Non-Price Equilibria for Non-Market Goods

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Introduction

The problem of non-market valuation:

- •Characterize preferences for a quasi-fixed public good
- •Examine well-being changes when level of the public good changes

Partial equilibrium emphasis…

- •Use sophisticated models of quality differentiated demand
- •Treat environmental variables as (exogenous) attributes of private choices
- •Examples: recreation demand, residential choice, wage hedonic

… by construction ignores **general equilibrium** aspects:

- Usually don't think of equilibrium concepts in non-market space
- Contrasts with market studies in which GE feedback effects can be the most interesting

e.g. tax interaction, empirical IO

- Might GE feedback effects be empirically important in non-market space?
- Do we ignore important **endogenous attributes** that might give rise to GE feedback effects in welfare analysis?

e.g. congestion and catch rates in recreation demand

traffic in residential location

Objectives for this Study

Consider the extent to which non-price equilibria can be identified and accounted for in non-market valuation:

- How to define equilibria and feedback effects in non-price attribute space?
- How to make operational inclusion of endogenous non-price attributes in models of quality differentiated demand?

  → in estimation *and* counterfactual welfare analysis?
- How to evaluate policy relevance and operational accuracy?
- How to lay out a research agenda on this issue?

Specifics Tasks

1) Suggest definitions for non-price equilibria we might find in non-market valuation

2) Consider a particular example: congestion in recreation demand models

3) Investigate econometrically:

   - Include site congestion and account for its econometric endogeneity

   - Calculate partial and general equilibrium welfare effects

4) Investigate via CGE:

   - Look at robustness, specification, computational issues

The ‘Frontiers’ Connection

GE effects in non-market valuation:

- Little empirical work on benefits-side feedback effects
- Less still when equilibrium arises outside of markets
- Might this be relevant for large-scale policy interventions?

→ a policy-motivated research agenda around this theme

Technical/conceptual challenges in quality-differentiated goods models:

- Use of both econometric and CGE techniques to further the state of the art

Congestion in recreation models:

- Important but often-ignored attribute of sites

Outline of Talk

I. Introduction (Dan)

II. Conceptual Overview (Dan)

III. Modeling Framework (Dan)

IV. Application (Dan)

V. Empirical Model and Results (Dan)

VI. CGE Modeling (Jared)

VII. Discussion: Lessons from Life on the Frontier (Jared)

Conceptual Overview

Behavioral setup – *N* consumers each maximize utility:

- Choose levels of a (J+1)-vector of quality-differentiated goods ($\mathbf{z}_i$,x_i) subject to budget constraint
- Each person *i* takes elements of an attribute matrix *Q* as given

$$\max_{\mathbf{z}_i, x_i} U_i = U_i(\mathbf{z}_i, x_i; Q) \quad s.t. \quad p_i' z_i + x_i \le y_i, \quad z_{ij} \ge 0, \quad j = 1, \ldots, J$$

Endogenous attributes – transmission functions

- Functions that relate aggregate behavior to levels of attributes

$$q_{mj} = q_{mj}(\mathbf{z}_1, \ldots, \mathbf{z}_N, E) \quad \text{for } m \text{ endogenous}$$

$$q_{mj} = q_{mj}(E) \quad \text{for } m \text{ exogenous}$$

Definitions

Simple sorting equilibrium – $q_{mj}(\mathbf{z}_1,\ldots,\mathbf{z}_N)$:

•Endogenous non-price attributes determined *only* by interaction among agents

•Examples: congestion in recreation, racial mixing, school peer effects

Complex sorting equilibrium – $q_{mj}(\mathbf{z}_1,\ldots,\mathbf{z}_N, E)$:

• Endogenous attributes determined by interactions among agents *and* a quasi-supplier, often the natural environment

•Examples: catch rates in recreation, educational outcomes, commercial fish stocks

Related Literature

Conceptual motivation:

- Schelling (1978) *Micro Motives and Macro Behavior*

Congestion in recreation demand:

- Timmins and Murdock (2007)

Empirical locational sorting models:

- Bayer and Timmins (2005, 2006), Smith et al. (2004), Epple

Local public finance/local public goods:

- Ferreyra (2006) – endogenous school quality
- Irwin et al. (yesterday)

Bio-economics:

- Massey, Newbold, Genter (2006), Sanchirico, Smith, Wilen (yesterday)

Modeling Framework

Examine demand for annual trips to *J* recreation sites. Model must:

- Link behavior to utility-theoretic framework
- Admit zero-visit outcomes for subsets of sites
  - → both to accommodate data *and* for modeling congestion
- Link non-price attributes to demand
  - → attribute levels (including congestion) should impact intensive *and* extensive margins

We employ the Lee and Pitt (1986) 'dual approach':

- Uses concept of 'virtual price' to accommodate non-consumption

Dual Model

Starts with specification of **notional** indirect utility function:

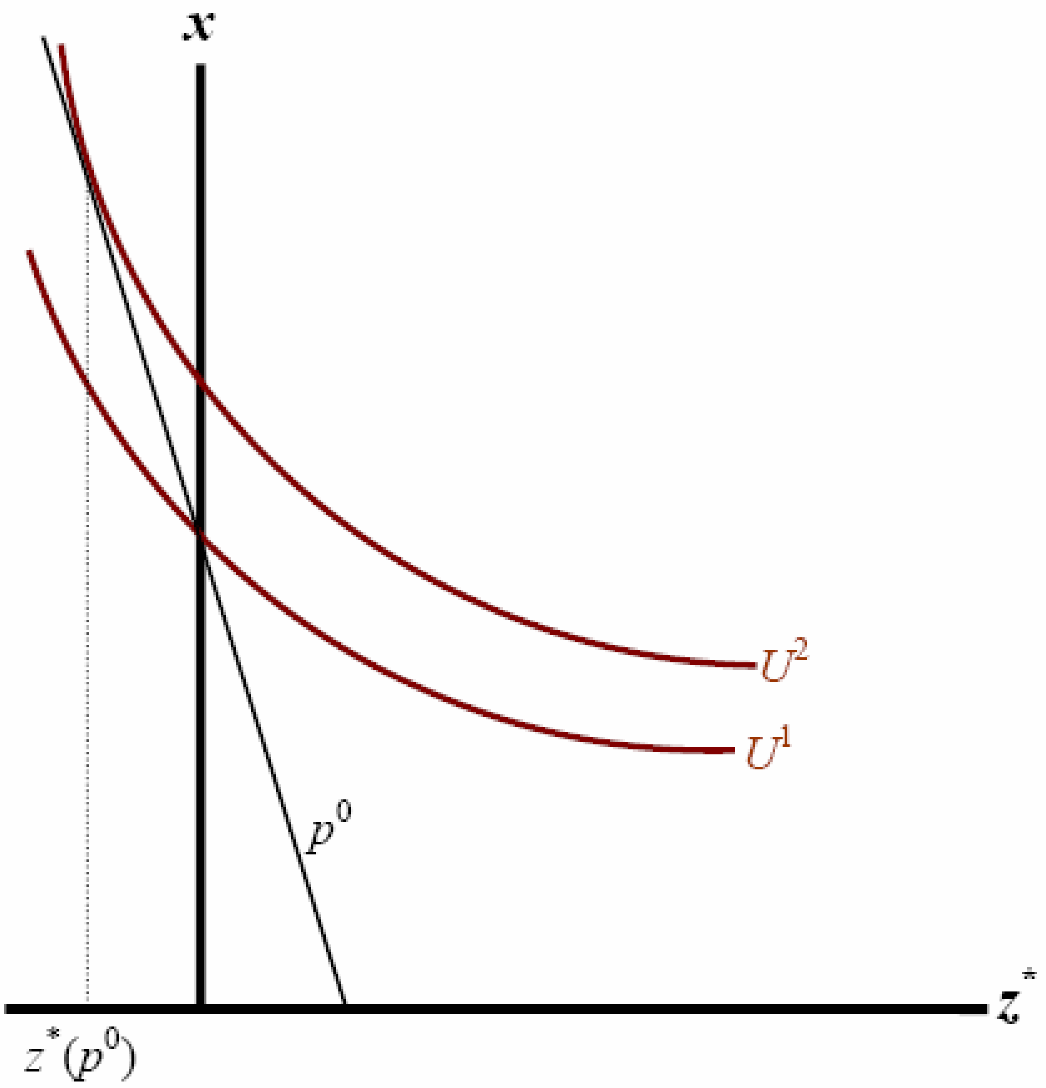
$$H\left(p, y; Q, \theta, \varepsilon\right) = \underset{z}{Max}\left\{U\left(z, x; Q, \theta, \varepsilon\right) \mid p'z + x = y\right\}$$

Derive **notional** demands using Roy's Identity:

$$z_j^*(p, y; Q, \theta, \varepsilon) = -\frac{\dfrac{\partial H\left(p, y; Q, \theta, \varepsilon\right)}{\partial p_j}}{\dfrac{\partial H\left(p, y; Q, \theta, \varepsilon\right)}{\partial y}}, \quad j = 1, \ldots, J$$

Note:

•Non-negativity constraints are *not* included here…notional demands can be negative – signals a corner solution



x
U2
U1
p0
z*
z*(p0)

Virtual prices sort consumption from non-consumption. Suppose first r goods are not consumed:

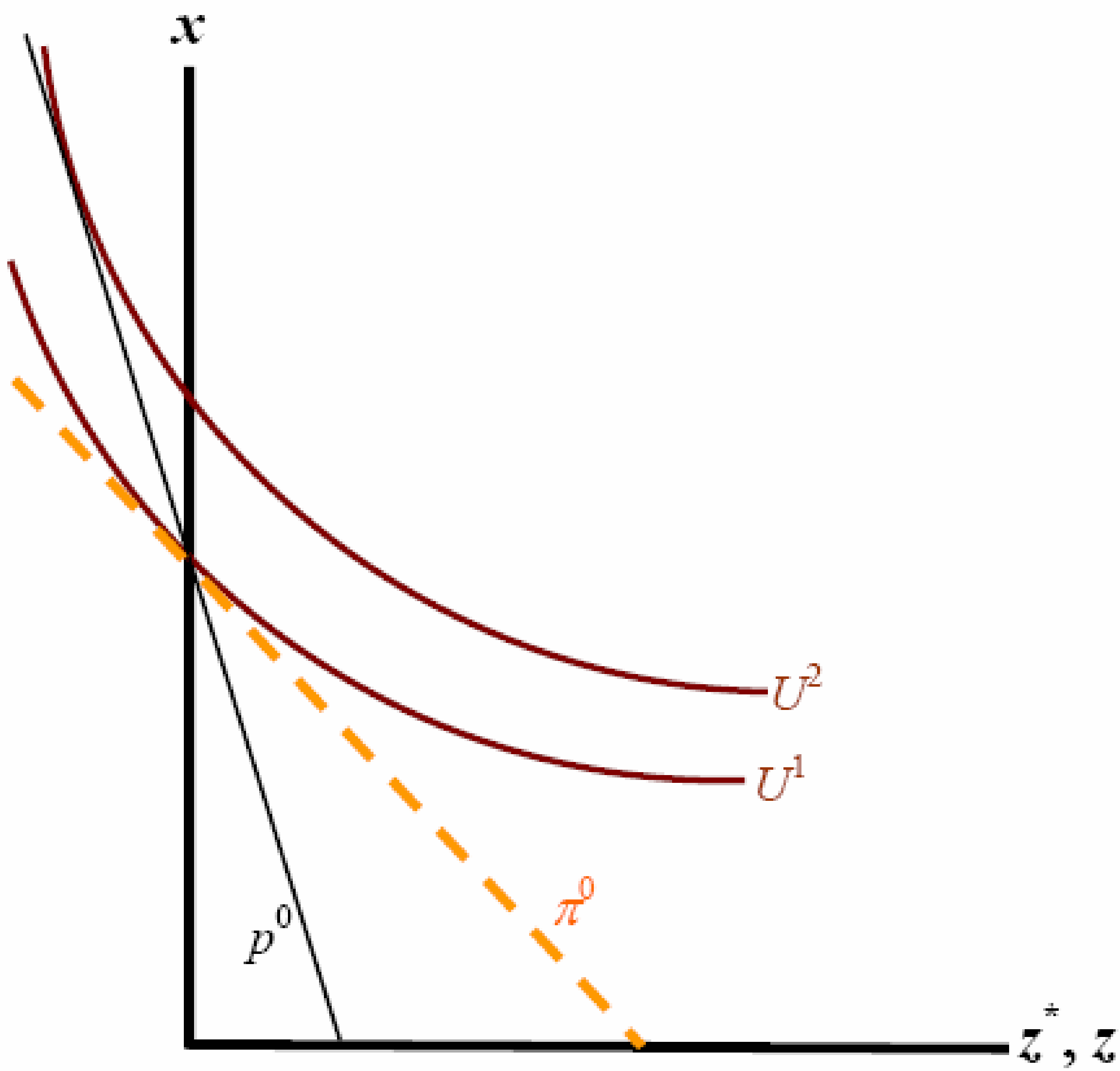
$$p_N = (p_1, \ldots, p_r)'$$
$$p_C = (p_{r+1}, \ldots, p_J)'$$

Define virtual prices for non-consumed goods $\pi_N = (\pi_1, \ldots, \pi_r)$ using:

$$0 = \frac{\partial H\left[\pi_1\left(p_C; Q, \theta, \varepsilon\right), \ldots, \pi_r\left(p_C; Q, \theta, \varepsilon\right), p_C, y; Q, \theta, \varepsilon\right]}{\partial p_j}, \quad j = 1, \ldots, r$$

Note:

- Virtual prices are **endogenous reservation prices** that rationalize non-consumption
- If $\pi_k < p_k \rightarrow$ good is *not* consumed



x
U^2
U^1
π^0
p^0
z^*, z

Actual demands are derived by substituting in virtual prices:

$$z_j = \frac{\dfrac{\partial H\left(p^*, y; Q, \theta, \varepsilon\right)}{\partial p_j}}{\dfrac{\partial H\left(p^*, y; Q, \theta, \varepsilon\right)}{\partial y}} = z_j\left(p^*, y; Q, \theta, \varepsilon\right), \quad p^* = (\pi_1, \ldots, \pi_r, p_{r+1}, \ldots, p_N)$$

Note:

$$z_j\left(p^*, y; Q, \theta, \varepsilon\right) = 0, \quad j = 1, \ldots, r$$

$$z_j\left(p^*, y; Q, \theta, \varepsilon\right) = z_j, \quad j = r+1, \ldots, J$$

Actual indirect utility: $V\left(p, y; Q, \theta, \varepsilon\right) = \max_{\omega \in \Omega} \left\{ H(p^\omega, y; Q, \theta, \varepsilon) \right\},$

Why the Dual Model?

Advantages:

- Endogenous regime switching model – predicts both intensive and extensive margins
- Virtual price: a quality-adjusted reservation price

$$\uparrow q_j \rightarrow \downarrow \pi_j \rightarrow \text{switch non-visitor to visitor?}$$

- Predicting visitor vs. non-visitor status for site j: a determinant of congestion.

Challenges:

- Conceptually elegant but computationally difficult
- Relatively few applications in literature

Application

Recreation demand application using Iowa Lakes Project data:

- •Four year panel study on visits to 129 IA lakes by large sample of residents
- •Extensive survey data on use patterns; auxiliary information on environmental conditions (i.e. clarity, chlorophyll levels, nutrients)
- •Use 2002 sub-sample – 749 users take 8.1 trips on average to 128 lakes
- •Corner solutions typical: most visit only a small subset of lakes
- •Objective: estimate demand for annual visits to 128 lakes as a function of travel cost and lake quality.

Our Specification

Trips to each site depend on:

- Travel costs - $0.28 per mile plus one third the wage rate for travel time
- Secchi disk readings – a measure of water clarity
- Chlorophyll readings – indicator of phytoplankton plant biomass responsible for greenness, algae blooms
- A measure of congestion at the site…

Counterfactual Welfare Scenarios

Scenario 1:

- Loss of 9 most heavily visited lakes in 9 regions of the state

Scenario 2:

- Loss of 9 moderately visited sites in 9 regions of the state

Scenario 3:

- Moderately improve water quality state-wide such that all lakes obtain a 'good' rating…a minimum secchi reading of 2.16m and maximum chlorophyll level of 8.26ug/l

Scenario 4:

- Improve a set of 7 'target lakes' to minimum secchi reading of 5.17m and maximum chlorophyll level of 2.6ug/l

Empirical Model

Notional demands:

$$z_{ij}^{*}=\alpha_j+\sum_{j=1}^{J}\beta_{jk}p_{ik}+\eta_j y_i+\varepsilon_{ij},\quad \alpha_j=\gamma' q_j+\gamma_s s_j+\xi_j,\quad j=1,\ldots,J$$

$$\eta_j=0\forall j\quad \beta_{jj}=\beta_1\forall j\quad \beta_{jk}=\beta_2\forall j\neq k$$

$$\varepsilon_{ij}\sim N(0,\sigma_j^2)$$

Congestion at site j – the *proportion of people who visit the site*:

$$s_j=N^{-1}\sum_{i=1}^{N}I_{ij},\quad I_{ij}=\begin{cases}0 & z_{ij}^{*}\leq 0\\ 1 & z_{ij}^{*}>0\end{cases}$$

Note:

- Our measure of congestion ignores timing and intensity of use
- …but connects nicely to virtual prices

Virtual Prices

Virtual prices for person *i* with first *r* sites not visited:

$$\pi_{iN} = -\beta_{NN}^{-1}\left[\alpha_N + \beta_{NC}p_{iC} + \varepsilon_{iN}\right]$$

$$\alpha_N = \begin{bmatrix} \alpha_1 \\ \vdots \\ \alpha_r \end{bmatrix}, \quad \beta_{NN} = \begin{bmatrix} \beta_{11} & \cdots & \beta_{1r} \\ \vdots & \ddots & \vdots \\ \beta_{r1} & \cdots & \beta_{rr} \end{bmatrix}, \quad \beta_{NC} = \begin{bmatrix} \beta_{1,r+1} & \cdots & \beta_{1J} \\ \vdots & \ddots & \vdots \\ \beta_{r,r+1} & \cdots & \beta_{rJ} \end{bmatrix}$$

Note:

- Attribute levels (including congestion) affect virtual prices via α_j’s

Actual Demands

Demand equations for person *i* with latter *J*−*r* sites visited:

$$z_{iC} = \alpha_C + \beta_{NC}\pi_{iN} + \beta_{CC}p_{iC} + \varepsilon_{iC}$$

$$\alpha_C = \begin{bmatrix} \alpha_{r+1} \\ \vdots \\ \alpha_J \end{bmatrix} \quad \beta_{CC} = \begin{bmatrix} \beta_{r+1,r+1} & \cdots & \beta_{r+1,J} \\ \vdots & \ddots & \vdots \\ \beta_{J,r+1} & \cdots & \beta_{JJ} \end{bmatrix}$$

Note:

- Demand functions depend only on prices of visited sites
- …but depend on attributes of all sites
- Errors enter non-linearly

Estimation

Estimation is complicated by curse of dimensionality:

- Classical estimation requires computation of $(J-1)$-dimension integrals
- Use Bayesian computational methods to construct posterior distribution of unknown parameters (Pitt and Millimet)

Congestion is econometrically endogenous:

- We use a second stage linear IV estimator (Timmins and Murdock)

Estimation proceeds in two steps:

1) Use Gibbs sampler to accumulate empirical distributions for β_1, β_2, $\alpha_1,\ldots,\alpha_J$, $\sigma_1,\ldots,\sigma_J$
2) Use linear IV approach to estimate components of α_j's

First Stage

Objective is to sample from posterior distribution for $\theta = (\beta_1, \beta_2, \alpha_1,\ldots,\alpha_J, \sigma_1,\ldots,\sigma_J)$:

$$p\left(z^*, \theta \mid z\right) \propto p\left(z \mid z^*, \theta\right) p\left(z^* \mid \theta\right) p\left(\theta\right)$$

Sample sequentially from full set of conditional distributions:

a) Augment data to obtain full set of notional demands – draw from $p(z^* | z, \alpha, \beta_1, \beta_2, \Sigma)$

b) Update $\Sigma = (\sigma_1,\ldots,\sigma_J)$ – draw from $p(\Sigma | z^*, z, \alpha, \beta_1, \beta_2)$

c) Update α, β_1, β_2 – draw from $p(\alpha, \beta_1, \beta_2 | z^*, z, \Sigma)$

Provides empirical distribution of size B for all $2J+2$ elements of θ – posterior means, standard errors, etc. characterize unknown parameters

Second Stage

First stage provides *B* realizations from distribution for $\alpha_1,\ldots,\alpha_J$:

- Second stage task is to decompose intercepts into observable and unobservable components

$$\alpha_j^b = \gamma^{b\prime} q_j + \gamma_s^b s_j + \xi_j^b, \quad j = 1,\ldots,J, \quad b = 1,\ldots,B$$

Use OLS for decomposition?

- s_j and ξ_j are (positively) correlated
- Unobserved factors that make site *j* attractive also draw more visitors – higher s_j
- We need an instrument for s_j – use Timmins and Murdock strategy for IV estimation

Empirical Results – Selected Parameters

Table 3: Summary of Selected Parameters from Posterior Distributions: 1st Stage[a]

Parameter	Posterior Mean	Posterior Std. Deviation	Mean/Std. Deviation	Posterior Median
β_{own}	-0.046	0.0015	-30.596	-0.0459
β_{cross}	0.0002	0.000	20.10	0.0002

[a]Calculated using 800 simulated draws from the posterior distribution. Posterior summaries for intercepts and variances shown in a subsequent table.

Table 5: Summary of Selected Parameters from Posterior Distributions: 2nd Stage IV Decomposition[a]

Parameter	Posterior Mean	Posterior Std. Deviation	Mean/Std. Deviation	Posterior Median
γ_0	-4.081	0.2225	-18.34	-4.072
γ_{secchi}	0.1122	0.0867	1.294	0.1128
$\gamma_{chlorophyll}$	-0.0064	0.0019	-3.36	-0.0064
$\gamma_{congestion}$	-55.91	4.29	-13.00	-55.78

[a]Calculated via IV regressions of each first stage draw of the intercepts on the site characteristics. Summaries are calculated from the resulting 800 sets of 2nd stage estimates.

Welfare Analysis

Estimation characterizes preference up to unknown errors from known distribution – use to compute *CS* for changes in prices or quantities $(\mathbf{p}^0, Q^0) \rightarrow (\mathbf{p}^1, Q^1)$

Steps needed for single person in sample (partial equilibrium):

a) Simulate errors consistent with observed choices/observed demand regime

b) Determine total **baseline surplus** from visited sites

c) Determine **new demand regime/choices** under new conditions

d) Determine total **changed surplus** from visited sites

e) Take difference, repeat steps multiple times, average

Technically challenging but conceptually straightforward

Welfare Analysis: General Equilibrium

Change in prices, site availability, or exogenous attributes will have **feedback effects:**

- Visitors re-allocate trips to available sites leading to new equilibrium level of congestion
- GE welfare algorithm needs to nest prediction of endogenous attribute –

Behavior all i under $\mathbf{p}^1, \tilde{Q}^0$ ⟶ Calculate new $\tilde{Q}^0$

(Calculate new $\tilde{Q}^0$ loops back to Behavior all i under $\mathbf{p}^1, \tilde{Q}^0$) ⟶ Q^1

Welfare Calculation Challenges

Technical and conceptual:

- Lots of ‘solving the consumer’s problem’ type computations
- Uniqueness and existence of equilibrium for congestion
- Computation of new equilibrium for congestion

…there is still a lot of work to do on fully understanding welfare calculation in this model

Counterfactual Welfare Results

Table 6: Point Estimates for Welfare Effects[a]

Counterfactual Scenario	Partial Equilibrium Estimate		General Equilibrium Estimate	
	Sample mean	Sample Median	Sample Mean	Sample Median
Scenario 1: Loss of nine highly popular sites.	-$630.40	-$67.64	-$726.11	-$142.84
Scenario 2: Loss of nine moderately popular sites	-$51.86	$0.00	-$58.21	-$5.08
Scenario 3: Widespread small quality improvements	$207.92	$146.01	$87.28	$61.16
Scenario 4: Localized large quality improvements	$50.23	$17.14	$21.09	$7.57

[a]Measured in dollars per active lake visitor person per year

CGE Analysis

Tasks

1. Specify recreational demand system, congestion functions
2. Calibrate to match observed equilibrium in IA Lakes data
3. Calibrate model responsiveness to our empirical estimates
4. Study results of same four counterfactual experiments

So what's the value added here?

Value Added by CGE – Economics

How do we evaluate large-scale environmental policy?

- GE researchers routinely work “out of sample”

- Benefits of replication exercises

Use the numerical model as a laboratory

- a link from theory to empirics

Value Added by CGE – Technique

How do we combine tool kits?

- Non-market valuation and equilibrium modelling
- Estimation vs. Calibration
- Local vs. Global
- Probabilistic vs. Deterministic

Specific Experiment

Two dimensions of model sensitivity:

- Form of congestion transmission function
- Congestion responsiveness of demand

Congestion Transmission Function

Shares:

- Mimics empirical model and discrete choice literature

$$q_{1j} = \frac{\sum_i z_{ij}}{\sum_i \sum_k z_{ik}}$$

Totals:

- Captures effects of visitation intensity

$$q_{1j} = \sum_i z_{ij}$$

Congestion Responsiveness

$$z_{ij} = \alpha_{ij} + \sum_m \gamma_m q_{mj} + \sum_k \beta_{jk} \pi_{ik} + \varepsilon_{ij} \geq 0 \;\perp\; \pi_{ij} \leq p_{ij}$$

$$\gamma_{congest} = -54.34$$

Sensitivity analysis:

$(0.5) \times \gamma_{congest}$ $(1) \times \gamma_{congest}$ $(2) \times \gamma_{congest}$

Calibration and Solution Technique

The model is a Mixed Complementarity Problem (MCP)... a system of equation/inequalities paired w/ inequality constraints

(PATH solver in GAMS)

$$z_{ij} = \alpha_{ij} + \sum_{m} \gamma_m q_{mj} + \sum_{k} \beta_{jk} \pi_{ik} + \varepsilon_{ij} \geq 0 \ \perp \ \pi_{ij} \leq p_{ij}$$

$$q_{1j} = \sum_{i} z_{ij}$$

Calibration and Solution Technique

Model is calibrated to match the benchmark demands in the data

Incorporating preference heterogeneity means drawing realizations of the ε_{ij} terms that are consistent with observed visitation patterns:

- For visited sites, this is easy – unique ε_{iC} given prices and number of trips taken.

- For unvisited sites ε_{iN}, these terms may take on a range of values following the empirical distribution: $N(0,\Sigma_{NN})$

ε_{iC} and π_{iN} realizations in the benchmark equilibrium are jointly determined as the solution to a system of equations

Calibration and Solution Technique

MCP model solved repeatedly for different draws from:

1. The ε_{iN} distributions
2. The sample of individuals in the data (300 out of 749)

Numbers presented here based on 10 such repeated solutions for each set of model results

Welfare measurement based on same surplus-change logic as in the empirical model

Table 2: PE and GE welfare estimates by policy scenario and Totals vs. Shares Congestion Specification, Full Congestion Effect

	Totals Specification			Shares Specification		
Scenario	PE	GE	%Diff	PE	GE	%Diff
1	-524.5	-527.2	0.5	-580.0	-618.3	6.2
2	-193.3	-189.9	-1.8	-197.6	-212.1	6.9
3	153.6	106.7	-44.0	161.9	172.2	6.0
4	58.2	41.8	-39.2	61.2	56.0	-9.2

-- site shutdown scenarios (price)

-- quality improvement scenarios (quality)

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4	58.2	41.8	-39.2	61.2	56.0	-9.2

-- site shutdown scenarios (price)

-- quality improvement scenarios (quality)

Table 1: PE and GE welfare estimates by policy scenario and intensity of congestion effect, Totals specification

	Half Congestion Effect			Full Congestion Effect			Double Congestion Effect		
Scenario	PE	GE	%Diff	PE	GE	%Diff	PE	GE	%Diff
1	-552.3	-549.1	-0.6	-524.5	-527.2	0.5	-469.0	-506.7	7.4
2	-195.4	-193.3	-1.1	-193.3	-189.9	-1.8	-189.0	-184.2	-2.6
3	157.7	126.2	-25.0	153.6	106.7	-44.0	145.3	88.1	-64.9
4	59.7	49.4	-20.9	58.2	41.8	-39.2	55.2	32.8	-68.1

-- site shutdown scenarios (price)

-- quality improvement scenarios (quality)

Summary of Findings

Shares model parallels findings of empirical model

Totals model shows impact of visit intensity on congestion:

- matters very little for price scenarios (~1% PE-GE diff)
- matters a lot for quality scenarios (~40% PE-GE diff)

Intuition:

Substitution-based congestion (price scenarios)

vs.

Intensity-based congestion (quality scenarios)

Findings Continued

Sensitivity with respect to congestion response yields expected results:

- Larger value implies larger PE-GE differences due to congestion's enhanced role

- Differences suggestive of quantitative significance

Discussion: Lessons from Life on the Frontier

So what have we learned?

- Benefits estimation can benefit from modeling GE responses

- The action may be outside of markets

Both dimensions present **technical** and **conceptual** challenges for the analyst

Technically, this stuff is tough sledding:

On the estimation side –

- Simulated estimation, IV identification, welfare calculations

On the CGE side –

- Working with large models, random parameters

Unexpected Benefits:

Solution techniques from CGE may be useful for welfare measurement in corner solution models

CGE with individual-level heterogeneity

Ultimately, the technical challenges are surmountable...

Conceptually, how do we move beyond the “black box”?

- Intuition building and policy relevance

Both individual responses and how they are translated to aggregate outcomes are important...

- Individual – congestion demand response

- Aggregate – congestion transmission function

More generally...

- Transmission function will be context specific
- Models with many moving parts require replication (Smith-Crowder vs. Finnoff-Tschirhart)
- Using CGE to prototype and decompose results of detailed, empirical models
- Existence and uniqueness?