Dynamics of Supply Chain Networks with Corporate Social Responsibility (CSR) through Integrated Environmental Decision-making

Jose M. Cruz
Department of Operations and Information Management
School of Business
University of Connecticut at Storrs

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Outline

- CSR Research Themes
- CSR & Supply Chain Management
- Model Framework
- Numerical Examples
- Empirical Results
- Future Research

Definition of CSR

Business in the Community defines CSR as: "a company's positive impact on society and the environment, through its operations, products or services and through its interaction with key stakeholders such as employees, customers, investors, communities and suppliers."

CSR Research Themes

- From 1953 to 1970:
  - Responsibility of the businessman (Bowen, 1953).
- From 1970 to 1980:
  - Characteristics of socially responsible behavior (Davis, 1973; Carroll, 1979)
- In the 1980s:
  - Stakeholder theory (Freeman, 1984)
  - Business ethics (Frederick, 1986
  - Corporate social performance (Drucker, 1984)
- In the 1990s:
  - Empirical studies attempted to correlate CSR with financial performance (Clarkson, 1991; Waddock and Graves, 1997; Berman et al., 1999; Roman et al., 1999)
- Today CSR is:
  - A prominent research theme
  - Found in corporate missions and value statements

CSR Stakeholders

CSR & Supply Chain

- Factors:
  - Legal requirements
  - Pressure from consumers
  - Changing consumer preferences
- Results:
  - Attempt to minimize their emissions
  - Produce more environmentally friendly products
  - Establish sound recycling network systems
  - Managing the corporate social responsibilities of their partners within the supply chain

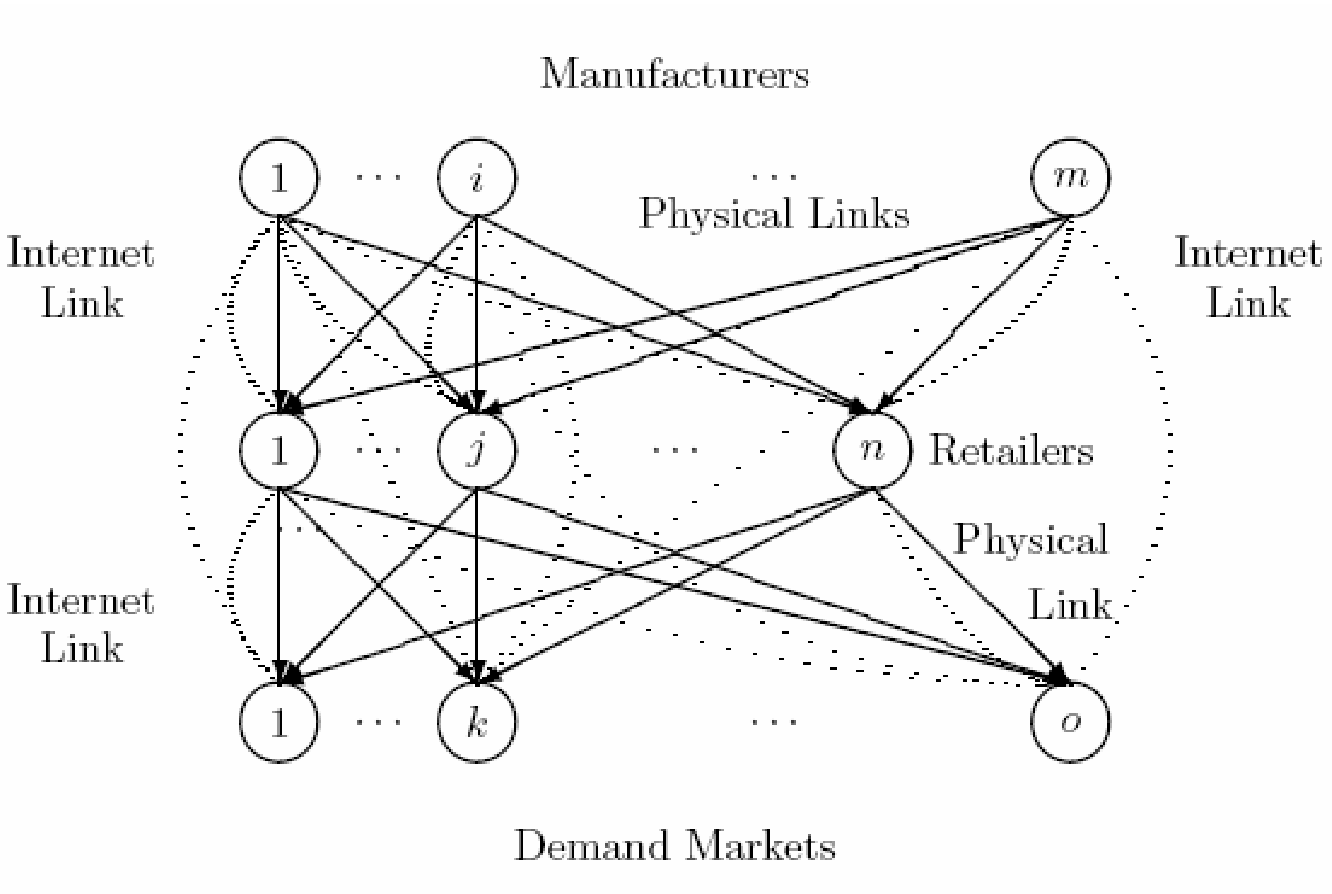
CSR & Supply Chain

- Operational benefits realized by improving environmental and working conditions performance
  - Lower energy cost
  - Less waste
  - Increased productivity
  - Improved safety
  - Decreased turnover and training cost
  - Brand risk management

CSR & Supply Chain

- How do companies benefit from the CSR concept?
  - Reduced costs
  - Increased business leads
  - Increased reputation
  - Increased staff morale and skills development
  - Improved relationships with the local community, partners and clients
  - Innovation in processes, products and services
  - Managing the risks a company faces

Network Structure



Features of the Model

- Captures multi-tiers
  - Manufacturers
  - Retailers
  - Demand markets
- Captures interactions among individual decision-makers
  - Competition at the same tier
  - Coordination among different tiers
- Incorporates multi-criteria decision-making
- Determines
  - Production quantities, shipments, price and levels of SR activities
- Dynamic evolution of
  - Product transactions, prices and levels of SR activities

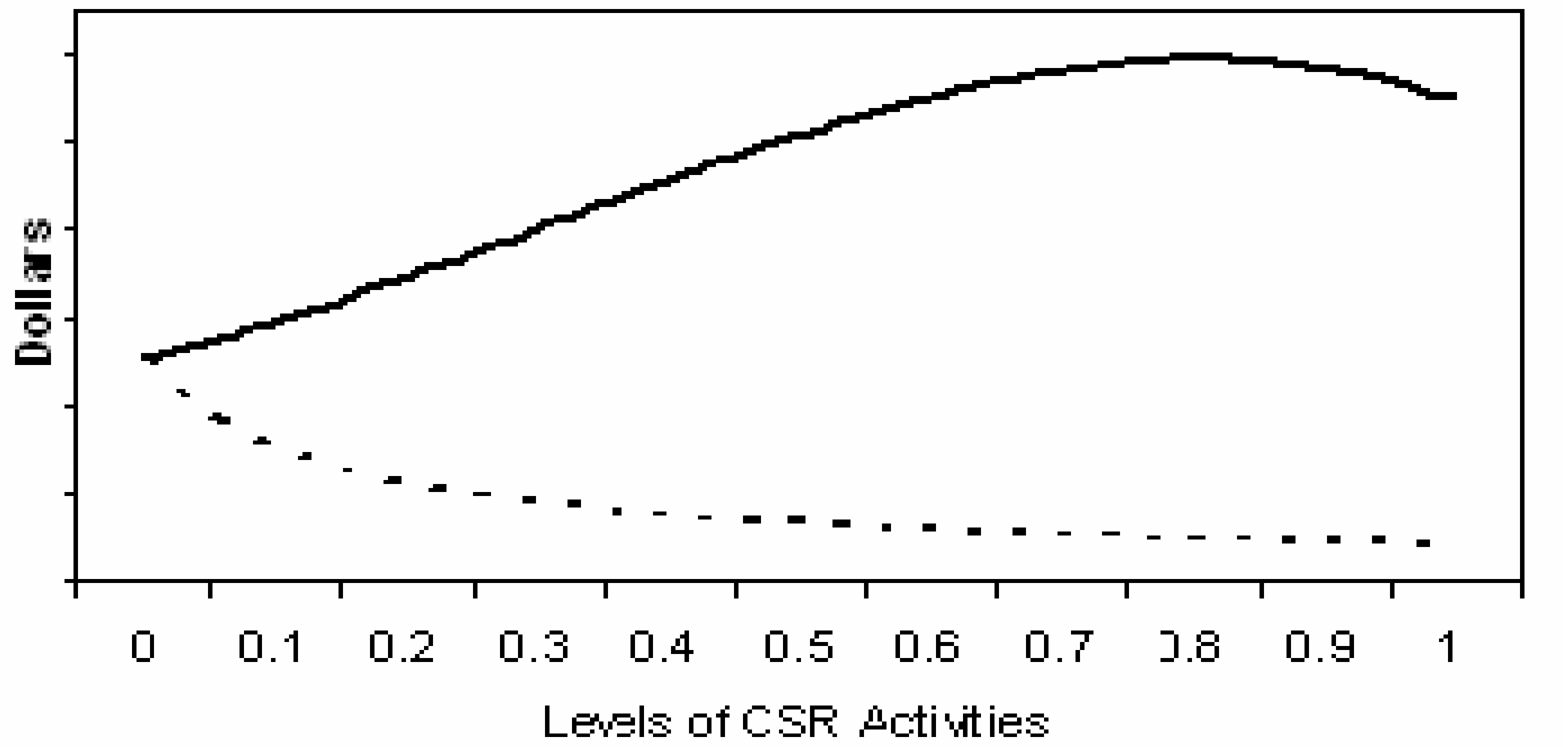
Assumptions

- Transactions either physically or electronically via Internet links
- Establishing levels of social responsibility activities incurs some costs
- Higher levels of social responsibility activities
  - Reduce transaction costs
  - Reduce risk
  - Reduce emission (waste)

Multicriteria Decision-Makers

- Manufacturers and retailers try to:
  - Maximize profit
  - Minimize emission (waste)
  - Minimize risk
  - Individual weights assigned to the different criteria
- Optimal solution will determine:
  - Optimal levels of CSR Investment
  - Optimal prices
  - Optimal levels of product transactions
- Nash equilibrium

CSR, Risk and Profit Relationship



A Manufacturer’s Decision-Making Problem

$$\text{Maximize} \quad \sum_{j=1}^{n}\sum_{l=1}^{2}\rho^{*}_{1ijl}q_{ijl} + \sum_{k=1}^{o}\rho^{*}_{1ik}q_{ik} - f_i(q_i) - \sum_{j=1}^{n}\sum_{l=1}^{2}c_{ijl}(q_{ijl},\eta_{ijl}) - \sum_{k=1}^{o}c_{ik}(q_{ik},\eta_{ik})$$

$$-\sum_{j=1}^{n}\sum_{l=1}^{2}b_{ijl}(\eta_{ijl}) - \sum_{k=1}^{o}b_{ik}(\eta_{ik}) - \alpha_i e^i(Q^1,Q^2,\eta_1,\eta_2) - \omega_i r^i(Q^1,Q^2,\eta_1,\eta_2)$$

$$\text{subject to:} \quad q_{ijl} \geq 0, \quad q_{ik} \geq 0, \quad 0 \leq \eta_{ijl} \leq 1, \quad 0 \leq \eta_{ik} \leq 1, \quad \forall j,k,l.$$

A Retailer's Decision-Making Problem

$$\text{Maximize} \quad \sum_{k=1}^{o}\sum_{l=1}^{2}\rho^*_{2jkl}q_{jkl} - c_j(q_j) - \sum_{i=1}^{m}\sum_{l=1}^{2}\hat{c}_{ijl}(q_{ijl},\eta_{ijl}) - \sum_{k=1}^{o}\sum_{l=1}^{2}c_{jkl}(q_{jkl},\eta_{jkl})$$

$$-\sum_{i=1}^{m}\sum_{l=1}^{2}\hat{b}_{ijl}(\eta_{ijl}) - \sum_{k=1}^{o}\sum_{l=1}^{2}b_{jkl}(\eta_{jkl}) - \sum_{i=1}^{m}\sum_{l=1}^{2}\rho^*_{1ijl}q_{ijl} - \alpha_j e^j(Q^1,Q^3,\eta_1,\eta_3) - \omega_j r^j(Q^1,Q^3,\eta_1,\eta_3)$$

subject to:

$$\sum_{k=1}^{o}\sum_{l=1}^{2}q_{jkl} \le \sum_{i=1}^{m}\sum_{l=1}^{2}q_{ijl}$$

and the non-negativity constraints: $q_{ijl} \ge 0, \quad q_{jkl} \ge 0, \quad 0 \le \eta_{ijl} \le 1, \quad 0 \le \eta_{jkl} \le 1, \quad \forall i,k,l$

Equilibrium Conditions for Demand Markets

$$\rho^*_{2jkl} + \hat{c}_{jkl}(Q^{2*}, Q^{3*}, \eta^*_2, \eta^*_3) \begin{cases} = \rho^*_{3k}, & \text{if} \quad q^*_{jkl} > 0 \\ \geq \rho^*_{3k}, & \text{if} \quad q^*_{jkl} = 0, \end{cases}$$

$$\rho^*_{1ik} + \hat{c}_{ik}(Q^{2*}, Q^{3*}, \eta^*_2, \eta^*_3) \begin{cases} = \rho^*_{3k}, & \text{if} \quad q^*_{ik} > 0 \\ \geq \rho^*_{3k}, & \text{if} \quad q^*_{ik} = 0. \end{cases}$$

$$d_k(\rho^*_3) \begin{cases} = \sum_{j=1}^{n} \sum_{l=1}^{2} q^*_{jkl} + \sum_{i=1}^{m} q^*_{ik}, & \text{if} \quad \rho^*_{3k} > 0 \\ \leq \sum_{j=1}^{n} \sum_{l=1}^{2} q^*_{jkl} + \sum_{i=1}^{m} q^*_{ik}, & \text{if} \quad \rho^*_{3k} = 0. \end{cases}$$

The Equilibrium State

- Definition: The equilibrium state of the network is one where the flows between the tiers of the network coincide and the product transactions, levels of social responsibility activities, and prices satisfy the sum of the optimality conditions and the equilibrium conditions.

The equilibrium state is equivalent to a VI of the form:

$$\text{determine } X^* \in \mathcal{K} \text{ satisfying}$$

$$\langle F(X^*), X - X^* \rangle \geq 0, \quad \forall X \in \mathcal{K},$$

Projected Dynamical System

- The dynamic models can be rewritten as a projected dynamical system (Nagurney and Zhang (1996a)) defined by the following initial value problem:

$$\dot{X} = \Pi_{\mathcal{K}}(X, -F(X)), \quad X(0) = X_0, \tag{66}$$

where $\Pi_{\mathcal{K}}$ is the projection operator of $-F(X)$ onto $\mathcal{K}$ at X and $X_0 = (Q^{10}, Q^{20}, Q^{30}, \eta^{10}, \eta^{20}, \eta^{30}, \lambda^0, \rho_3^0)$ is the initial point corresponding to the initial product transaction, relationship level, and price pattern.

- The set of stationary points of the projected dynamical system coincides with the set of solutions of the variational inequality problem.

The Disequilibrium Dynamics

- The trajectory of the PDS describes the dynamic evolution of:
  - Product transactions on the supply chain network
  - Levels on the social responsibility activities
  - Demand market prices
  - Lagrange multipliers or shadow prices associated with the retailers.

The Euler Method

Step 0: Initialization

Set $X^0 \in \mathcal{K}$ and set $T = 0$. T is an iteration counter which may also be interpreted as a time period.

Step 1: Computation

Compute X^{T+1} by solving the variational inequality problem:

$$X^{T+1} = P_{\mathcal{K}}(X^T - a_T F(X^T)),$$

where $\{a_T\}$ is a sequence of positive scalars satisfying: $\sum_{T=0}^{\infty} a_T = \infty$, $a_T \to 0$, as $T \to \infty$

and $P_{\mathcal{K}}$ is the projection of X on the set $\mathcal{K}$ defined as:

$$y = P_{\mathcal{K}} X = \arg\min_{z \in \mathcal{K}} \|X - z\|.$$

Step 2: Convergence Verification

If $\|X^{T+1} - X^T\| \leq \epsilon$, for some $\epsilon > 0$, a prespecified tolerance, then stop; else, set $T = T + 1$, and go to Step 1.

Qualitative Properties

I have established

- Existence of a solution to the VI
- Uniqueness of a solution to the VI
- Conditions for the existence of a unique trajectory to the projected dynamical system
- Convergence of the Euler method

Numerical Examples

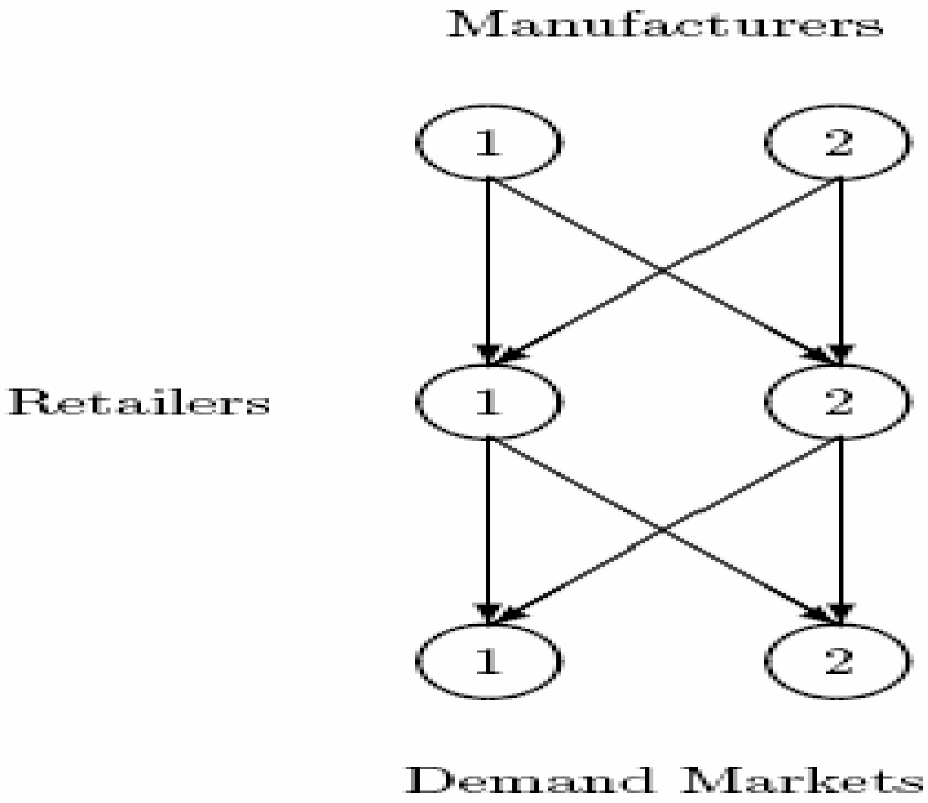


Figure 3: The network structure of the supply chain

Numerical Examples

Table 1: Functions for Numerical Examples 1-3

Notation	Definition
$f^i(q_i) = 2.5(\sum_{j=1}^{2} q_{ijl})^2$	Production costs faced by manufacturer i; $i = 1, 2$
$c_{ijl}(q_{ijl}, \eta_{ijl})$ $= (0.5 - 0.4\eta_{ijl})(q_{ijl})^2 + (3.5 - \eta_{ijl})q_{ijl}$	Transaction costs faced by manufacturer i; $i = 1, 2$, transacting with retailer j; $j = 1, 2$
$\hat{c}_{ijl}(q_{ijl}, \eta_{ijl}) = 1.5{q_{ijl}}^2 + 3q_{ijl}$	Transaction costs faced by retailer j; $j = 1, 2$, transacting with demand market k; $k = 1, 2$
$\hat{c}_{jkl}(Q^2, Q^3, \eta^2, \eta^3) = (1 - \eta_{jkl})q_{jkl} + 5$	Unit transaction cost faced by demand market k; $k = 1, 2$,transacting with retailer j; $j = 1, 2$
$d_1(\rho_3) = -2\rho_{31} - 1.5\rho_{32} + 1000$ $d_2(\rho_3) = -2\rho_{32} - 1.5\rho_{31} + 1000$	The demand functions at the demand markets
$e^i(Q^1, Q^2, \eta^1, \eta^2) = \sum_{j=1}^{2}(1 - \eta_{ijl})q_{ijl}$	Emission costs faced by manufacturer i; $i = 1, 2$
$e^j(Q^1, Q^3, \eta^1, \eta^3)$ $= \sum_{i=1}^{2}(1 - \eta_{ijl})q_{ijl} + \sum_{k=1}^{2}(1 - \eta_{jkl})q_{jkl}$	Emission costs faced by retailer j; $j = 1, 2$
$b_{ijl}(\eta_{ijl}) = 2\eta_{ijl}$	CSR activities costs faced by manufacturer i; $i = 1, 2$, transacting with retailer j; $j = 1, 2$
$b_{jkl}(\eta_{jkl}) = 2\eta_{jkl}$	CSR activities costs faced by retailer j; $j = 1, 2$, transacting with demand market k; $k = 1, 2$

Numerical Results

Table 1: Solutions to Examples 1–3

Variable	Example 1	Example 2	Example 3
Product Transactions between Manufacturers and Retailers			
q_{111}	15.43	17.55	19.93
q_{121}	15.43	14.30	13.31
q_{211}	15.43	14.91	16.88
q_{221}	15.43	15.83	15.00
η_{111}	0	1	1
η_{121}	0	0	0
η_{211}	0	0	0
η_{221}	0	0	0
Product Transactions between Retailers and Demand Markets			
q_{111}	15.43	16.29	30.58
q_{121}	15.43	16.29	6.23
q_{211}	15.43	15.06	6.04
q_{221}	15.43	15.06	22.27
η_{111}	0	0	1
η_{121}	0	0	0
η_{211}	0	0	0
η_{221}	0	0	0
Shadow Prices at Retailers			
λ_1	255.45	254.46	272.29
λ_2	255.45	255.69	256.25
Prices at Demand Markets			
ρ_{31}	276.89	276.75	268.29
ρ_{32}	276.89	276.75	284.52

Numerical Results

	Total Emissions				
	Example 1	Example 2	%Change	Example 3	% Change
Manufacturer 1	30.87	14.30	53.68	13.31	6.92
Manufacturer 2	30.87	30.87	0.00	30.87	0.00
Retailer 1	61.74	47.49	23.08	23.11	51.34
Retailer 2	61.74	61.74	0.00	61.74	0.00

Empirical Analysis

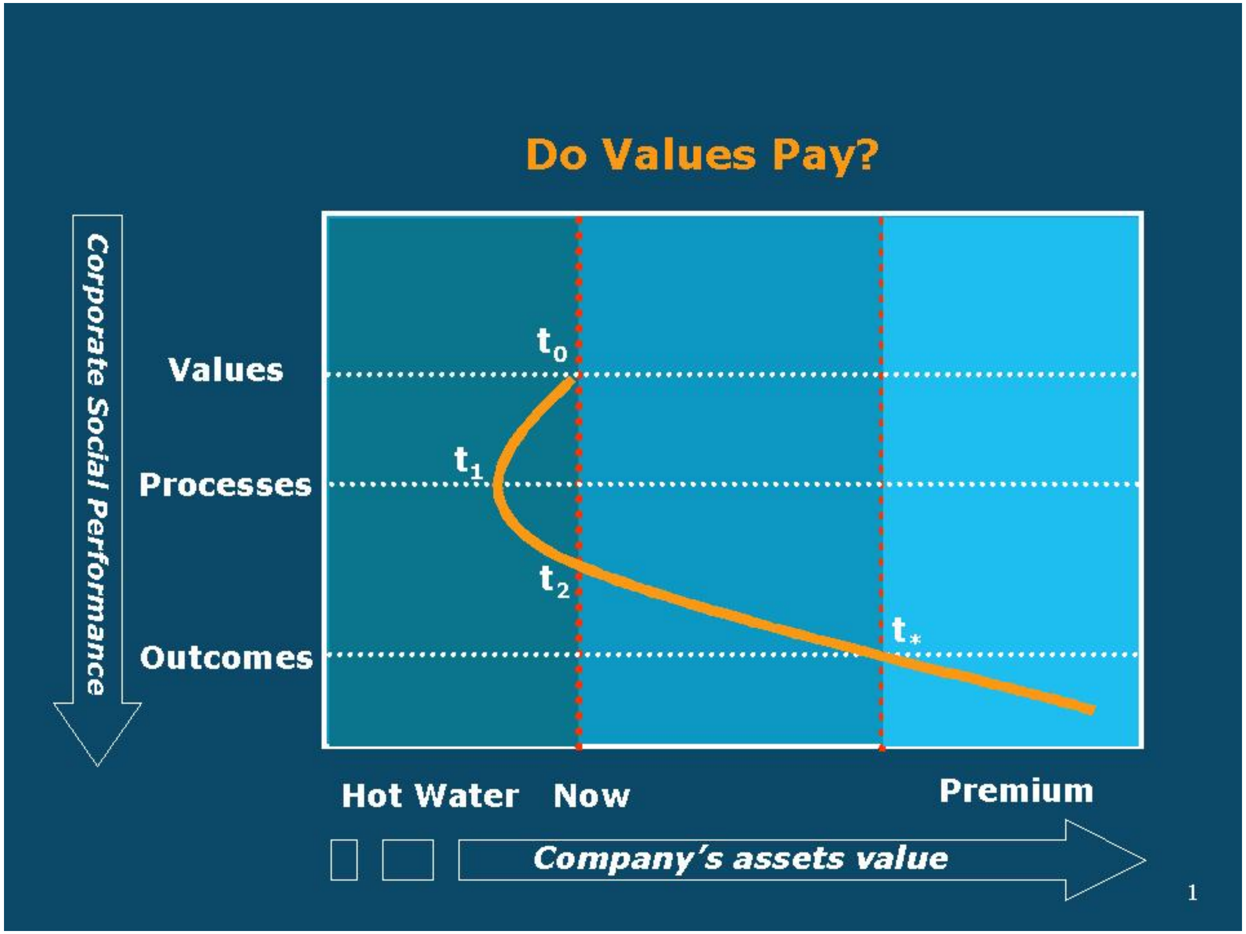
- Data-100 Best Corporate Citizens for 2004 (www.business-ethics.com)
  - Total return to shareholders
  - Community
  - Minorities & Women
  - Employees
  - Environment
  - Non-U.S. Stakeholders
  - Customers
- Hypothesis: There is a statistically significant relationship between CSR and total return to shareholders.

CSR vs. Return to Shareholders

Dependent variable: 2002 Total Return to Shareholders

	Coefficients	*P-value*	*P*
Intercept	1.937968738	5.32034E-16	< 0.05
Community	-0.24716076	0.000147182	< 0.05
Minorities & Women	-0.342385818	5.32594E-07	< 0.05
Employees	-0.381409466	3.10618E-06	< 0.05
Environment	-0.300882909	0.000462746	< 0.05
Non-U.S. Stakeholders	-0.114110214	0.504551562	>0.05
Customers	-0.309838777	0.001967295	< 0.11
R Square	*Adjusted R Square*	*F*	*Significance F*
0.41	0.37	10.66	5.46925E-09

The Values of CSR



Future Research

- Multi-period models
- Global supply chain networks & CSR
- Empirical analysis of CSR\Cost\Risk\Profit relationship
- Introduction of criteria weight functions
- Sensitivity analysis
    - Changes in transaction, handling, and production cost functions
    - Changes in demand and risk functions
    - Changes in weights for emission value and risk
    - Addition and removal of actors
    - Addition and removal of multiple transaction modes

Thank you!