Freight Demand Modeling: State of the Art and Practice

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(shamelessly stealing the credit and great work of E. Thorson, Q. Wang, N. Xu, C. González-Calderón, I. Sánchez-Díaz, and J. Mitchell)

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VREF's Center of Excellence on Sustainable Urban Freight Systems

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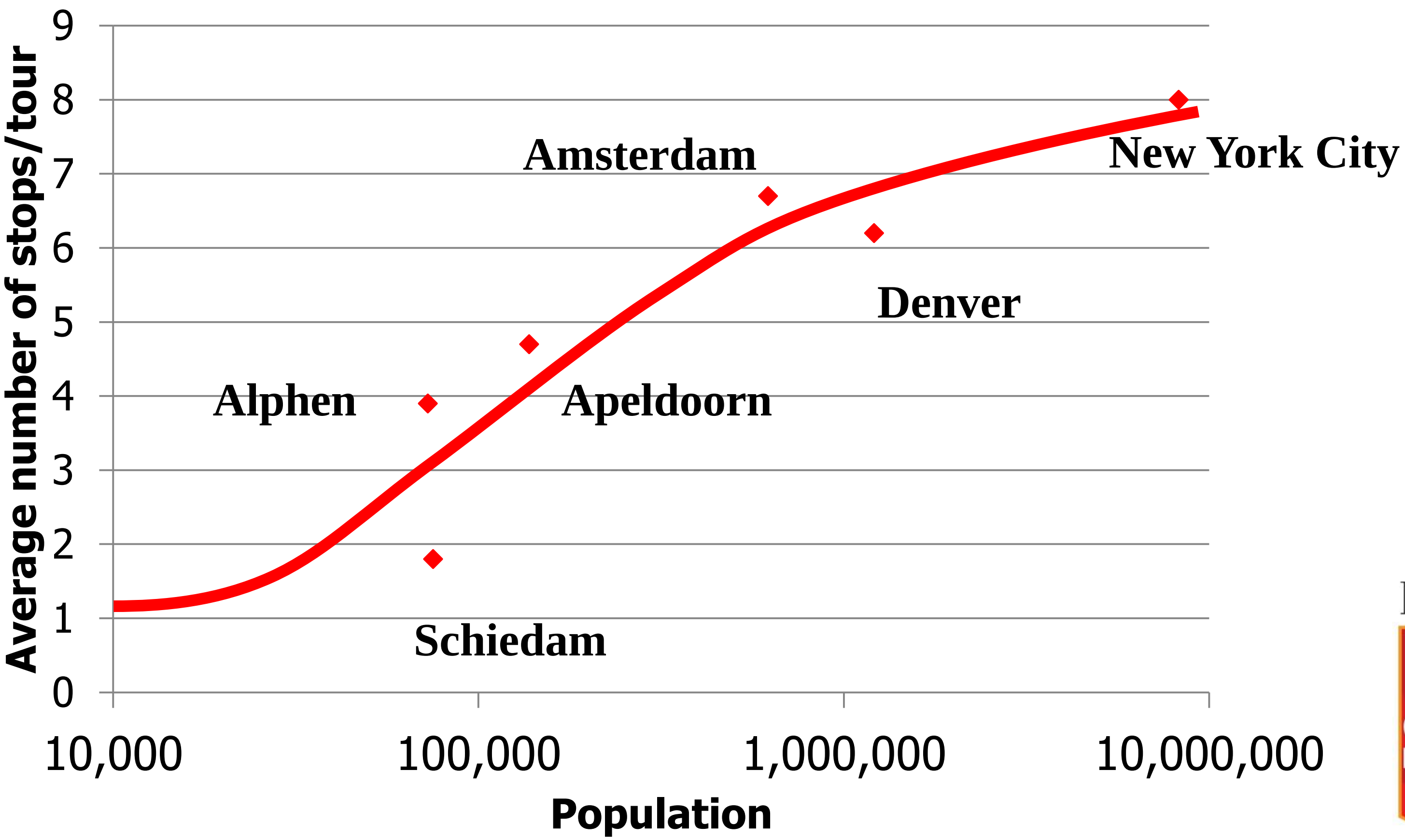
Empirical Evidence on Urban Freight Tours

Characterization of Urban Freight Tours (UFT)

- Number of stops per tour depends on: Country, city, type of truck, the number of trip chains, type of carrier, service time, and commodity transported



Characterization of Urban Freight Tours (UFT)

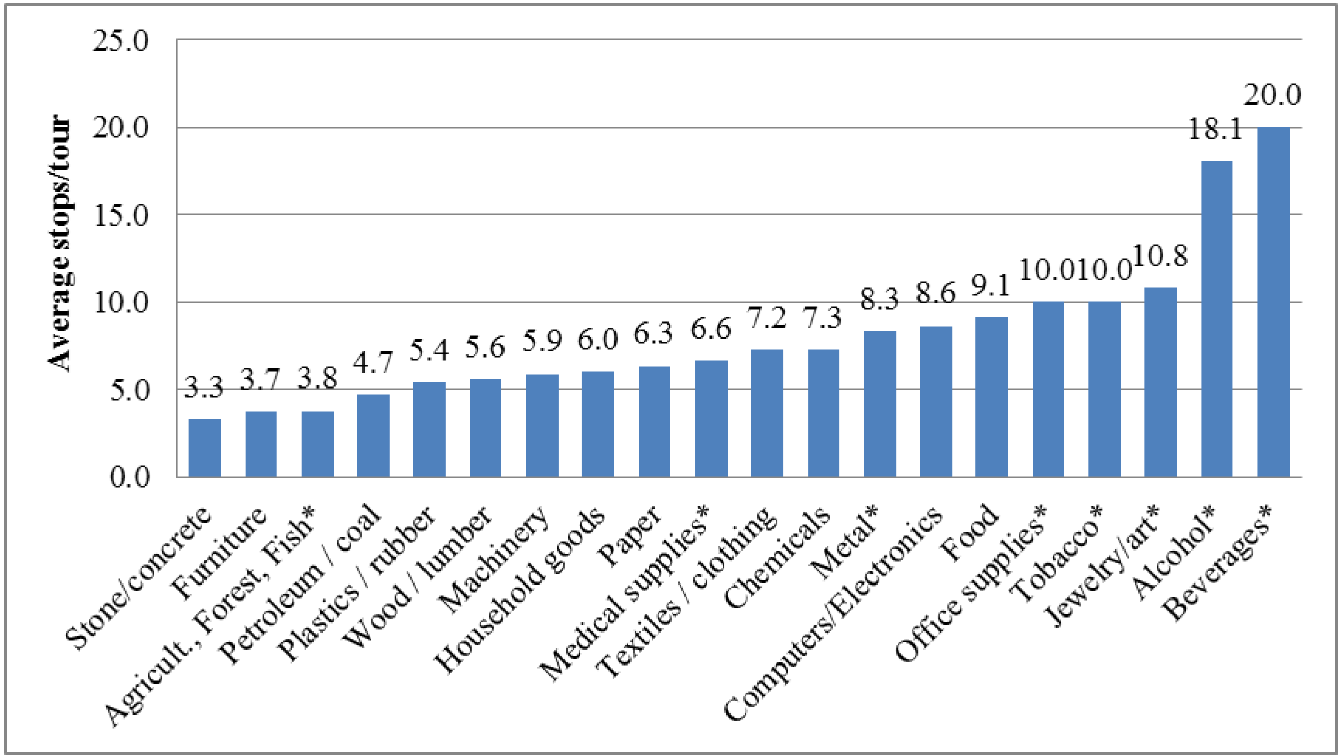
- Denver, Colorado (Holguín-Veras and Patil,2005):

Stops/Tour	Single Truck	Combination Truck
Average	*6.5*	*7.0*
1 tour/day	*7.2*	*7.7*
2 tours/day	*4.5*	*3.7*
3 tours/day	*2.8*	*3.3*

- Port Authority of NY and NJ (HV et al., 2006):
  - By type of company:
    - Common carriers: 15.7 stops/tour
    - Private carriers: 7.1 stops/tour
  - By origin of tour:
    - New Jersey: 13.7 stops/tour
    - New York: 6.0 stops/tour

Characterization of Urban Freight Tours (UFT)

- NYC and NJ (Holguin-Veras et al. 2012):
  - Average: 8.0 stops/tour   12.6%: 1 stop/tour
  - 54.9%: < 6 stops/tour   8.7% do > 20 stops
  - Parcel deliveries: 50-100 stops/tour



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Urban Freight Tour Models

Urban Freight Tour Models

- The UFT models could be subdivided into:
  - Simulation models
  - Hybrid models
  - Analytical models

Simulation Models

Simulation Models

- Simulation models attempt to create the needed isomorphic relation between model and reality by imitating observed behaviors in a computer program
- Examples include:
  - Tavasszy et al. (1998) (SMILE)
  - Boerkamps and van Binsbergen (1999) (GoodTrip)
  - Ambrosini et al., (2004) (FRETURB)
  - Liedtke (2006) and Liedtke (2009) (INTERLOG)
  - Stefan et al. (2005) and Hunt and Stefan (2007) describe the Calgary model

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Hybrid Models

Hybrid Models

- Hybrid models incorporate features of both simulation and analytical models (e.g., using a gravity model to estimate commodity flows, and a simulation model to estimate the UFTs and logistical patterns)
- Examples include:
  - van Duin et al. (2007)
  - Wisetjindawat et al. (2007)
  - Donnelly (2007) describes the Oregon model

Analytical Models

Analytical Models

- Analytical models attend to achieve isomorphism using formal mathematic representations based on behavioral, economic, or statistical axioms
- Two main branches:
  - Spatial Price equilibrium models (disaggregate)
  - Entropy Maximization models (aggregate)
- Examples include:
  - Holguín-Veras (2000), Thorson (2005)
  - Xu (2008), Xu and Holguín-Veras (2008)
  - Holguín-Veras et al. (2012)
  - Wang and Holguín-Veras (2009), Sanchez and Holguín-Veras (2012)

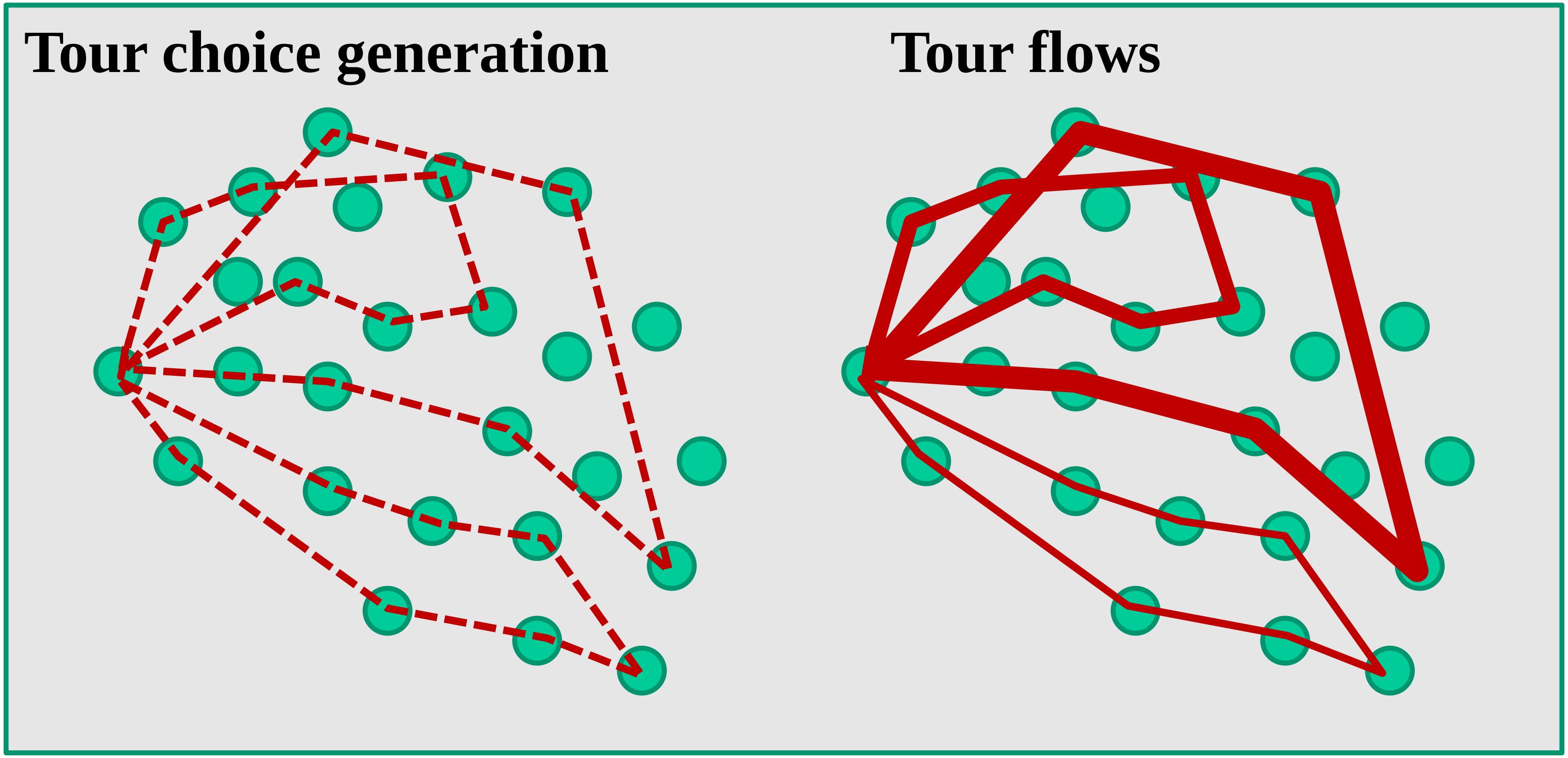
Entropy Maximization
Tour Flow Model

Entropy Maximization Tour Flow Models

- Based on entropy maximization theory (Wilson, 1969; Wilson, 1970; Wilson, 1970)
- Computes most likely solution given constraints
- Key concepts:
  - Tour sequence: An ordered listing of nodes visited
  - Tour flow: The flow of vehicle-trips that follow a sequence
- The problem is decomposed in two processes:
  - A tour choice generation process
  - A tour flow model

Entropy Maximization Tour Flow Model

- Tour choice: To estimate sensible node sequences
- Tour flow: To estimate the number of trips traveling along a particular node sequence



Static version of EM Tour Flow Model

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Entropy Maximization Tour Flow Model

$$\textbf{MIN}\ \ Z = \sum_{m=1}^{M} (t_m \ln t_m - t_m)$$

Subject to:

$$\sum_{m=1}^{M} a_{im} t_m = O_i \qquad (\lambda_i)$$

Trip production constraints

$$\sum_{m=1}^{M} c_{T\,m} t_m = C_T \qquad (\beta_1)$$

Total travel time constraint

$$\sum_{m=1}^{M} c_{H\,m} t_m = C_H \qquad (\beta_2)$$

Total handling time constraint

$$t_m \geq 0$$

Entropy Maximization Tour Flow Model

- First-order conditions (tour distribution models)

Formulation 1: $t_m^* = \exp(\sum_{i=1}^{N} \lambda_i^* a_{im} + \beta^* c_m) = \exp(\sum_{i=1}^{N} \lambda_i^* a_{im}) \exp(\beta^* c_m)$

Formulation 2: $t_m^* = \exp(\sum_{i=1}^{N} \lambda_i^* a_{im}) \exp(\beta_1^* c_{Tm} + \beta_2^* c_{Hm})$

- Traditional gravity trip distribution model

$$t_{ij}^* = A_i O_i B_j D_j \exp(\beta^* c_{ij})$$

Formulation 1 and the traditional GM model have <u>exactly</u> the same number of parameters

Entropy Maximization Tour Flow Model

- The optimal tour flows are found under the objective of maximizing the entropy for the system
- The tour flows are a function of tour impedance and Lagrange multipliers associated with the trip productions and attractions along that tour
- Successfully tested with Denver, Colorado, data:
  - The MAPE of the estimated tour flows is less than 6.7% given the observed tours are used
  - Much better than the traditional GM

Case Study: Denver Metropolitan Area

- Test network
  - 919 TAZs among which 182 TAZs contain home bases of commercial vehicles
  - 613 tours, representing a total of 65,385 tour flows / day
  - Calibration done with 17,000 tours (from heuristics)
- Estimation procedure
  - Sorting input data: aggregate the observed tour flows to obtain trip productions and total impedance
  - Estimation: estimate the tour flows distributed on these tours using the entropy maximization formulations
  - Assessing performance: compare the estimated tour flows with the observed tour flows

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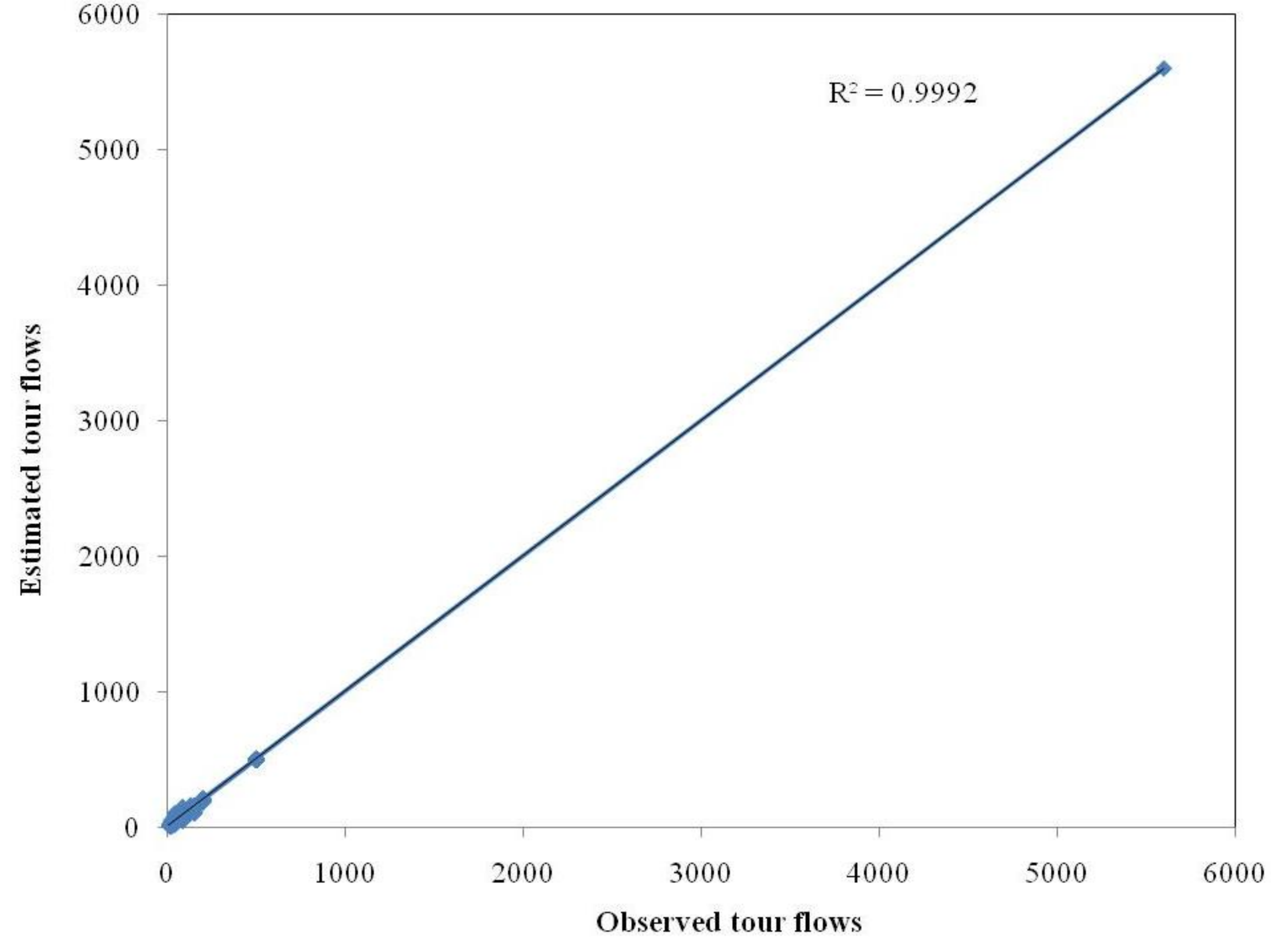
Performance of the Models



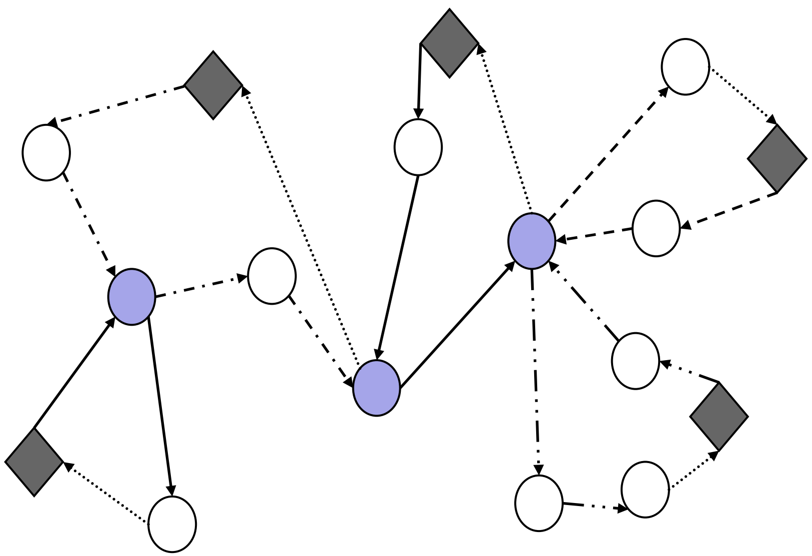
Spatial Price Equilibrium
Tour Models

General principles

- The models estimate commodity flows and vehicle trips that arise under competitive market equilibrium
- Conceptual advantages:
  - Account for tours
  - Provide a coherent framework to jointly model the joint formation of commodity flows and vehicle trips
- Based on the seminal work of Samuelson (1952), as it seeks to maximize the economic welfare associated with the consumption and transportation of the cargo, taking into account the formation of UFTs

Integrated Shipper-Carrier Operations

- Five suppliers deploy tours from their bases (rhomboids) to distribute the cargo they produce to various consumer (demand) nodes (circles)



Legend:

Supplier

Receiver

Empty trips

Loaded trips made by suppliers

(Contested nodes are shown as shaded circles)

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A Spatial Price Equilibrium UFT Model (P2)

MAX $NSP = \sum_{i=1}^{SN} S_i(E_i) - \sum_u C_V^u$ **(Net Social Payoff)**

Subject to: $S_i(E_i) = -\int_0^{E_i} s(x)dx$ **(Area under excess supply function)**

$$E_i = \sum_u \sum_j e_{ij}^u$$ **(Excess supply)**

$$we_{i,p_l^u = j}^u - Q\vartheta_{ij}^u \le 0$$ **(Linking flows to vehicle-trips)**

$$(t_{0i} + t_{i,p_1^u} + \sum_{l=1}^{L^u - 1} t_{p_l^u, p_{l+1}^u} + t_{L^u 0}) \le T$$ **(Tour length constraint)**

$$\sum_{i=1}^{L^u - 1} \sum_{j=i+1}^{L^u} we_{p_i^u, p_j^u}^u \le Q$$ **(Capacity constraint)**

$$\sum_{j,u} \vartheta_{ij}^u \le 1 \quad \forall j$$ **(Conservation of flow)**

$$\vartheta_{ij}^u \in (0,1) \quad \forall i, j, u$$ **(Integrality)**

$$e_{ij}^u \ge 0 \quad c_D, c_T, c_H \ge 0 \quad d_{i,j}, t_{i,j} \ge 0$$ **(Non-negativity)**

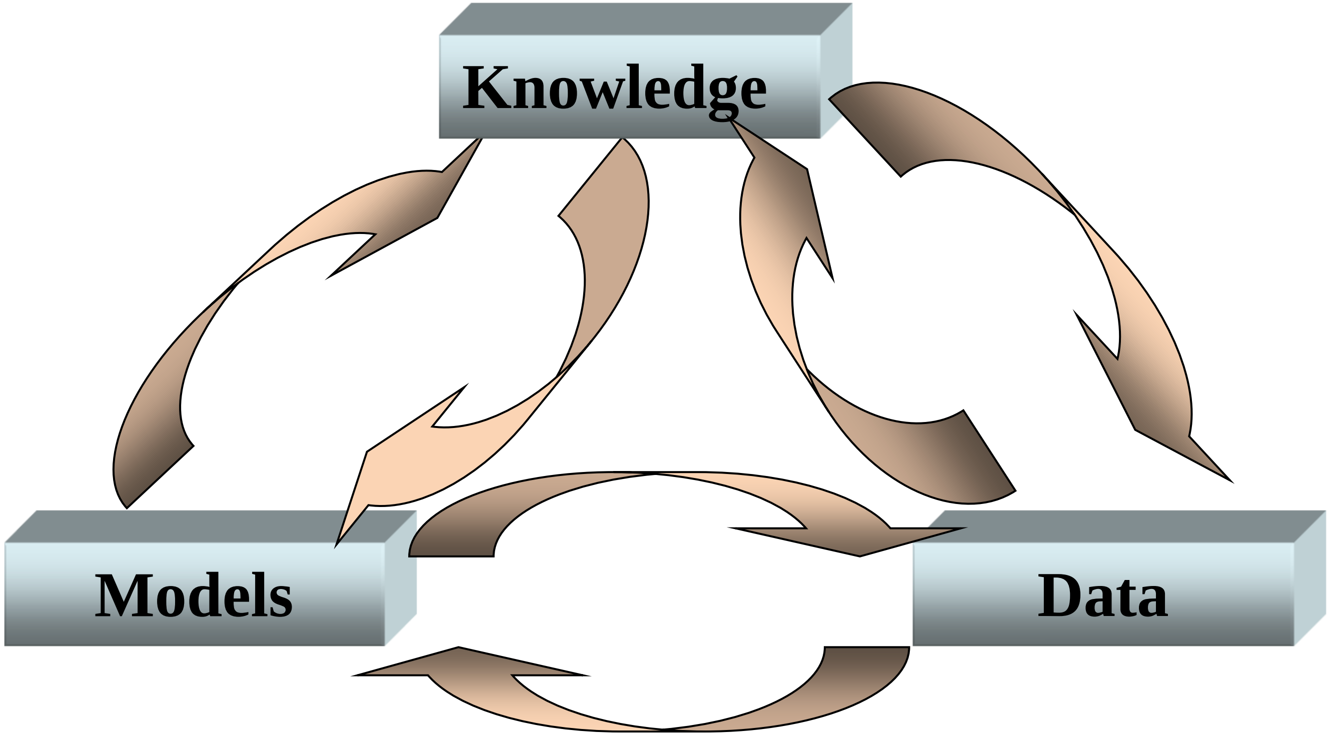
However…

- P2 is a nasty combinatorial and non-linear problem that is notoriously difficult to solve
- To solve it, frame it as:
  - A dispersed SPE problem
  - A problem of profit maximization subject to competition (which is equivalent to the NSP formulation produced by Samuelson)
  - A dynamic problem in which competitors adjust decisions based on the market competition results
- Use heuristics

Concluding Remarks

Knowledge, Models, and Data

- Data do not necessarily lead to Knowledge, D≠K
- Models cannot be developed without Knowledge
- Knowledge/Model inform Data collection: K+M→D
- We need integrative developments: K+M+D



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The allure (and trap) of the low hanging fruit

- We love the low hanging fruit…though we may not realize that we are benefiting from the trees planted by others…
- If that's all we plan to do…we are in trouble…we need to plant trees…

What should we do?

- We need to plant trees of different varieties to see which ones provide the best fruit… this is basic research…
- We need to evaluate the trees to see which ones are better…this is applied research…
- Then, we need to take the best trees and their fruit to the market…this is development…

Thanks! Questions?

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