The Supply Chain Game Theory Model of Cybersecurity Investments Under Network Vulnerability

Security Level of Retailer $i$, $s_i$:

$$0 \leq s_i \leq 1; \quad i = 1, \ldots, m.$$  

Average Network Security of the Chain, $\bar{s}$:

$$\bar{s} = \frac{1}{m} \sum_{i=1}^{m} s_i.$$  

Probability of a Successful Cyberattack on $i, p_i$:

$$p_i = 1 - (1 - s_i)^{(1 - \delta)}; \quad i = 1, \ldots, m.$$  

Price is a function of demand $d$ and average security. Profit of Retailer $i$, $i = 1, \ldots, m$ in absence of cyberattack and investments, $f_i^D(Q_i, s_i)$:

$$f_i^D(Q_i, s_i) = \bar{p}_i(Q_i, s_i) \times Q_i - c_i \sum_{j=1}^{m} \sum_{s_j} \nabla E(Q_j, s_j).$$  

Expected Utility/Profit for Retailer $i$, $i = 1, \ldots, m$:

$$E(U_i) = (1 - p_i)f_i(Q_i, s_i) + p_i(f_i(Q_i, s_i) - B_i) - h_i(s_i).$$  

Feasible Set: $X = \prod_{i=1}^{m} [0, 1]$, where $K = \{Q_i, s_i | \sum_{i=1}^{m} s_i \geq 0.5, s_i \leq 1 \}$. The problem is presented in the form of a Nash equilibrium if and only if it satisfies the variational inequality, $V(Q_i, s_i) \in K$.

Top of the Network

The Slater Condition: It is a sufficient condition for strong duality to hold for a convex optimization problem. Informally, Slater’s condition states that the feasible region must have an interior point.

The Euler method was implemented in FORTRAN and run on a Linux system. The convergence criterion $\epsilon$ was set to $10^{-3}$. The following equilibrium results are for two retailers and two demand markets.

The SCG Model of Cybersecurity Investments with Nonlinear Budget Constraints

The network is bipartite. The Security Level of Firm $i$, $s_i$:

$$0 \leq s_i \leq s_{max}, \quad i = 1, \ldots, m,$$  

where $s_{max} < 1$. This indicates that a Retailer $i$ cannot exceed its budget $B_i$.

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Numerical Results for the SCG Model with Nonlinear Constraints

Ex. 2: Budget of each Retailer is $2.5$ m (medium to large size firms). Lagrange multipliers are zero since both have unspent budget. Ex. 3: Increase in investment cost function of Retailer 1. Security level of Retailer 1 drops and budgets are all spent for both firms.

Cybersecurity and the AF

Results of our studies are consistent with those obtained in practice. The studies fulfill critical need for economic and game theoretic models in cyberspace. The models and results make way for exploring potential law and policy interventions.

• In the model, a certain retailer considers not just its own quantity and security levels, but of other retailers too. Hence, we assume that they have information on others’ security levels. Sharing of such information could lead to better network security.

• The approach could contribute more than trying to establish greater cybersecurity at the government/regulatory level.

• There is a need for more secure retailers, thereby, creating a need for building a secure supply chain infrastructure.

• The consumer base (like the Air Force) can signal their preferences through the inverse demand function in our model and lean toward more secure retailers, thereby, creating a need for building a secure cyber infrastructure.

Papers:


