Design of Global Supply Chains

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IERC Cleveland, Spring 2000

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Overview

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

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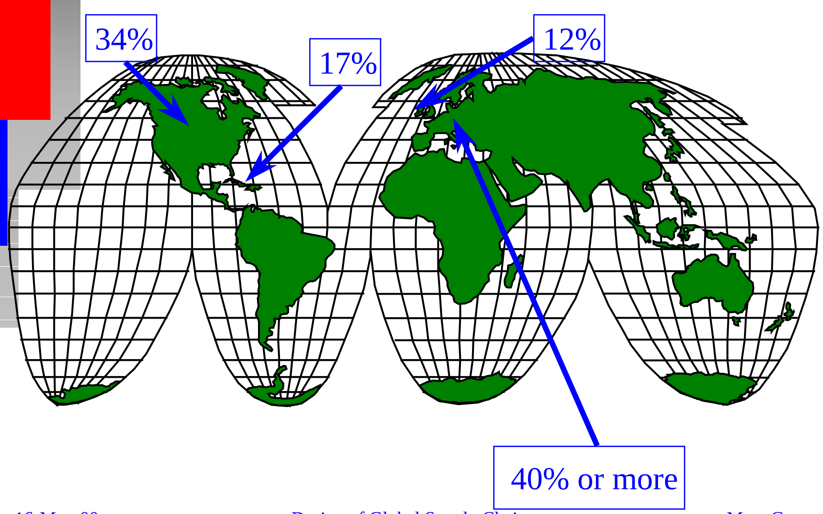
Global Logistics Systems Models

- 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



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)

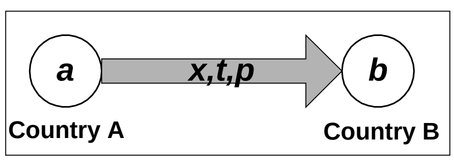
Previous Research Continued

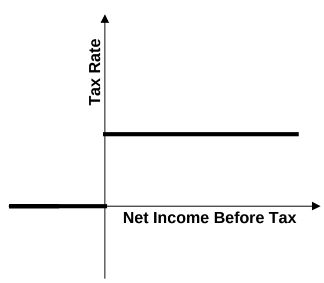
- Arntzen et al. (1995)
  - Comprehensive model for DEC
  - No TP and taxes part of production costs
  - Specialized MIP algorithms
- Canel and Khumawala (1997)
  - TP fixed a priori at LB or UB
  - MIP model

Previous Research Summary

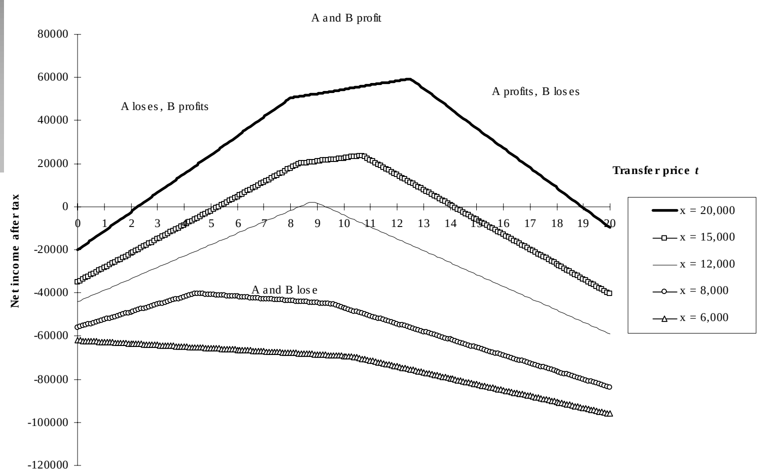
- TP either
  - Set a priori
  - Determined iteratively, local optimum, and no bound
  - Not included

Global Transactions and Tax Rates





Impact of Transfer Prices on After Tax Profits



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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**

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Before and After Tax Profit Objective and Constraint

$$max:(1-taxrate_k)ibtwf_k^+ - ibtwf_k^-$$

$$subject\ to:$$

$$\sum_{l\in C(k)}\sum_{m\in T(k,l)}\sum_{p\in P}\left(\frac{1}{E_l}\right)MPRICE_{lp}w_{klmp} - \sum_{l\in C(k)}\sum_{m\in T(k,l)}\sum_{p\in P}\left(\frac{1}{E_k}\right)\left[HANDC_{kp}+TRCWM_{klm}W_p\right]w_{klmp}$$

$$-\sum_{l\in C(k)}\sum_{m\in T(k,l)}\sum_{p\in P}\left(\frac{VP_{kp}H}{E_k}\right)\left[TTWM_{klm}+(CSF)\ SHIPFREQ_{klm}+SSFW_{kp}\sqrt{TTWM_{klm}}\right]w_{klmp}$$

$$-\sum_{j\in M}\sum_{m\in T(j,k)}\sum_{p\in P(j)}\left(\frac{1}{E_j}\right)\left[tppldc_{jp}\left(1+DUTY_{jkp}\right)+\left(1-propw_{jkm}\right)\ TRCPW_{jkm}W_p\right]x_{jkmp}$$

$$-\left(\frac{1}{E_k}\right)FIXDC_k = ibtwf_k^+ - ibtwf_k^- \qquad k\in W^f$$

The Basic Model (General Structure)

$$\textbf{Max}\quad c_0^T x$$

s. to:

$$\mathbf{P}(x,t,p)\qquad c_r^T x + x^T A_r t + x^T B_r p = b_r;\quad r=1,2,\ldots,m$$

$$Cx \le d$$

$$T^- \le t \le T^+$$

$$0 \le p \le 1$$

$$x \ge 0,\ t \ge 0$$

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

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Substitution of Transportation Cost Proportion Variables

$$prosp_{ijm} \sum_{r \in R(i) \cap R(j)} W_r s_{ijmr} = z_{ijm} \qquad i \in S',\ j \in M(i),\ m \in T(i,j)$$

$$propw_{jkm} \sum_{p \in P(j)} W_p x_{jkmp} = z_{jkm} \qquad j \in M,\ k \in W,\ m \in T(j,k)$$

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Transfer Prices Substitution and Constraints

$$tpsupl_{ijr} \quad \sum_{m \in T(i,j)} s_{ijmr} = y_{ijr} \qquad i \in S',\ j \in M(i),\ r \in R(i) \cap R(j)$$

$$tppldc_{jkp} \quad \sum_{m \in T(j,k)} x_{jkmp} = y_{jkp} \qquad j \in M,\ k \in W,\ p \in P(j)$$

$$\frac{y_{ij_n r}}{\sum_{m \in T(i,j_n)} s_{ij_n mr}} = \frac{y_{ij_{n+1} r}}{\sum_{m \in T(i,j_{n+1})} s_{ij_{n+1} mr}}$$

$$\frac{y_{jk_n p}}{\sum_{m \in T(j,k_n)} x_{jk_n mp}} = \frac{y_{jk_{n+1} p}}{\sum_{m \in T(j,k_{n+1})} x_{jk_{n+1} mp}}$$

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Transformed Formulation

Max $d_0^T v$

s. to:

$$c_r^T x + d_r^T v + e_r^T y + g_r^T z = f_r; \qquad r = 1,2,\ldots,m$$

$$Cx \le b$$

$$D^l x \le y \le D^u x$$

$$z - Ex \le 0$$

$$x^T F_q y = 0; \qquad q = 1,2,\ldots,h \qquad \text{(constraints to be relaxed)}$$

$$x \ge 0,\ y \ge 0,\ v \ge 0,\ z \ge 0$$

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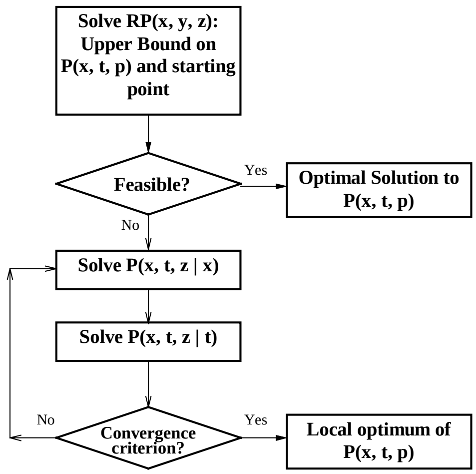
Optimization-Based Heuristic



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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

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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

MEDIUM INSTANCES[a]

No.	Starting Point	% gap from the upper bound	Solution time (s)	No. of iterations[b]
3	Opt_Flows	0.251	127.16	2
	Opt_TP	0.400	423.10	13
	Heu_TP	3.473	107.48	2
	LB_TP	1.384	118.95	2
	UB_TP	0.782	147.35	3
	Mid_TP	0.614	140.41	3
	Init_Flows = 0	1.384	143.81	3
4	Opt_Flows	0.773	242.18	7
	Opt_TP	0.525	117.22	2
	Heu_TP	6.691	126.49	3
	LB_TP	2.186	143.41	3
	UB_TP	1.515	126.21	2
	Mid_TP	1.965	239.12	7
	Init_Flows = 0	2.186	206.57	5
5	Opt_Flows	1.340	10,637.81	372
	Opt_TP	0.504	21,836.41	793
	Heu_TP	6.527	698.22	37
	LB_TP	5.260	14,295.65	677
	UB_TP	3.174	34,447.42	1,356
	Mid_TP	4.829	26,312.53	1,177
	Init_Flows = 0	5.241	22,873.70	1,028

Global Optimization Procedure

- Specified Optimality Gap ε
- Ben-Tal (1994) Branch and Bound Method for Reducing Duality Gap

$$f \leq \max_i g_i \leq g_T$$

- Acceleration Techniques
  - Branching rule: largest TP interval
  - Branching rule: interior transfer prices

Computational Experiment Global Optimization Procedure

MEDIUM INSTANCES

No.	Target Tolerance ε (%)	% gap achieved	Solution time (s)	No. of branches[b]
3	N/A[a]	0.624 (0.405)[d]	91.17	2
	1.000	0.935	138.09	1
	0.900	0.867	1204.15	12
	0.800	0.796	3015.55	28
	0.600	0.496	430.02	3
	0.400	0.391	7537.98	59
4[c]	N/A[a]	0.568 (0.568)[d]	22410.60	1001
	0.550	0.543	988.24	1
	0.500	0.522[e]	11532.04	9[e]
5	N/A[a]	0.061 (0.28)[d]	3612.42	206
	0.060	0.042	142.21	1
	0.040	0.032	226.13	2
	0.020	0.028[e]	2709.06	16[e]

Profit Increases for Optimal Transfer Prices

	Transfer Price Heuristics			
Instance	Middle Point	Tax Rate	Lower Bound	Upper Bound
1	2.4	0.2	0.8	4.1
2	23.2	12.1	17.1	29.2
3	22.6	30.2	39.9	16.2
4	45.6	65.0	95.2	32.1

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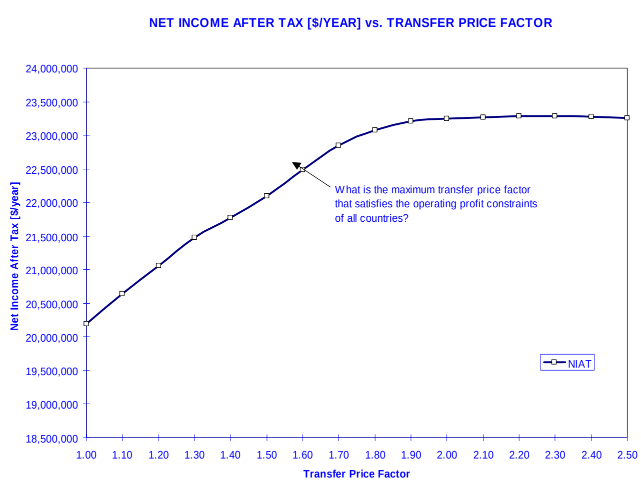
Impact of Transfer Price on Corporate Profits



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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

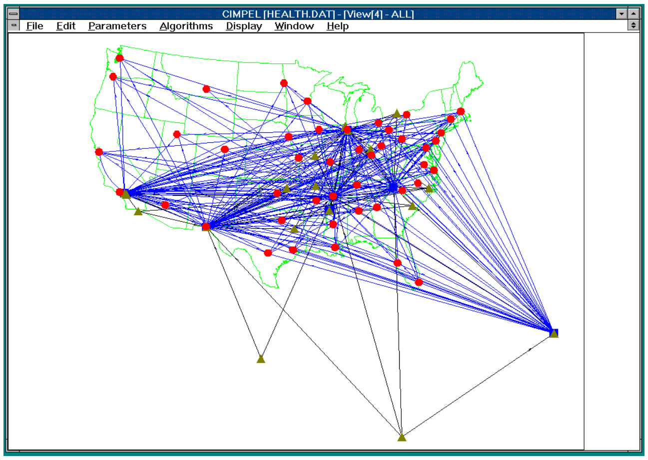
Supply Chain Solution Algorithms Challenges

- 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...



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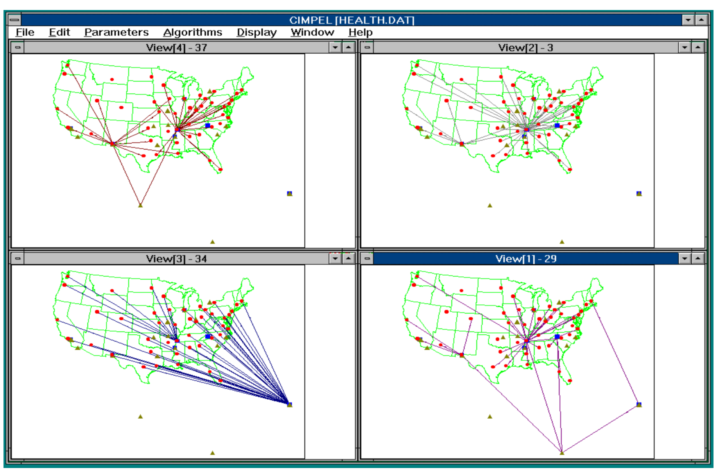
...and Configuration by a Current Design Tool



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To Design Tools for the Next Century

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