An Appointment Overbooking Model To Improve Client Access and Provider Productivity

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New Challenges in Service Operations
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Appointment Scheduling

Appointment Waiting

"When I arrived I was cleanshaven."

POMS/EurOMA Service Operations Conference, London, July 2007

Appointment Services

- Types of services
  - Medical care & mental health clinics
  - Dentists and medical specialists
  - Government offices; law offices
  - Counseling & admissions offices
  - Retail (tax help, salons, …)
- We call these “*appointment services*”
  - Where “providers” in “offices” serve “clients”

The "No-Show" Problem

- Research motivated by a outpatient mental health clinic in Denver, CO
  - 16 daily appointments / clinician
  - 30% no show rate
- Office no-show rates vary from 0-80%
  - <10% Brahimi & Worthington (1991); Warden (1995)
  - 10-30% Barron (1980)
  - 3-80% Rust *et al.* (1995)

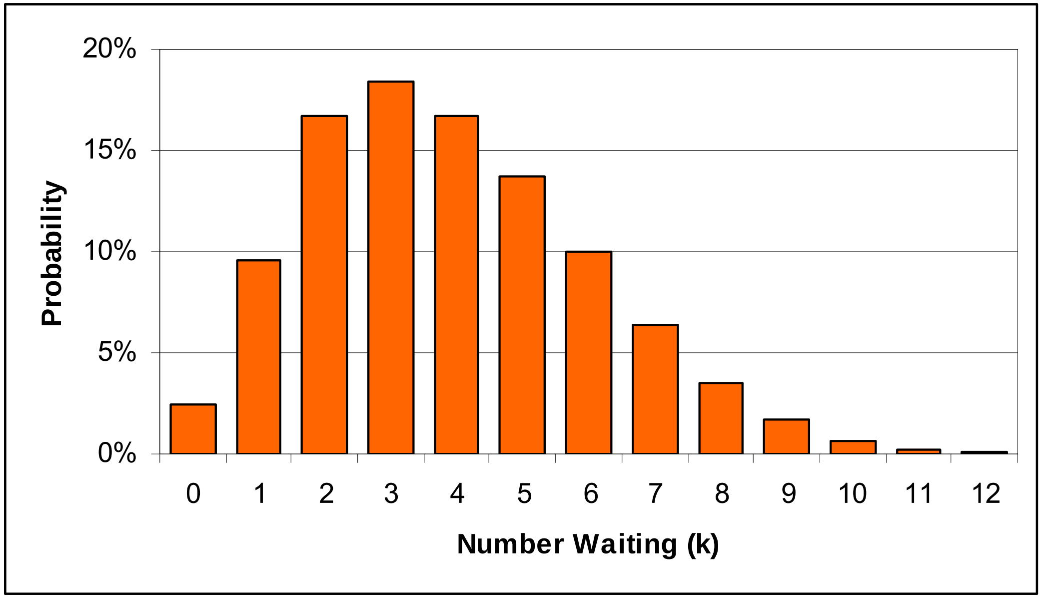
Possible Solutions

- Sending clients reminder cards
  - Rust *et al* (1995)
- Call clients to remind them of appointments
- Providing public transport information
  - Bean & Talaga (1995)
- **Overbooking has not been closely examined as a possible response**
  - Widely used other businesses (*e.g.*, airlines)

Literature

- Blanco White & Pike (1964)
  - Appointment systems in out-patients' clinics and effect of patients' unpunctuality. *Medical Care 2*(3), 133-145
- Vissers (1979)
  - Selecting a suitable appointment system in an outpatient setting. *Medical Care*, *17*(12), 1207-1220
- Cayirli & Veral (2003)
  - Outpatient scheduling in health care: A review of the literature. *Production and Operations Management,* 12(4), 519-549
- LaGanga & Lawrence (2007a)
  - Clinic overbooking to improve patient access and increase provider productivity. *Decision Sciences, 38*(2).
- LaGanga & Lawrence (2007b)
  - "Appointment scheduling with overbooking to mitigate productivity loss from no-shows." *Proceedings of Decision Sciences Institute Annual Conference*, Phoenix, Arizona, November 17-20, 2007 (forthcoming)

Appointment Scheduling and Overbooking Model



How to Handle No-Shows?

- How to balance competing goals?
  - Provide better client access
  - Minimize client waiting
  - Minimize office overtime
  - Maximize provider productivity
- How to measure a “good” policy?
  - Is this a monetary problem?
  - A service problem?

Overbooking Utility Model

- Maximize office “utility”
- Trade-off
  - Client access (number of clients seen)
  - Average client waiting times
  - Expected office overtime
- Note that provider productivity is implicit in this model

Assumptions

- Clients "show" on time with probability σ
- Client service times deterministic
  - No variability
- Clients serviced by assigned provider
- Office accrues
  - Benefits for serving additional clients
  - Penalties for keeping clients waiting
  - Penalties for office overtime

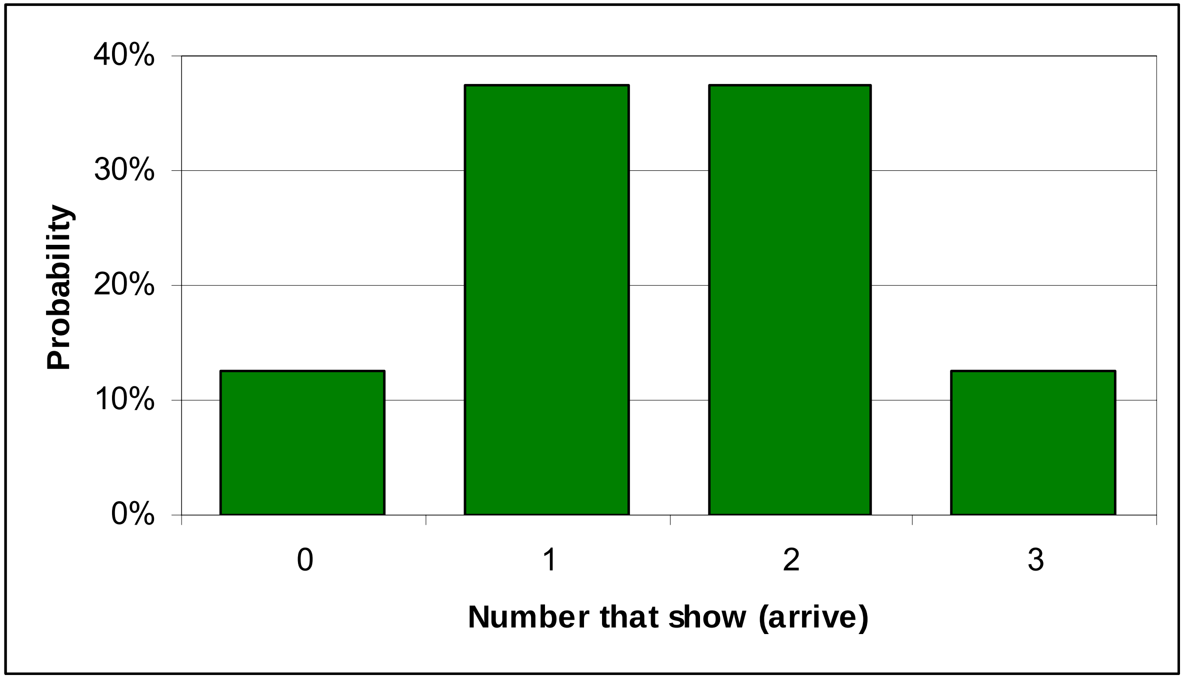
Probability that a_j Clients Arrive

- Arrivals are binomially distributed
  - s_j clients scheduled for appt slot j
  - Probability of a client showing is σ
  - $a_j \le s_j$ clients show for appointment

$$f\left(a_j; s_j, \sigma\right) = \binom{s_j}{a_j} \sigma^k \left(1-\sigma\right)^{s_j - a_j} = \frac{s_j\,!}{a_j\,!\left(s_j - a_j\right)!} \sigma^k \left(1-\sigma\right)^{s_j - a_j}$$

Arrival Distribution Example

3 clients scheduled; 50% show rate



N =162, σ =50%, slot j = 12, (ω, τ) = (0.5, 1.0) linear

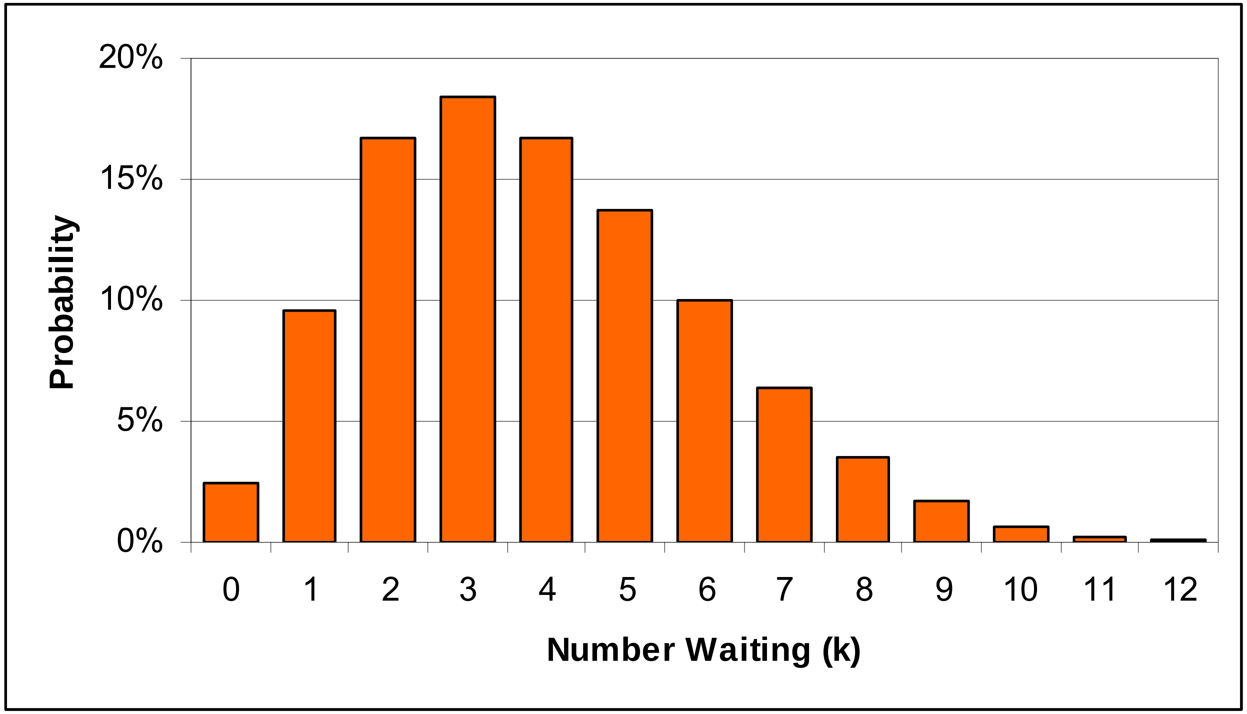
Probability of k clients Waiting

$$\theta_{j+1,k} = \theta_{j,0}\alpha_{j+1,k} + \sum_{i=0}^{k} \theta_{j,i+1}\alpha_{j+1,k-i}$$

- α_{jk} = probability of k clients arriving for service at the start of appointment slot j
- θ_{jk} = probability of k clients waiting for service at start of appointment slot j

Number Waiting Example

Appointment slot 12; 3 clients scheduled

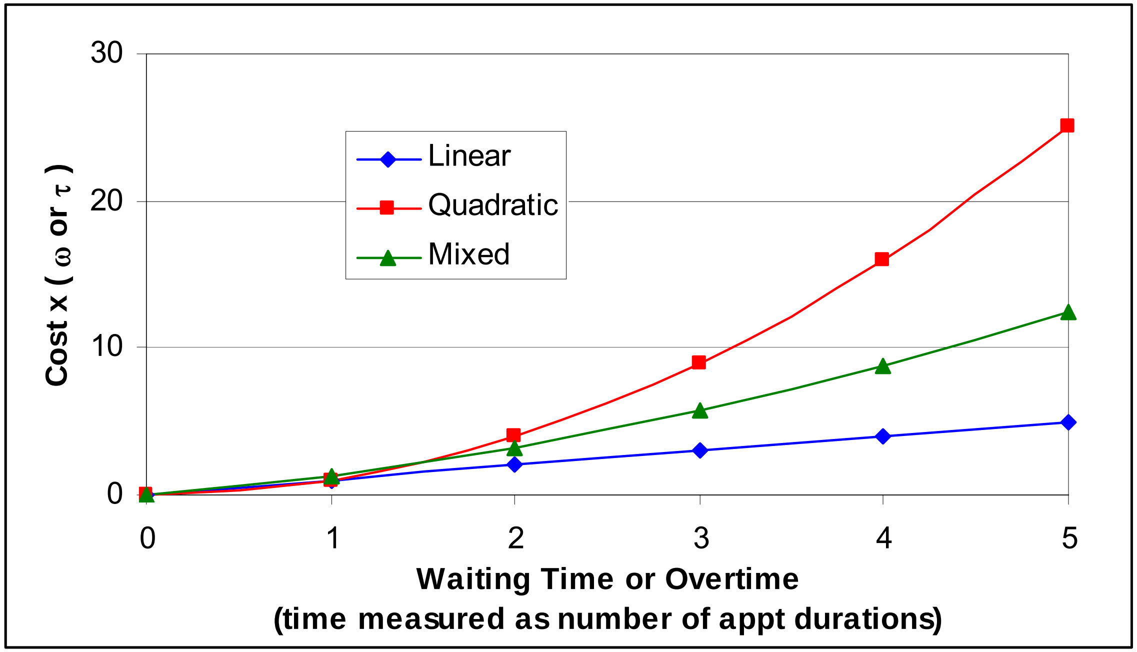


N =16, σ =50%, slot j = 12, (ω, τ) = (0.5, 1.0) linear

Relative Benefits and Penalties

- π = Benefit of seeing additional client
- ω = Penalty for client waiting
- τ = Penalty for office overtime
- Numéraire of π, ω, and τ doesn't matter
  - Ratios (relative importance) are important
- Allow both linear and quadratic costs

Linear & Quadratic Costs



- Model allows 2nd order polynomials
  - Results not reported in this paper

Linear & Quadratic Objectives

- Linear Utility Function

$$\hat{U}^L(\mathbf{S}) = \pi\hat{A} - \frac{\omega}{\hat{A}}\left(\sum_{j=1}^{N}\sum_{k} k\theta_{jk} + \sum_{k}\sum_{i=1}^{k} i\,\theta_{N+1,k}\right) - \tau\sum_{k} k\theta_{N+1,k}$$

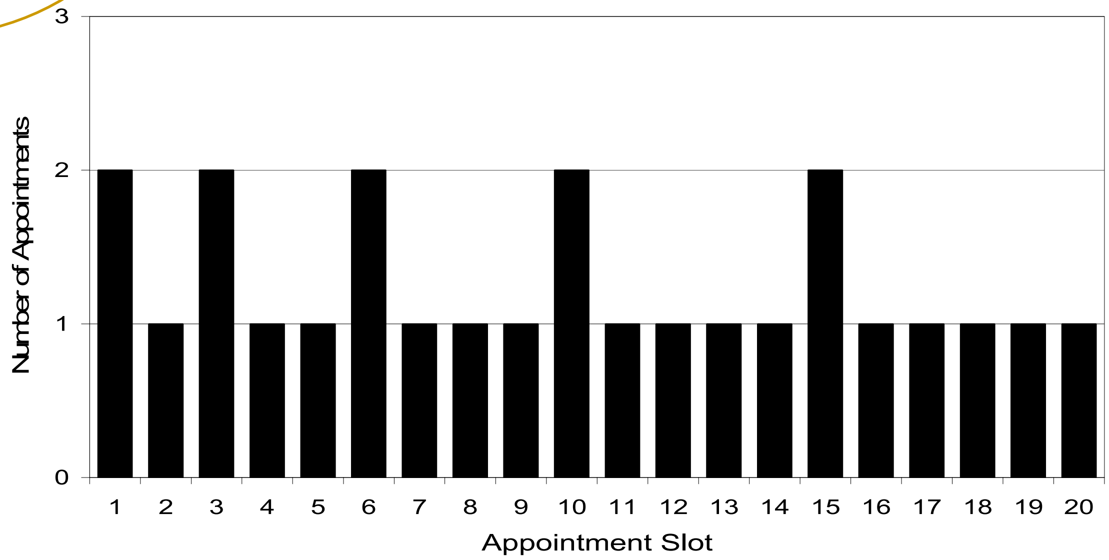
- Quadratic Utility Function

$$\hat{U}^Q(\mathbf{S}) = \pi\hat{A} - \frac{\omega}{\hat{A}}\left(\sum_{j=1}^{N}\sum_{k} (2k-1)\theta_{jk} + \sum_{k}\sum_{i=1}^{k} i^2\theta_{N+1,k}\right) - \tau\sum_{k} k^2\theta_{N+1,k}$$

Solution Methodology

1. Gradient search
   - Increment/decrement appointments scheduled in each slot
   - Choose the single change which provides the greatest improvement in utility
   - Iterate until no further improvement found
2. Pairwise interchange
   - Exchange appointments scheduled in all appointment slot pairs
   - Choose the single swap which provides the greatest improvement in utility
   - Iterate until no further improvement found

3. Computational Results

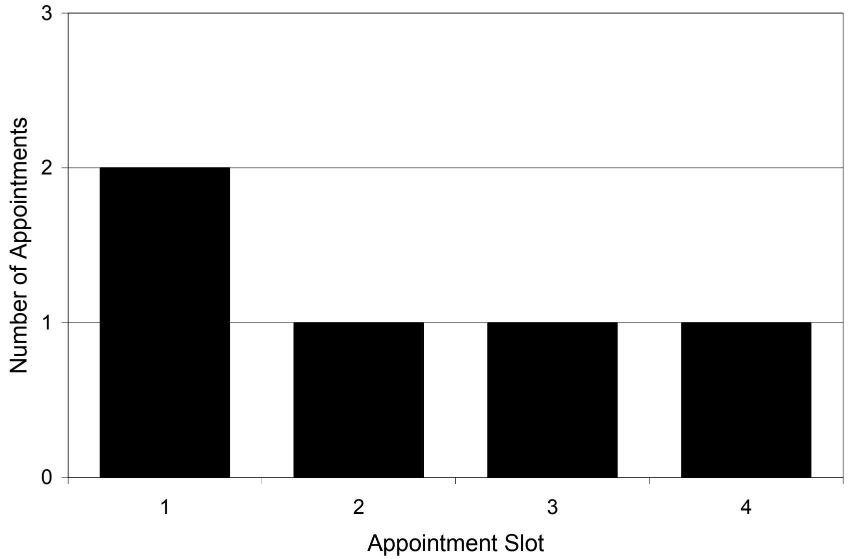


Example Schedules

- 180 example problems solved
- Office sizes
  - N = {4, 8, 12, 16, 20, 24}
- Show rates
  - σ = {90%, 80%, …, 50%}
- Benefit of additional client
  - π = 1.0
- Waiting / overtime costs
  - (ω, τ) = (1.0,1.0) (0.5, 1.5) (1.5, 1.5)
- Linear and quadratic cost functions

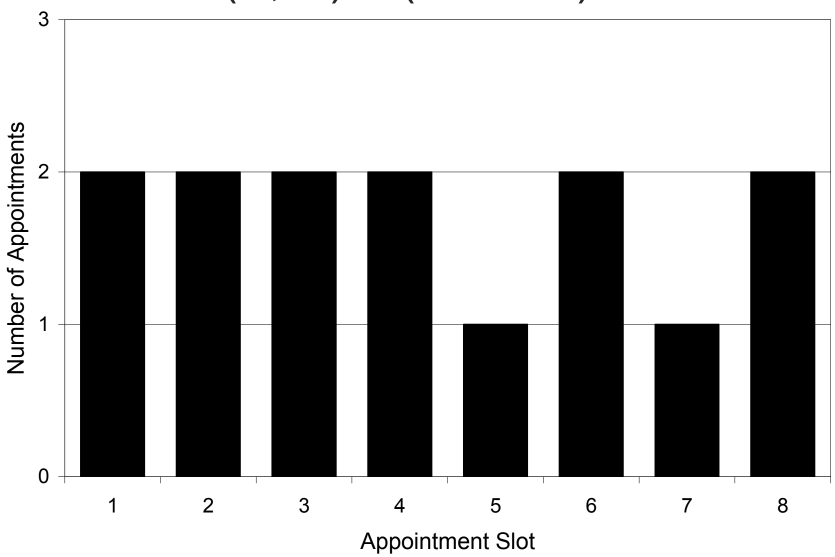
Example Schedules (1/3)

6A. N=4, σ=0.8
(ω, τ) = (0.5, 1.5) quadratic



- Front-loading
  - Bailey (1952)

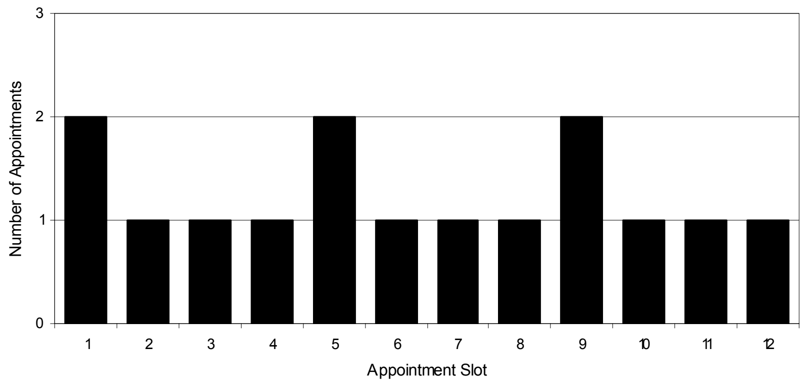
6B. N =8, σ=0.5
(ω, τ) = (1.0, 1.0) linear



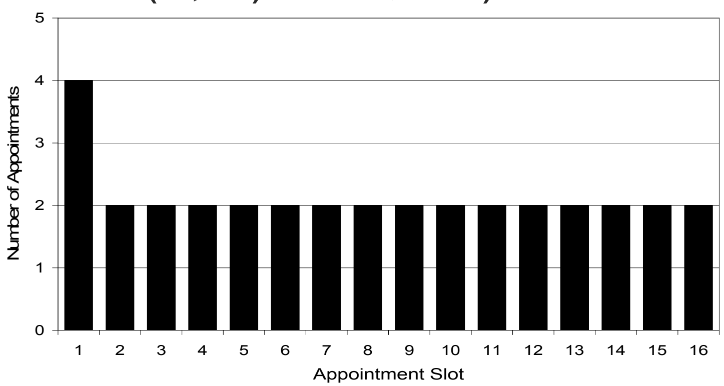
- Double-booking
  - Welch & Bailey (1952)

Example Schedules (2/3)

6C. N =12, σ =0.7
(ω, τ) = (1.0, 1.0) quadratic



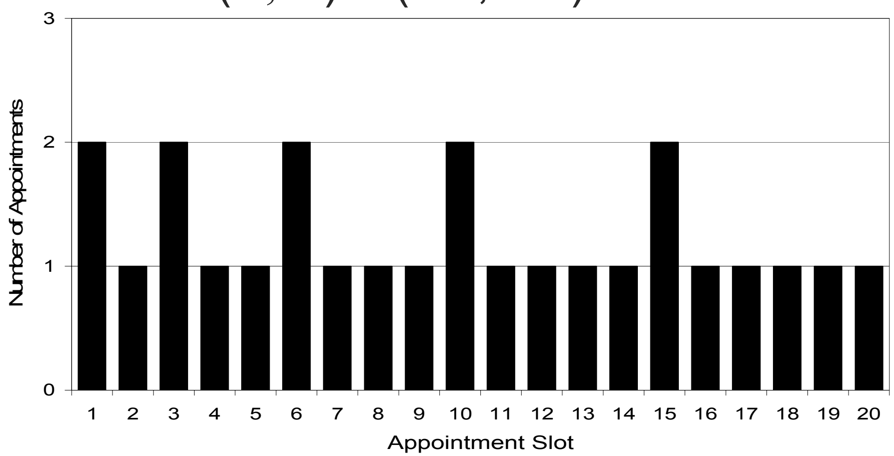
6D. N =16, σ =0.5
(ω, τ) = 1.0, 1.0) linear



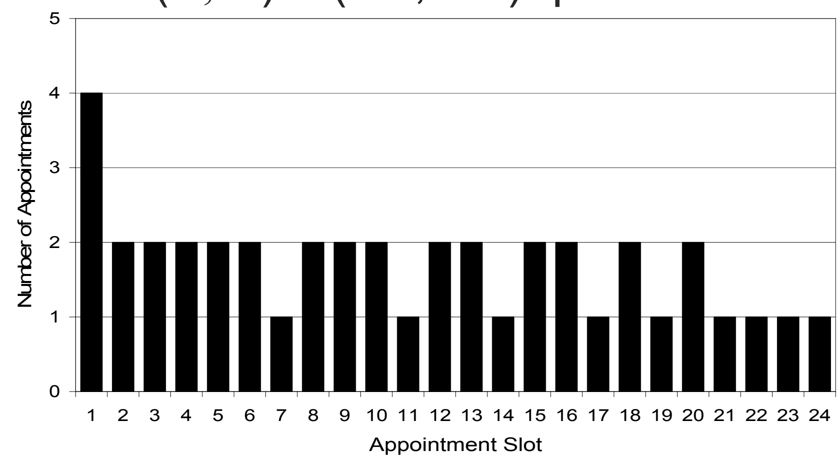
- Wave schedule
  - Baum (2001)
- Front-loading + double-booking

Example Schedules (3/3)

6E. N =20, σ =0.8
(ω, τ) = (0.5, 1.5) linear



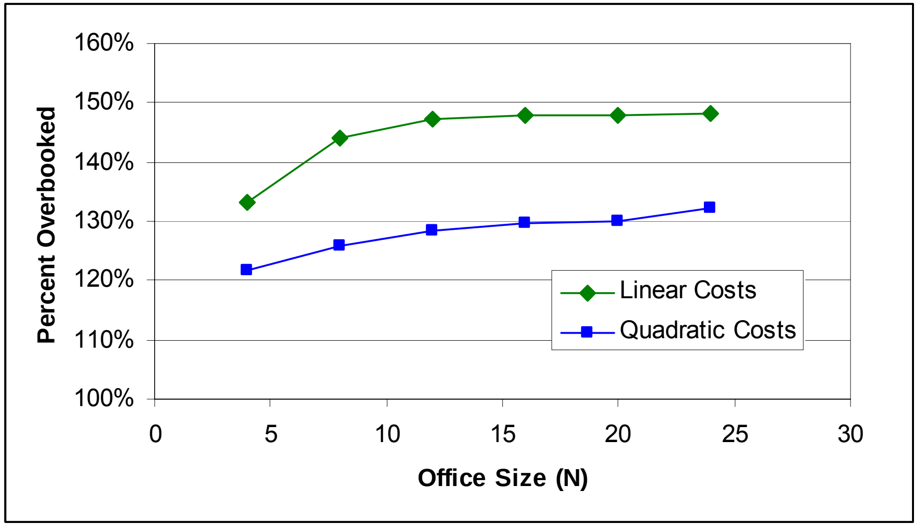
6F. N =24, σ =0.5
(ω, τ) = (0.5, 1.5) quadratic



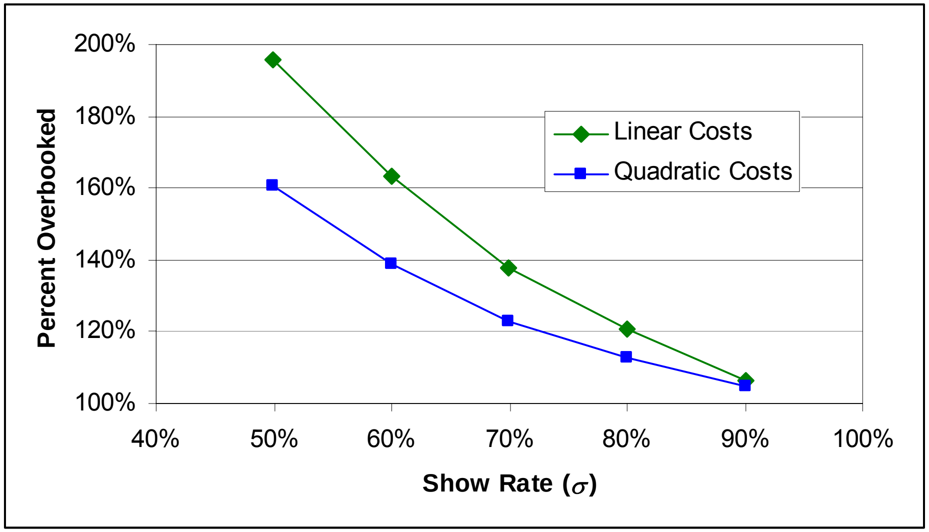
- Waves with increasing period

- Front-loading + double-booking + erratic waves

Appointments Overbooked

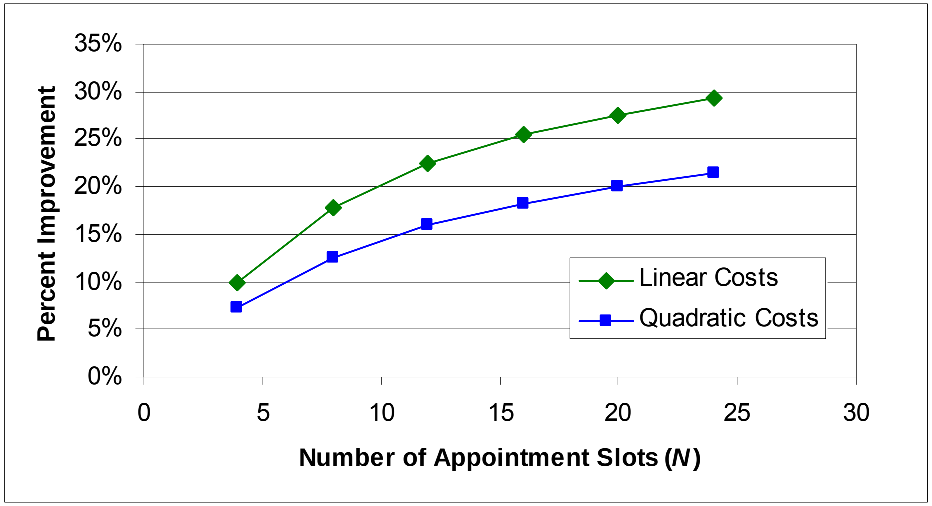


1A. Overbooking vs. office size *N*

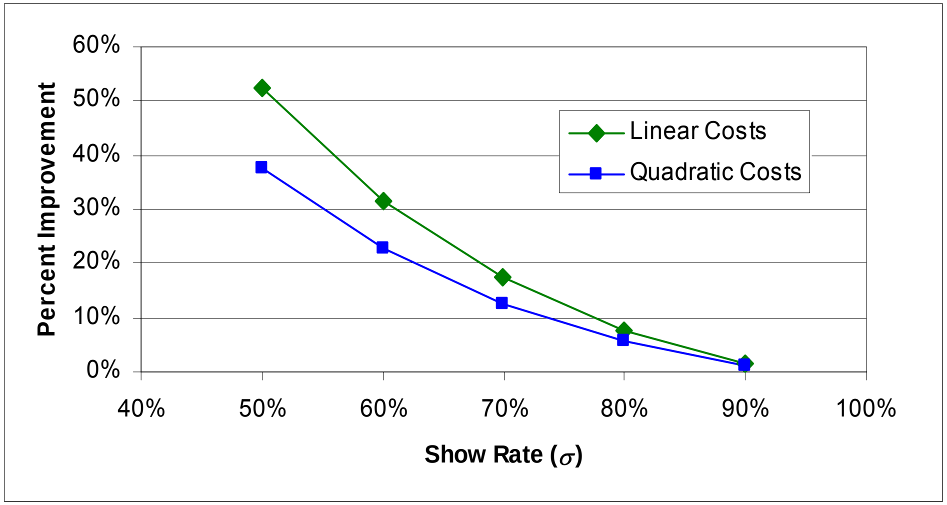


1B. Overbooking vs. show rate σ

Net Utility Improvement

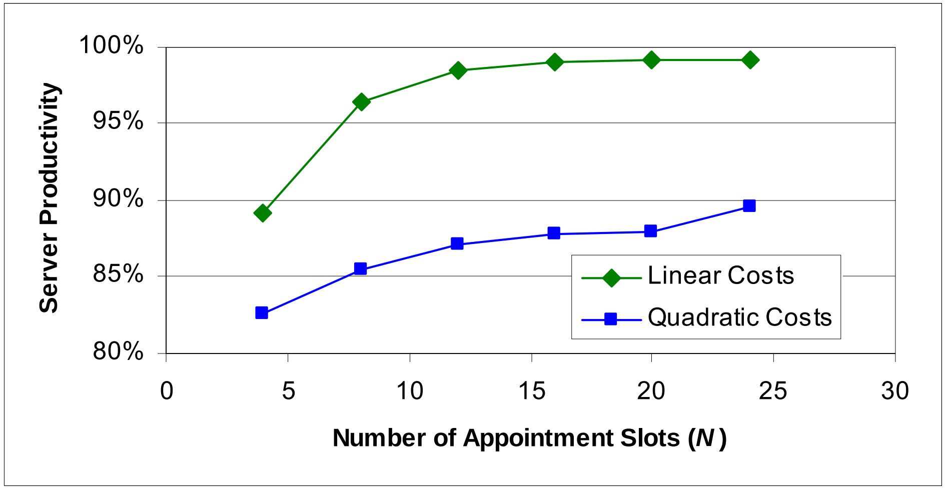


2A. Utility improvement vs. office size *N*

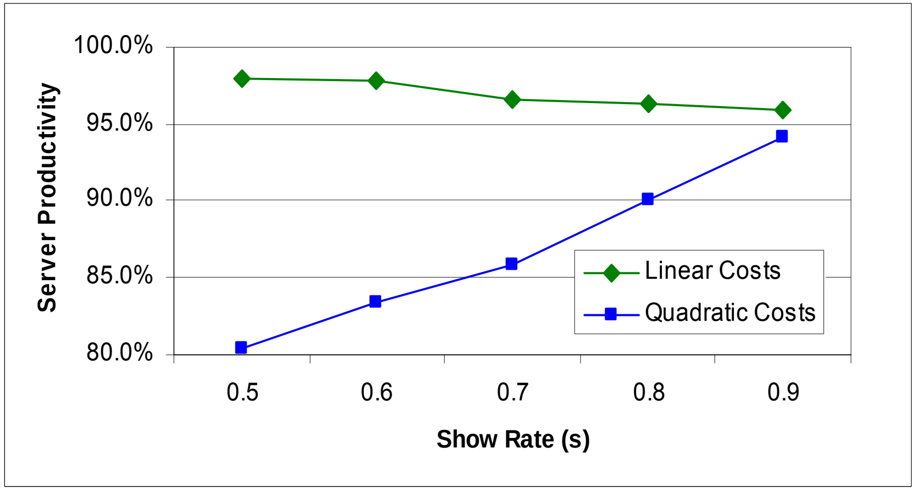


2B. Utility improvement vs. show rate σ

Server Productivity



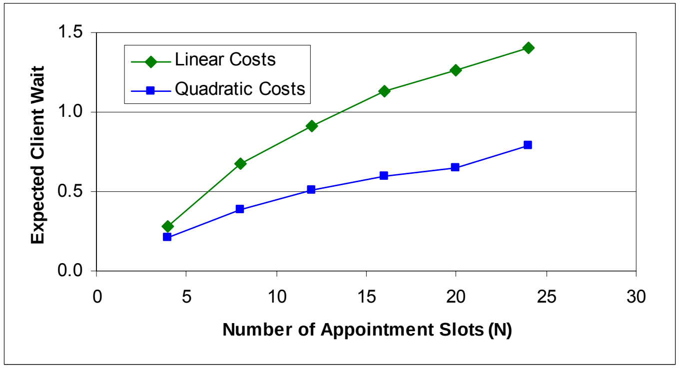
3A. Productivity vs. office size *N*



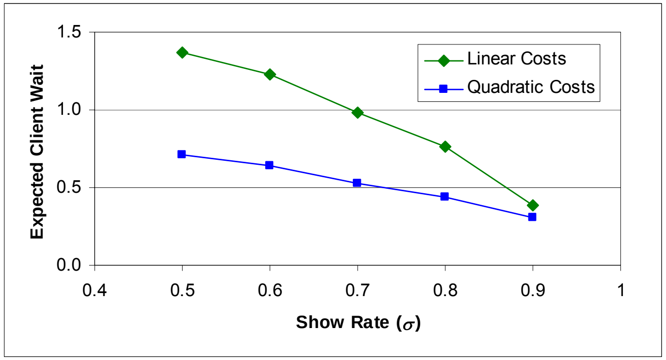
3B. Productivity vs. show rate σ

Without overbooking, provider productivity is equal to the show rate σ.

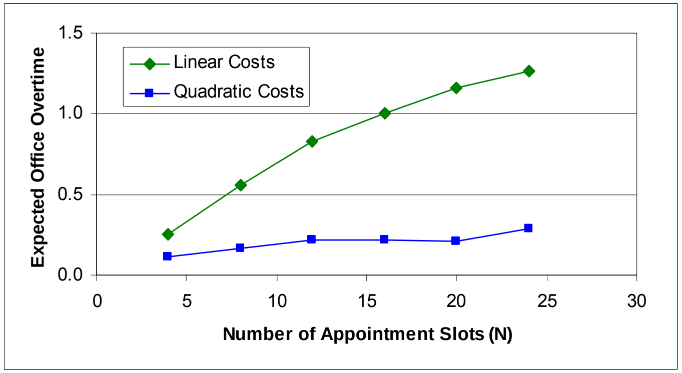
Expected Waiting & Overtime



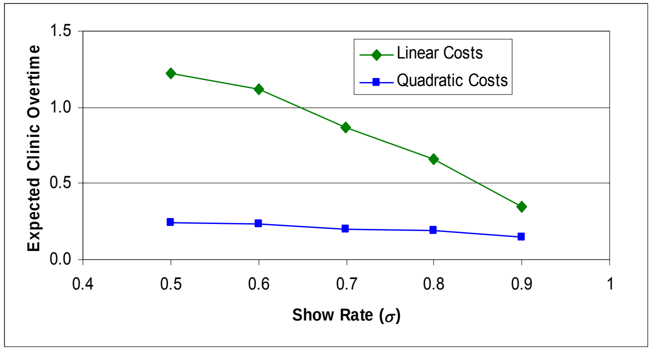
4A. Expected waiting vs. office size *N*



4B. Expected waiting vs. show rate σ

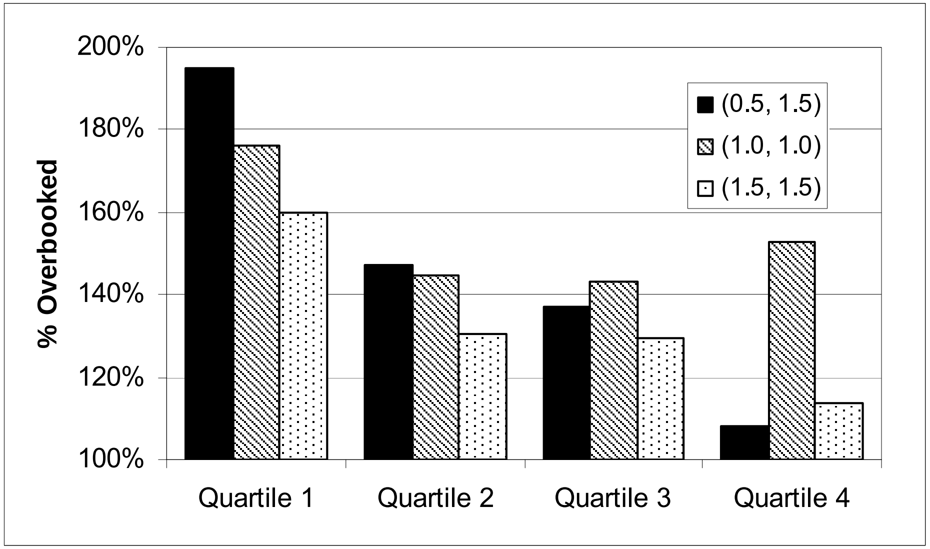


4C. Expected overtime vs. office size *N*

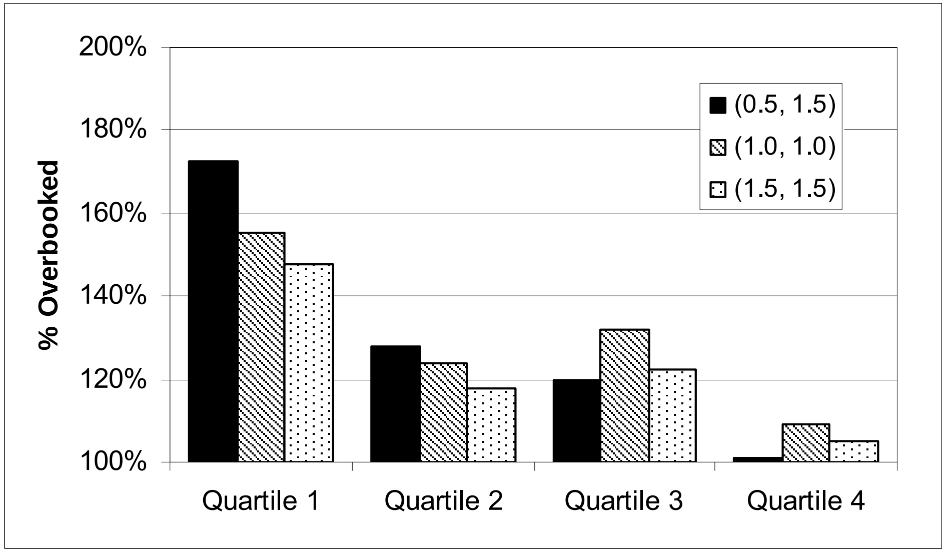


4D. Expected overtime vs. show rate σ

Overbooking Patterns



5A. Linear costs



5B. Quadratic costs

Managerial Implications

- Overbooking (OB)
  - Improves customer service (serve more)
  - Increases provider utilization
  - Increases expected client wait times
  - Increases expected clinic overtime
- OB patterns are problem specific
  - Unlikely simple rules will satisfice
  - Need optimal or near-optimal schedules

Contributions of Research

- Demonstrate benefits of appointment overbooking
- Analytic model of appointment scheduling with overbooking
  - Maximize utility
  - Balance service, waiting, and overtime
  - Linear and quadratic cost functions
- Fast and effective heuristic solutions
- Previous literature shown to be special cases of our analytic model

Future Extensions

- Stochastic service times
- Service times vary by service type
- Show rates vary by time of day
- Appointments scheduled at any time
  - Not just at start of appointment slot
- Walk-ins

Questions or Comments?

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