Overview

- Global Supply Chain Problem
- Bilinear Transfer Price Formulation
- Iterative Heuristic
- Global Optimization Procedure
- Computational Example
- Conclusions
Global Logistics Systems Models

- Domestic Plus Exchange Rates, Duties, Taxes
- Objective is Worldwide After-Tax Profit Maximization
- Decisions are Material Flows, Transportation Cost Allocations, and Transfer Prices

Tax Rates and Profit Realization

- Tax Rates: 34%, 17%, 12%
- Profit Realization: 40% or more
Previous Research

- **Nieckels (1976)**
  - NLP to solve TPP iteratively, local opt.
  - Single commodity, no BOM

- **Cohen et al. (1989)**
  - Dyn. NL MIP, solved iteratively, local opt.
  - TP are markup
  - Strong country tax reduction (feasible?)
  - Implementation Cohen and Lee (1989)

Continued

- **Arntzen et al. (1995)**
  - Comprehensive model for DEC
  - No TP and taxes part of production costs
  - Specialized MIP algorithms

- **Canel and Khumawala (1997)**
  - TP fixed a priori at LB or UB
  - MIP model
Previous Research Summary

- **TP either**
  - Set a priori
  - Determined iteratively, local optimum, and no bound
  - Not included

Global Transactions and Tax Rates

![Diagram showing tax rates and net income before tax between two countries, A and B, with variables a, x, t, p, and b.](image-url)
Impact of Transfer Prices on After Tax Profits

The basic model

Maximize global after tax profit:

- After tax profit of internal suppliers
- After tax profit at plants
- After tax profit at distribution centers
- Inventory costs

Subject to:
- Nonlinear expressions for the net income before tax
- Suppliers’ capacity (internal and external suppliers)
- Production capacity at plants
- Customer demand constraints
- Bill of materials (at plants)
- Balance constraints at DCs
- Minimum profit for internal suppliers, plants and DCs (optional)
- Bounds on decision variables
**Before and After Tax Profit**

**Objective and Constraint**

\[
\begin{align*}
\text{max} & : (1 - \text{taxrate}_i) \text{ibtof}_{-i}^* - \text{ibtof}_{-i}^- \\
\text{subject to} : & \\
\sum_k \sum_l \sum_p \left( \frac{1}{E_k} \right) \text{MPRICE}_{lpk} w_{lpk} & - \sum_k \sum_l \sum_p \left( \frac{1}{E_k} \right) \left[ \text{HANDC}_{lp} + \text{TRCWM}_{lmp} w_{lmp} \right] w_{lpk} \\
& - \sum_k \sum_l \sum_p \left( \frac{1}{E_k} \right) \left[ \text{MPRICE}_{lpk} \left( \frac{v_{Hk}}{w_{lpk}} + \sqrt{\text{TTWM}_{lmp}} \right) \text{SHIFREQ}_{lmp} + \text{SSFW}_{lp} \text{TTWM}_{lmp} \right] w_{lpk} \\
& - \sum_k \sum_l \sum_p \left( \frac{1}{E_k} \right) \left( \text{MPRICE}_{lpk} \left( 1 + \text{DUTY}_{lp} \right) + \left( 1 - \text{prowp}_{lp} \right) \text{TRCPW}_{rp} W_p \right) x_{lpk} \\
& - \left( \frac{1}{E_k} \right) \text{FIXDC}_k = \text{ibtof}_{-i}^* - \text{ibtof}_{-i}^- \quad k \in W^I
\end{align*}
\]
**Solution Methodology**

- An optimization-based heuristic:
  - Substitution of proportion variables
  - Redefinition and substitution of TP variables
  - Relaxation of nonlinear constraints
  - Iterative procedure

- Global optimization
  - Tightening of Dual Bound with Primal Heuristics

\[ \text{prop}_{ijm} \sum_{r \in R(i \cap R(j))} W_r x_{ijur} = z_{ijm} \quad i \in S', j \in M(i), m \in T(i, j) \]

\[ \text{prop}_{jkm} \sum_{p \in P(j)} W_p x_{jknp} = z_{jkm} \quad j \in M, k \in W, m \in T(j, k) \]
Transfer Prices Substitution and Constraints

\[ \text{tpsul}_{ijr} \sum_{m \in T(i,j)} s_{ijmr} = y_{ijr} \quad i \in S', j \in M(i), r \in R(i) \cap R(j) \]

\[ \text{tppldc}_{jkp} \sum_{m \in T(j,k)} x_{jkmp} = y_{jkp} \quad j \in M, k \in W, p \in P(j) \]

\[ \sum_{m \in T(i,j_k)} y_{ijr} = \sum_{m \in T(i,j_{k+1})} y_{ijr+1} \]

\[ \sum_{m \in T(j,k_p)} x_{jkmp} = \sum_{m \in T(j,k_{p+1})} x_{jkmp+1} \]

Transformed Formulation

Max \( d_0^T v \)

s. to:

\[ c_r^T x + d_r^T v + e_r^T y + g_r^T z = f_r; \quad r = 1,\ldots,m \]

\( Cx \leq b \)

\( D^T x \leq y \leq D^T x \)

\( z - Ex \leq 0 \)

\( x^T F_q y = 0; \quad q = 1,\ldots,h \quad \text{(constraints to be relaxed)} \)

\( x \geq 0, y \geq 0, v \geq 0, z \geq 0 \)
**Optimization-Based Heuristic**

Solve \( RP(x, y, z) \):
- Upper Bound on \( P(x, t, p) \) and starting point

Feasible?
- Yes: Optimal Solution to \( P(x, t, p) \)
- No: Solve \( P(x, t, z | x) \)

Convergence criterion?
- Yes: Local optimum of \( P(x, t, p) \)
- No: Solve \( P(x, t, z | t) \)

**Starting Points for Heuristic Procedure**

- Optimal TP (From Relaxation)
- Optimal Flows (From Relaxation)
- Tax Heuristic
- Lower Bound TP
- Upper Bound TP
- Middle Point TP Interval
- Zero Initial Flows
Computational Test Case

- 50 Raw Material Suppliers
- 8 Plants, 10 Distribution Centers
- 80 Customers
- 35 Components, 12 Finished Products
- 3.1 Modes per Channel
- 10100 Variables, 2900 Constraints

Heuristic Computation Results

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<tr>
<th>No.</th>
<th>Starting Point</th>
<th>% gap from the upper bound</th>
<th>Solution time (s)</th>
<th>No. of iterations</th>
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Global Optimization Procedure

- Specified Optimality Gap $\varepsilon$
  \[ f \leq \max_i g_i \leq g_T \]
- Acceleration Techniques
  - Branching rule: largest TP interval
  - Branching rule: interior transfer prices

### Computational Experiment

Global Optimization Procedure

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<tr>
<th>MEDIUM INSTANCES</th>
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## Profit Increases for Optimal Transfer Prices

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<th>Instance</th>
<th>Middle Point</th>
<th>Tax Rate</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
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### Impact of Transfer Price on Corporate Profits

**Graph:**
- **Title:** NET INCOME AFTER TAX ($/YEAR) vs. TRANSFER PRICE FACTOR
- **Question:** What is the maximum transfer price factor that satisfies the operating profit constraints of all sources?

![Graph showing the relationship between Net Income After Tax and Transfer Price Factor](image)
**Conclusions**

- **Transfer Price Formulation is Bilinear**
- **Iterative Heuristic**
  - Efficient,
  - Case Dependent Gap
- **Global Optimization Procedure**
  - A Priori Gap
  - Efficient with Acceleration Techniques
- **Significant Impact on After Tax Profits**

**Supply Chain Modeling Challenges**

- **Multiple Periods**
  - Periodic demand
  - Dynamic strategic systems
- **Global**
  - Taxes and profit realization
  - Local contents, duty drawback
- **Stochastic**
  - Flexibility, robustness, risk, scenarios
Supply Chain Solution Algorithms Challenges

- Large Scale Models
- Non-Linear Models
- Stochastic Models
- Standard MIP Linear Algorithms Cannot Solve Very Large Cases
- NL-MIP or Stochastic Algorithms Only for Small Cases or Nonexistent

Supply Chain Design Challenges

- Integrated models are large and complex
- Accommodate diversity of local characteristics
- Cost, flexibility, and responsiveness tradeoffs for performance measures
- Strategic design as a continuous effort
- Technology transfer to logistics professionals and students
From a Multicommodity Case...

...and Configuration by a Current Design Tool
To Design Tools for the Next Century