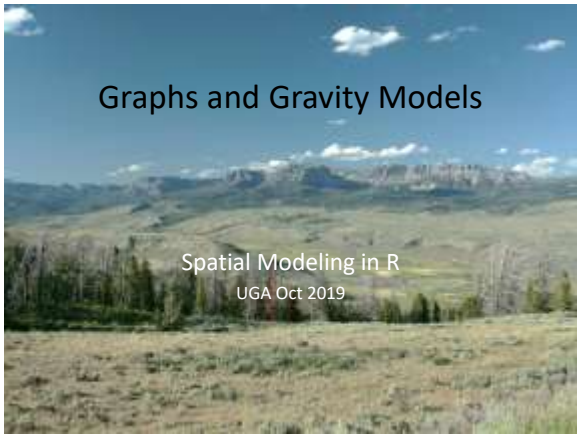
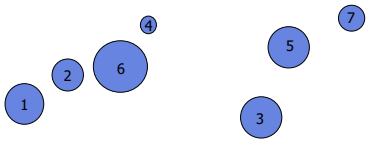


1

What is a graph?



Object (points, **nodes**, vertices)

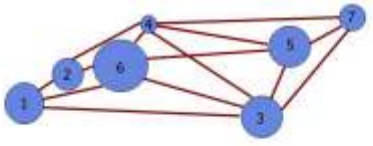
2

What is a graph?

Relationship (lines, **edges**, arcs)

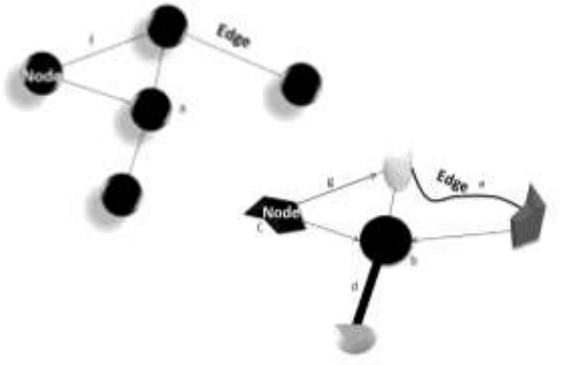
3

What is a graph?



Links indicate functional connectivity (Urban et al 2009)
Implicit and explicit relationship to metapopulations

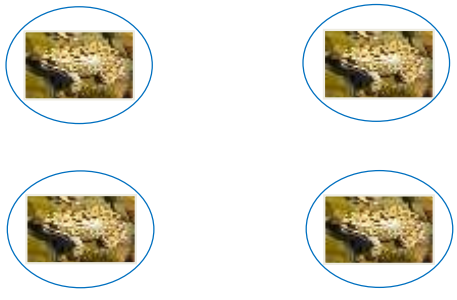
4



(Murphy *et al.* 2015; *Landscape Genetics: Concepts, Methods, Applications*)

5

Site Data



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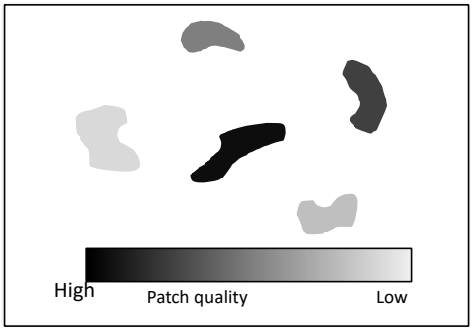
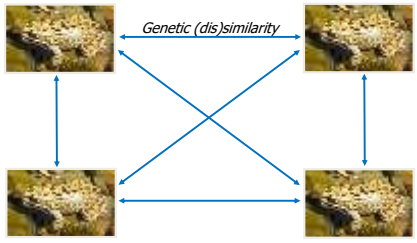


7

Pairwise data

(Murphy *et al. 2015; Landscape Genetics: Concepts, Methods, Applications*, Storfer *et al.* 2007; Heredity)



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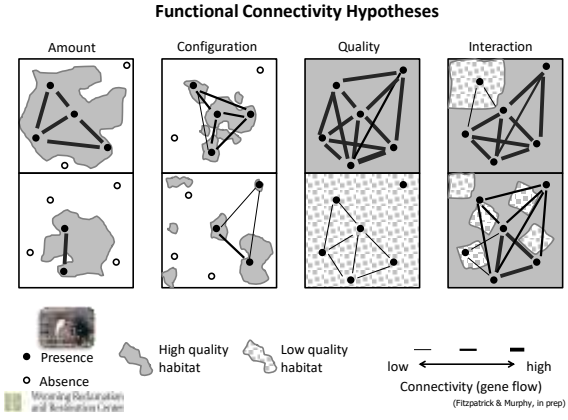


9

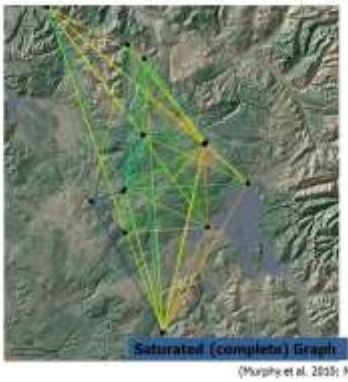
Network "Assumptions"

- Nodes easily defined/delineated
- Measuring (gene) flow
- Connections reasonable estimate of this process

(Murphy *et al.* 2015; *Landscape Genetics: Concepts, Methods, Applications*)

10

Network Topology – What is connected?



(Murphy et al. 2015; Murphy & Evans 2011)

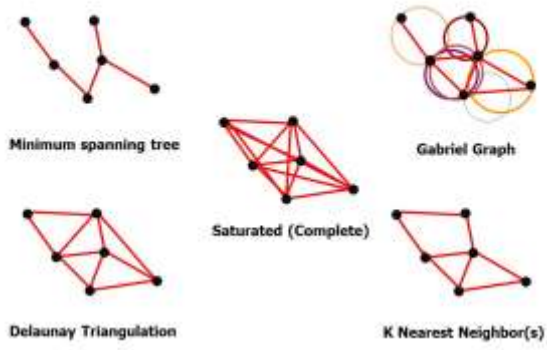
11

Network Optimization

- Reduce problem to relevant edges
- Identify connections with highest gene flow
- Can avoid overlapping connections
- Avoid long edges

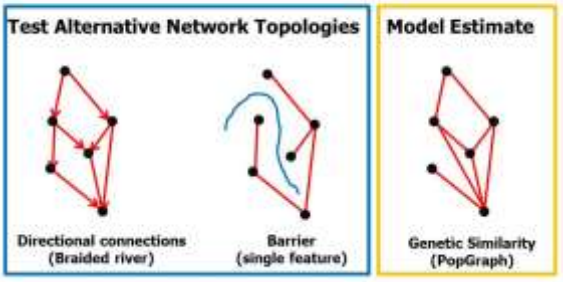
12

Rule-based networks



13

Hypothesized or model based



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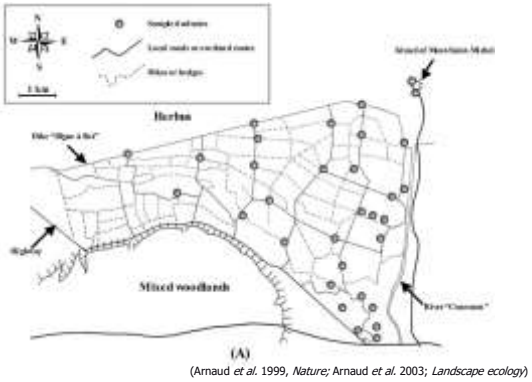
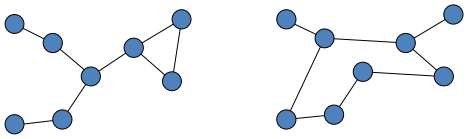
Hypothesis Based Network



(Arnaud *et al.* 1999, *Nature;* Arnaud *et al.* 2003; *Landscape ecology*)

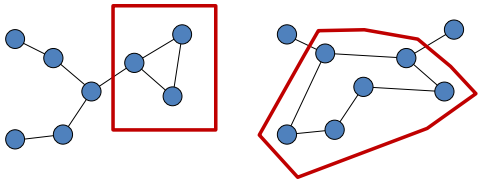
15

Graph Metrics



16

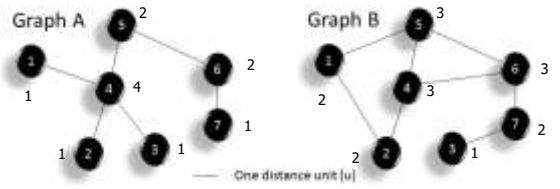
Graph Metrics



Cycle

17

Degree
Number of nodes linked to a node



(Murphy *et al.* 2015; *Landscape Genetics: Concepts, Methods, Applications*)

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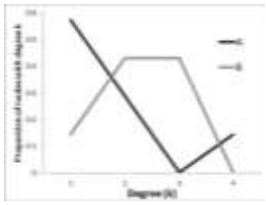
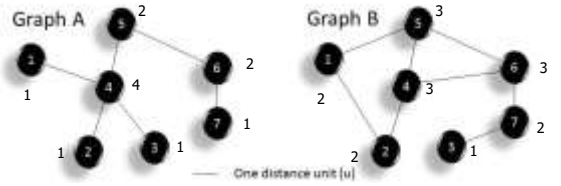
Degree Distribution





(Murphy *et al.* 2015; *Landscape Genetics: Concepts, Methods, Applications*)

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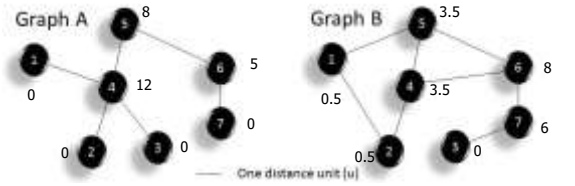
Betweenness

Number of times node is the shortest path



(Murphy *et al.* 2015; *Landscape Genetics: Concepts, Methods, Applications*)

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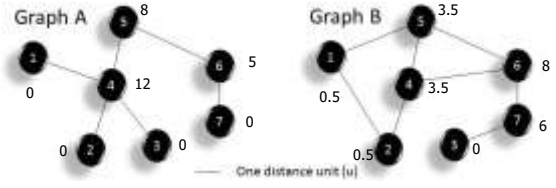
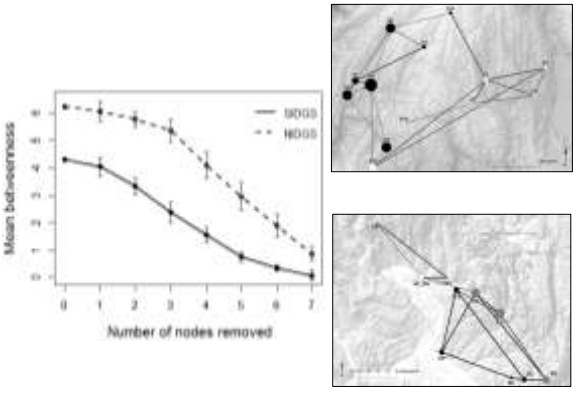
Mean Betweenness



3.57 3.14

(Murphy *et al.* 2015; *Landscape Genetics: Concepts, Methods, Applications*)

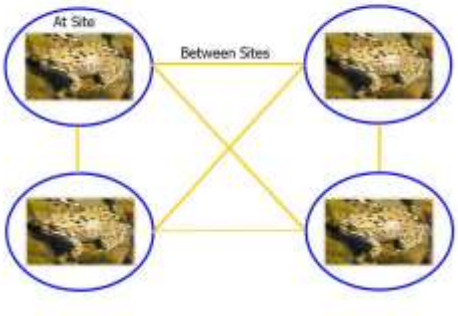
21



(Zero et al. in review)

22

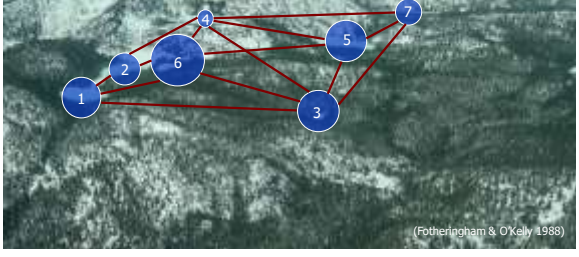
Do at site and between site processes limit connectivity?



23

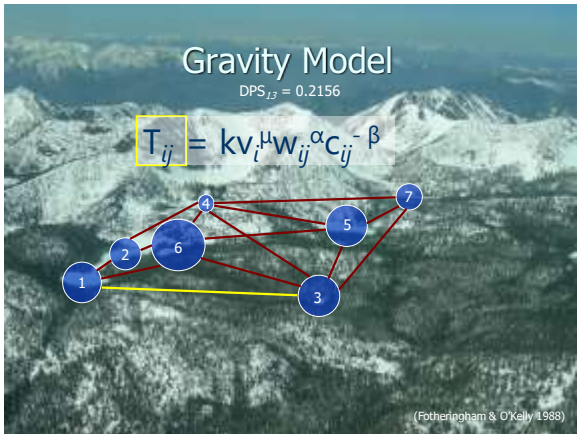
Gravity Model

$$T_{ij} = kv_i^{\mu} w_{ij}^{\alpha} c_{ij}^{-\beta}$$



(Fotheringham & O'Kelly 1988)

24



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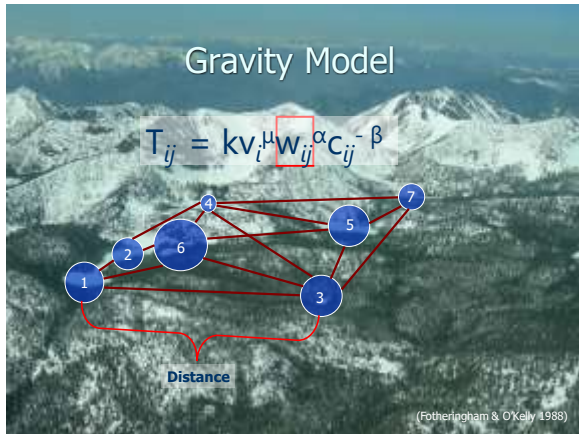

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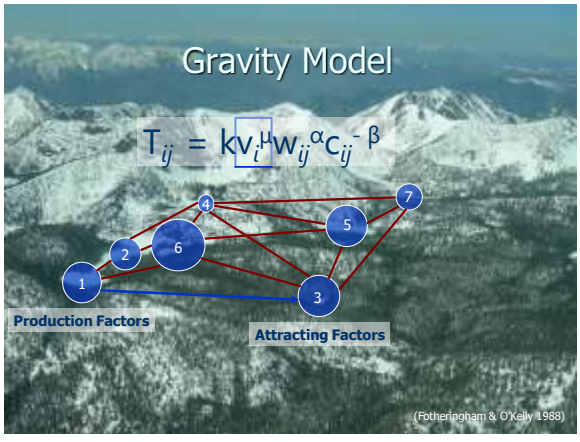
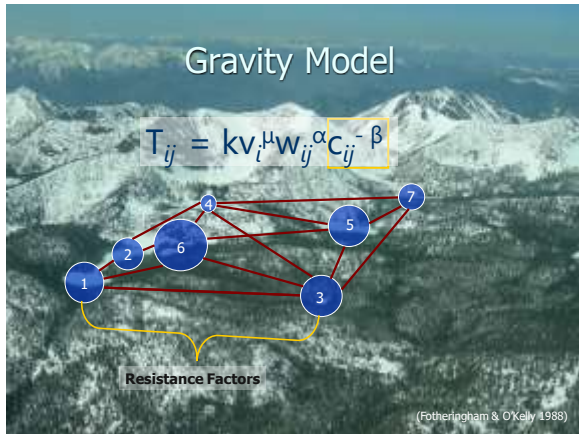


27



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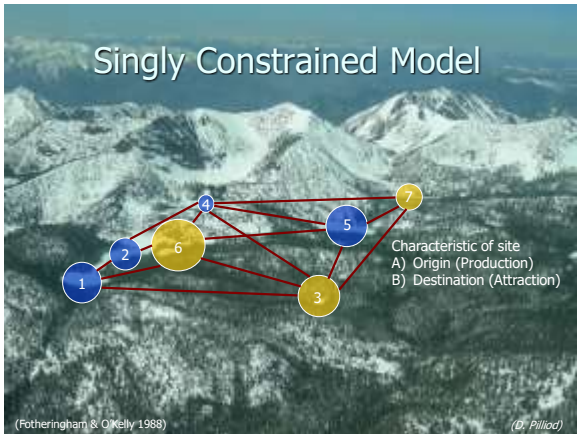

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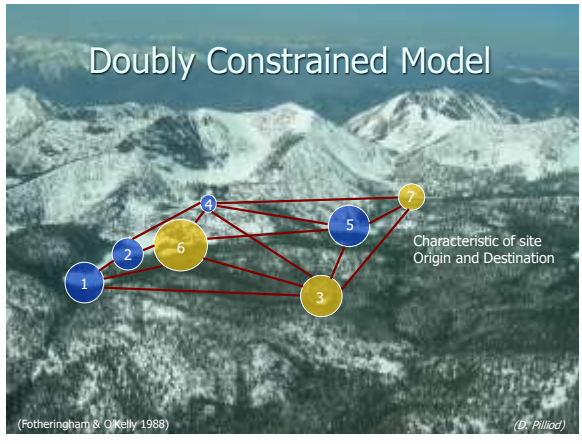

30

"Calibration" of Gravity Equation

$$T_{ij} = kv_i^{\mu} w_{ij}^{\alpha} c_{ij}^{-\beta}$$

Singly Constrained

$$\ln T_{ij} = \ln k_i + (\ln(\mu v_i) + \ln(\alpha w_{ij}) - \ln(\beta c_{ij}))$$

Mixed Effects Models
MLE

(Fotheringham & O'Kelly 1988)

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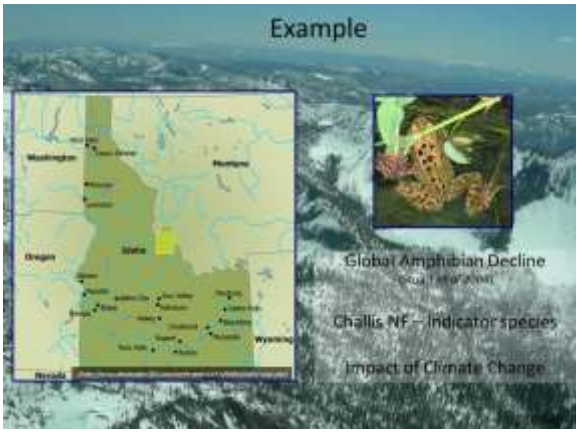

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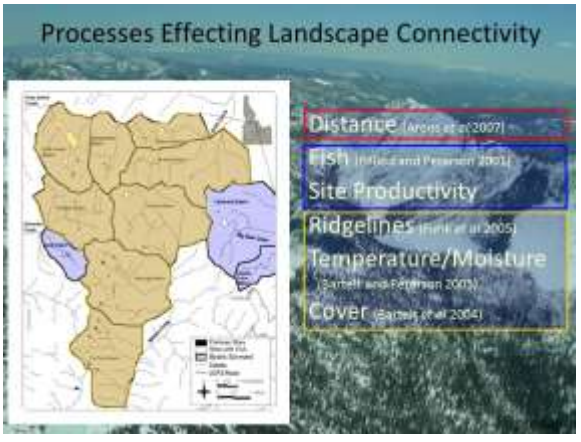

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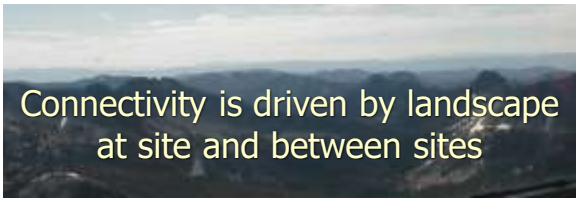

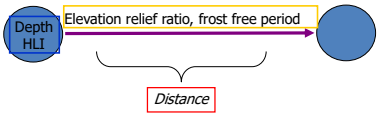

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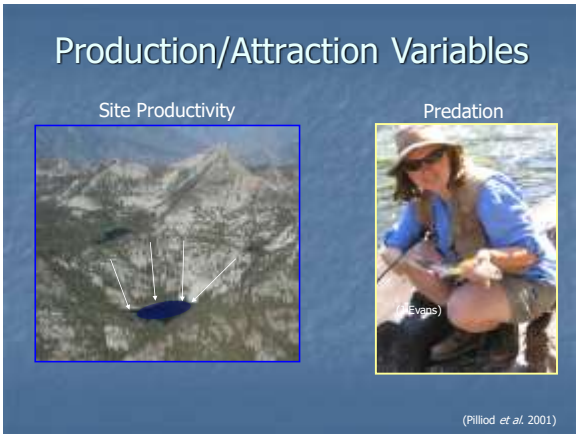

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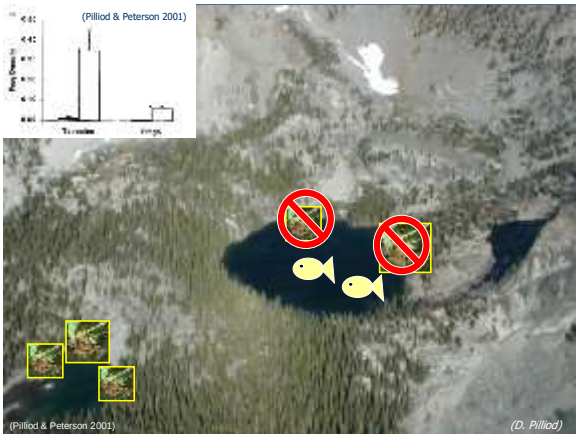

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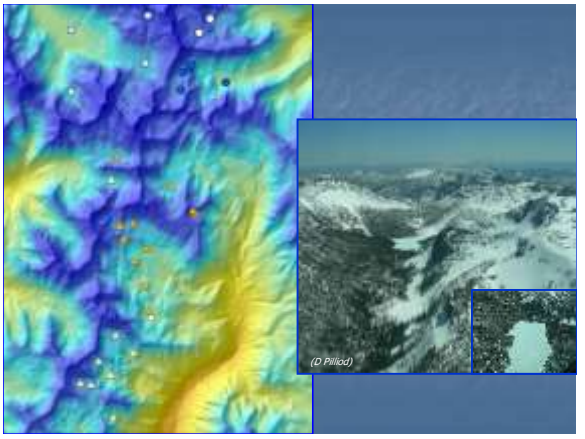

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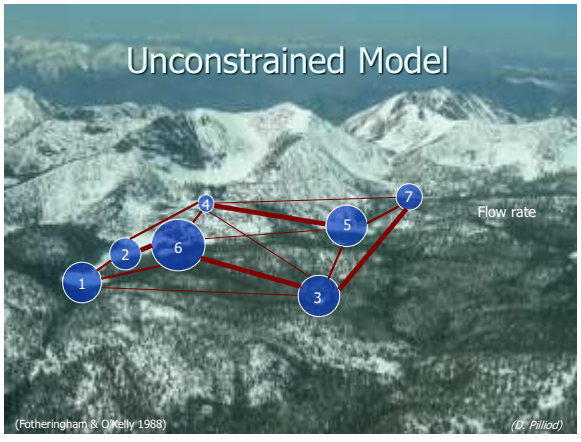

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"Calibration" of Gravity Equation

$$T_{ij} = kv_i^{\mu} w_{ij}^{\alpha} c_{ij}^{-\beta}$$

Unconstrained

$$\ln T_{ij} = \ln k + \ln(\mu v_i) + \ln(\alpha w_{ij}) - \ln(\beta c_{ij})$$

Linear regression – OLS
MLE

(Fotheringham & O'Kelly 1988)

40

"Calibration" of Gravity Equation

$$T_{ij} = kv_i^{\mu} w_{ij}^{\alpha} c_{ij}^{-\beta}$$

Doubly Constrained

$$\ln T_{ij} + \ln T_{ji} - \ln T_{jj} - \ln T_{ii} = \beta(\ln c_{ji} + \ln cji - \ln cii - \ln cjj)$$

MLE

(Fotheringham & O'Kelly 1988)

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