firm of producing that product.

- When salvage value is negligible and remanufacturing unconstrained, decentralization is not an issue ($\alpha^* = 1$).

- When cost is allocated to a second department, it must be allocated so it is a sunk cost, not a variable cost.
SPECIAL ANNOUNCEMENT

As part of the Anderson/Interface Chair Natural Systems Speaker Series, Dr. Karl-Heinz Robiet will be speaking at Georgia Tech on April 29th. This lecture, as well as the others in this series, are co-sponsored by the Institute for Sustainable Technology and Development and the School of Industrial & Systems Engineering. Please visit our Campus Lectures page for further details on this series.

Also, please consider attending a Technical Lecture by Dr. Robiet on Friday, April 30th at 11 AM. It will be held in L222 in the Millett Hall, exact venue to be determined.

Check back for updates. Please RSVP for this event to 404-894-7999.

- Dr. Karl-Heinz Robiet
  Time: Thursday, April 29, 2004 @ 5:10 PM
  Duration: 1 hour
  Location: College of Management Auditorium, Technology Square, 600 West Peachtree Street NW, Tennenbaum Auditorium