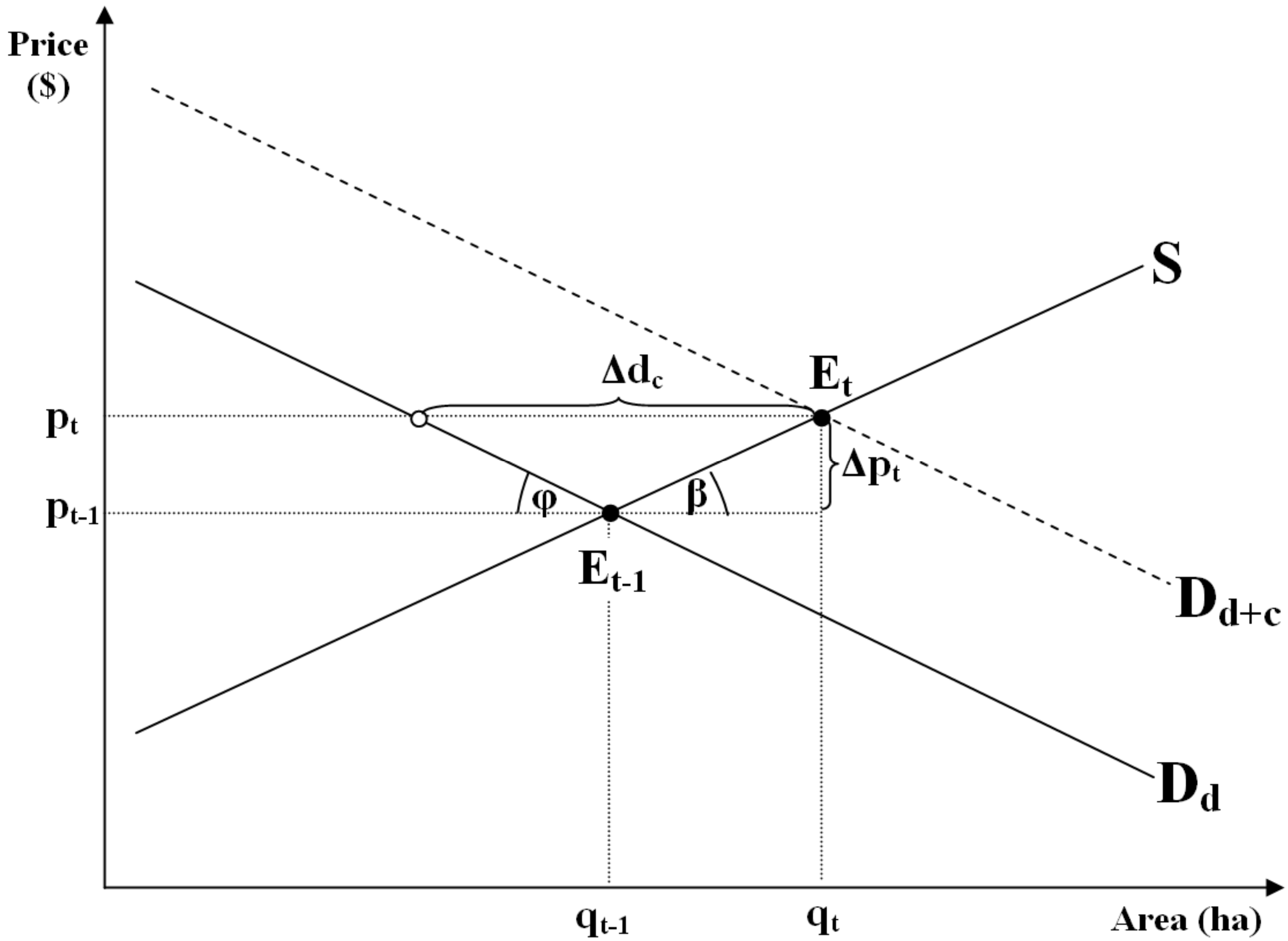
Dynamic Reserve Selection with Land Price Feedbacks

(an example of Integer Programming)

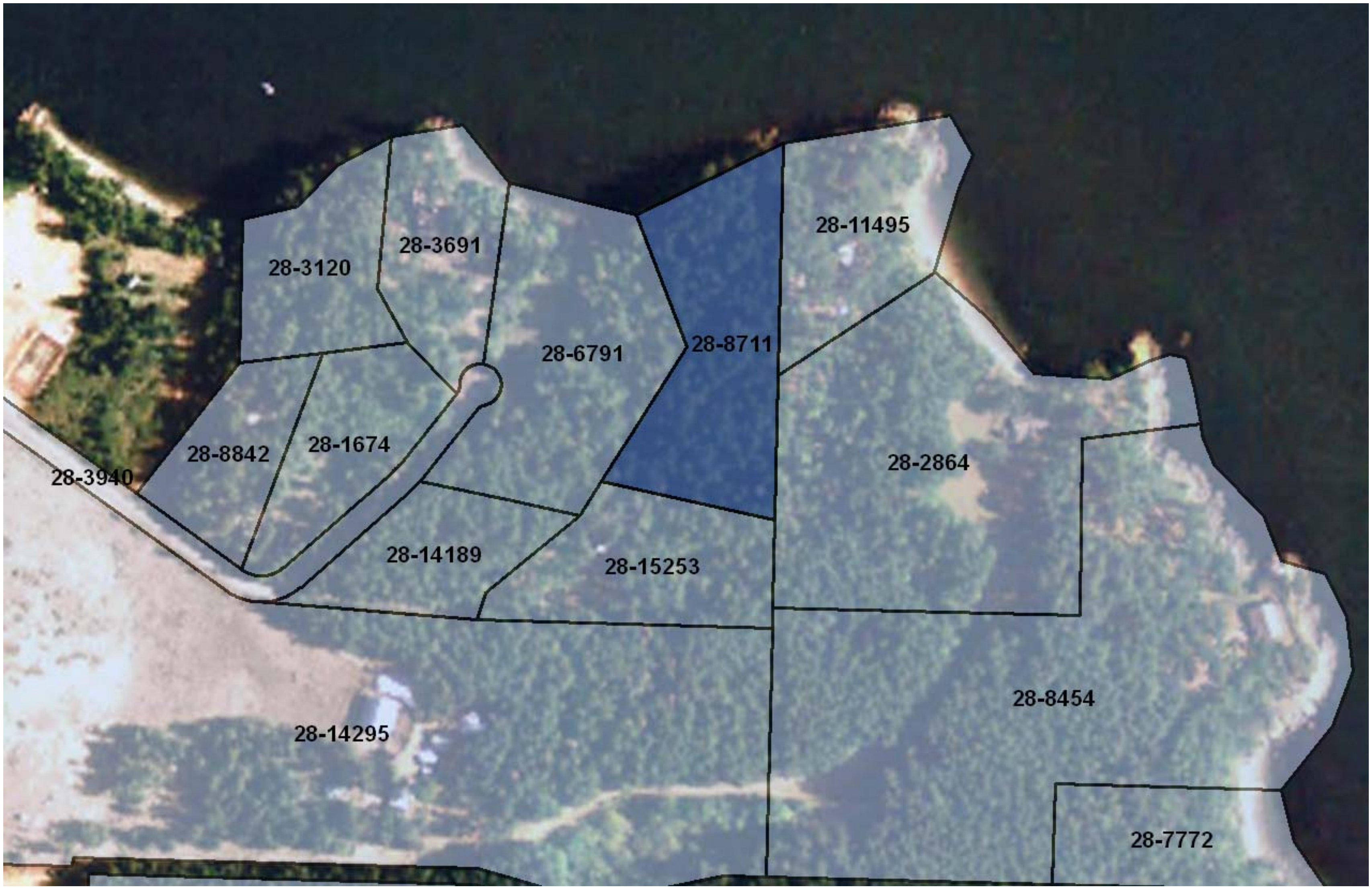
Lecture 9 (5/3/2017)

Motivation 1: Armsworth et al. 2006
Shifting Equilibriums in Competitive Land Markets

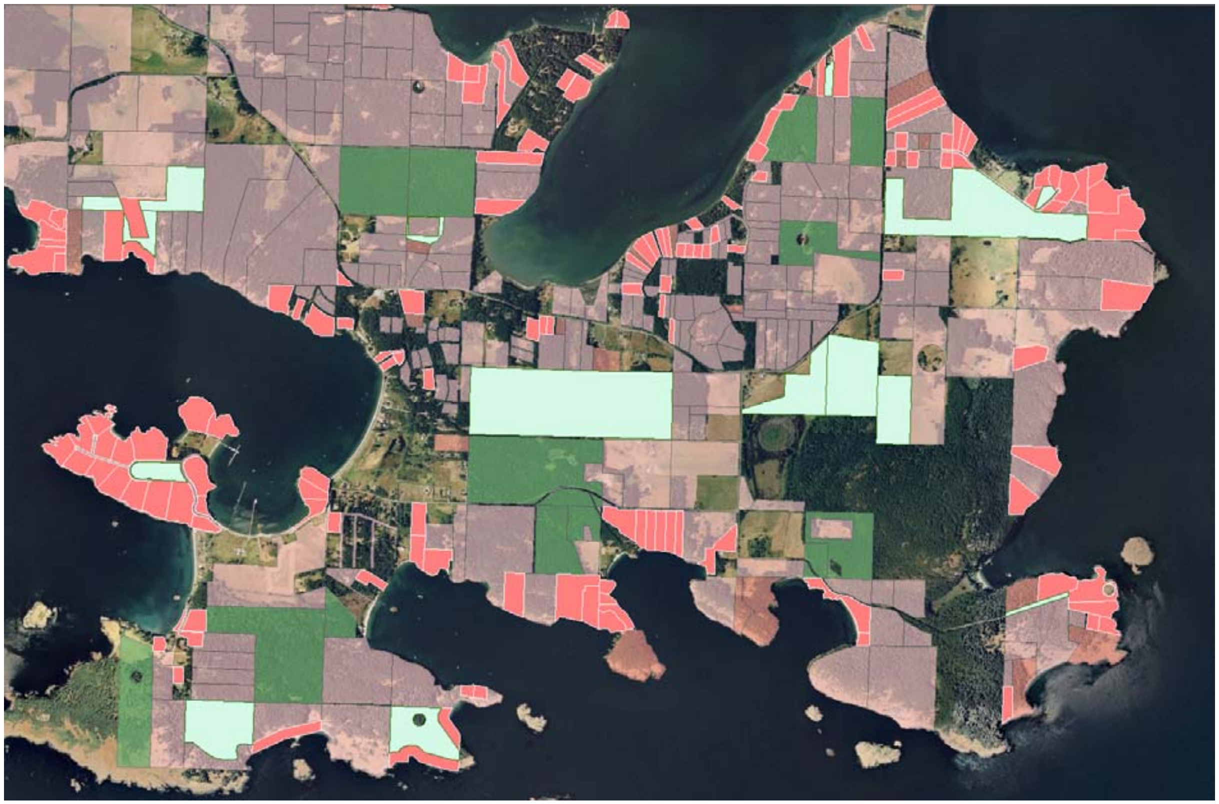


Source: Armsworth et al. 2006

Motivation 2:
Thornses 2002 – The Amenity Premium



3. <u>Motivation 3:</u> Irwin and Bockstael 2004
Development Hazard



$$R_{it} - \delta R_{i(t+1)} - A_{it} \geq \theta$$

An Integer Programming Approach

$$Max\left[\sum_i a_i div_i \sum_t x_{it} + \alpha \sum_i a_i div_i \left(1 - \sum_t x_{it} - \sum_t z_{it}\right)\right]$$

conservation

development

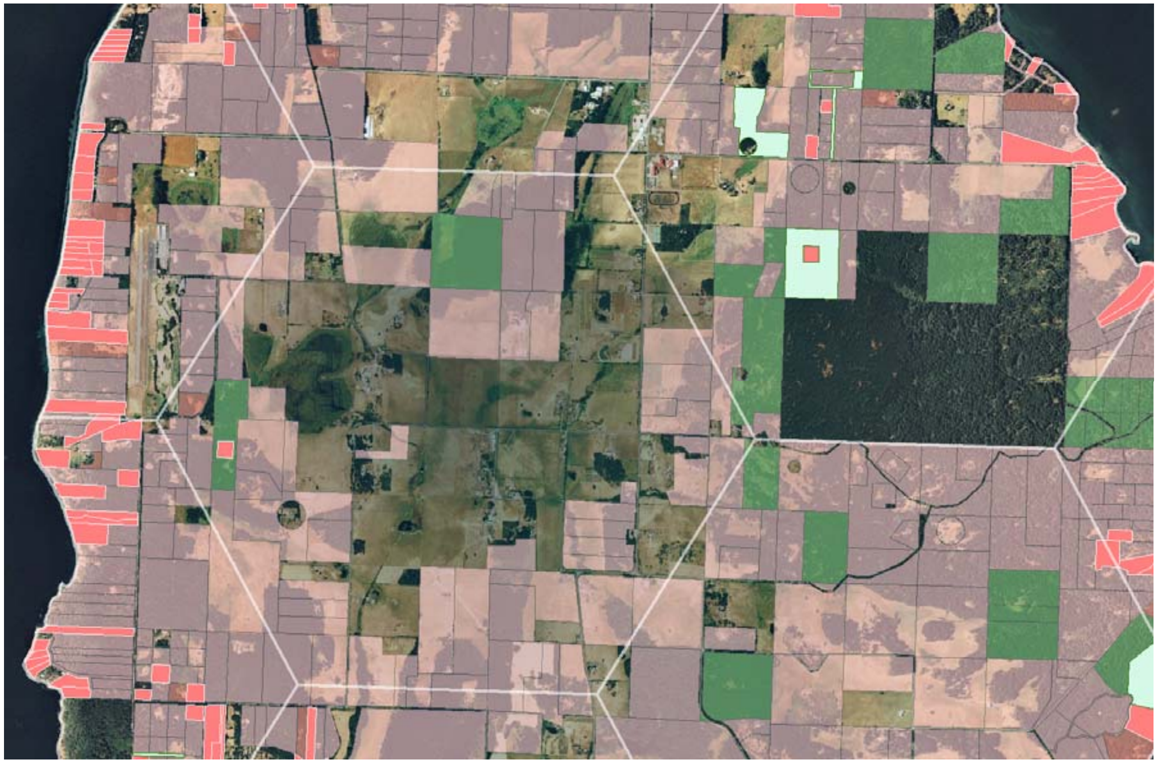
$Where:$

$x_{it},\ z_{it}\ \{0,1\}$

$$\sum_t (x_{it} + z_{it}) \le 1 \quad \forall\ i \in I$$

$$\sum_i p_{it} x_{it} \le B_t \quad \forall\ t \in T$$

$$p_{it} \in \mathbb{R}^+$$



1. Price Feedbacks Driven by Amenity Effects

$$\boxed{p_{it} = p_{i(t-1)}\left[1+\left(r+ey_{it}\right)\right]}$$

$$y_{it} \in \{0,1\}$$

$$\sum_{k \in S_i} x_{k(t-1)} \geq y_{it}$$

$$\sum_{k \in S_i} x_{k(t-1)} \leq |S_i| y_{it}$$

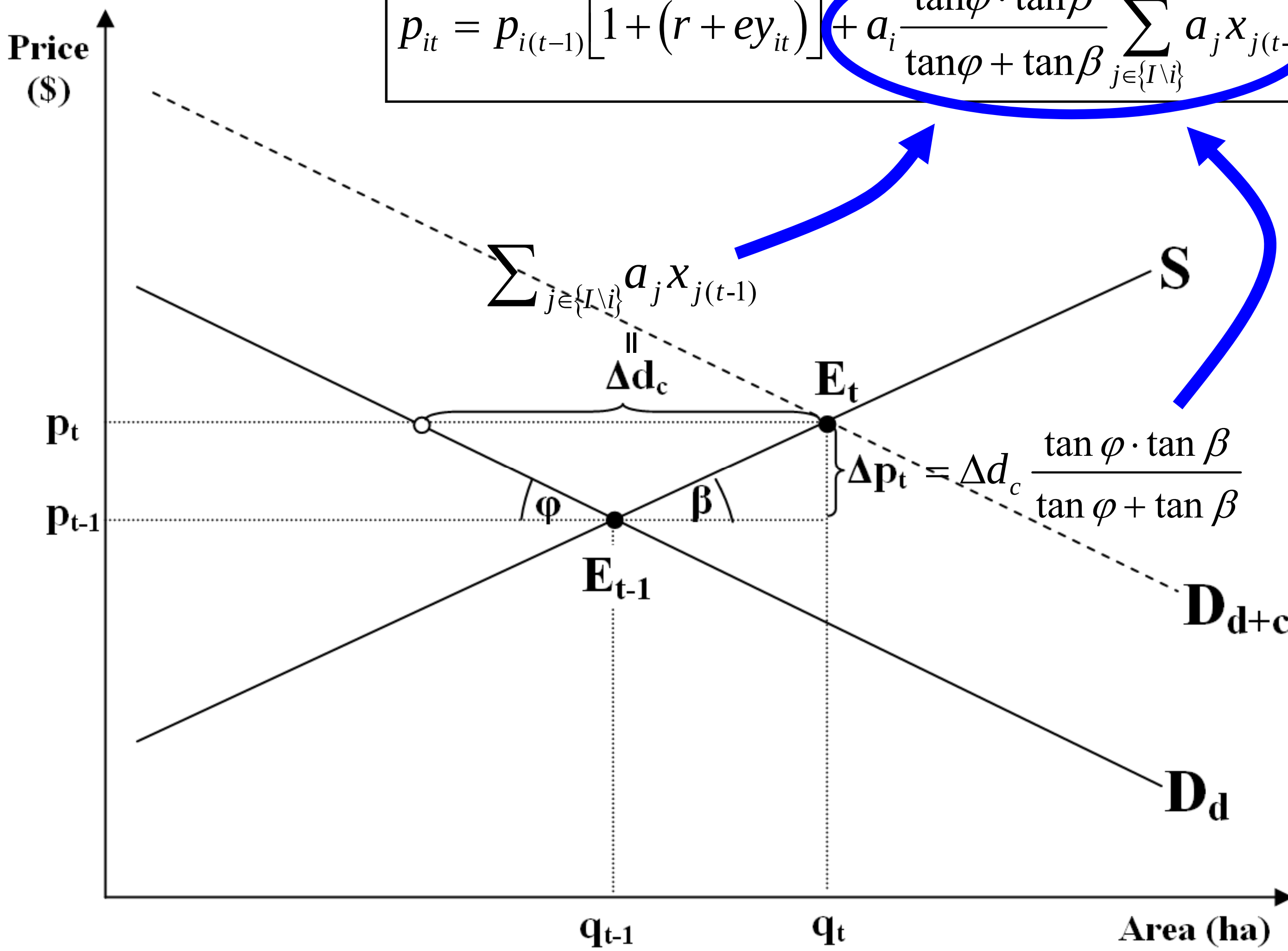
$\underline{Example:}$

$$x_{28-8711(1)} + x_{28-2864(1)} \geq y_{28-11495(2)}$$

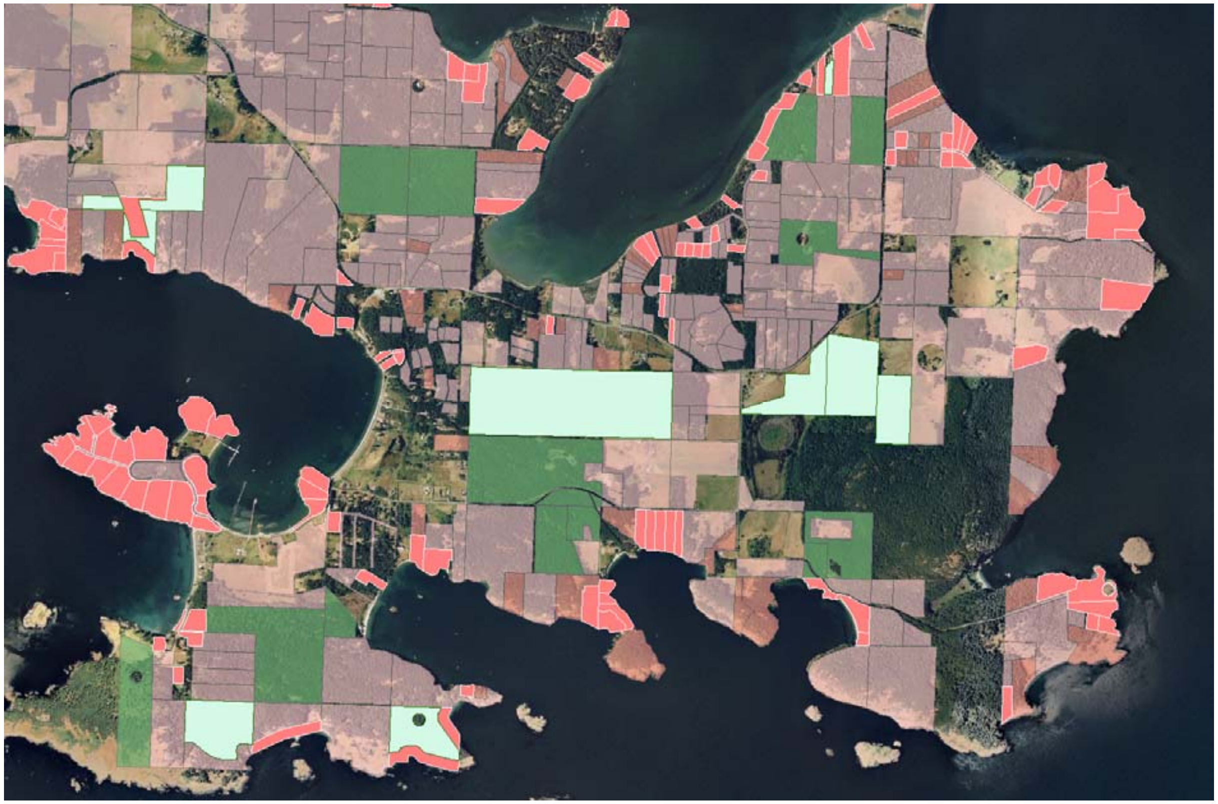
$$x_{28-8711(1)} + x_{28-2864(1)} \leq 2y_{28-11495(2)}$$

2. Price Feedbacks Driven by Shifting Competitive Equilibriums

$$p_{it} = p_{i(t-1)}\left[1+\left(r+ey_{it}\right)\right] + a_i \frac{\tan\varphi \cdot \tan\beta}{\tan\varphi + \tan\beta} \sum_{j\in\{I\setminus i\}} a_j x_{j(t\text{-}1)}$$



3. Development



Development or market value

Forest value

$$\frac{p_{it}}{FV_i + \theta_t} \geq z_{it}$$

Development indicator

$$\left(1 - \sum_{t'=1}^{t} z_{it'} - \sum_{t'=1}^{t} x_{it'}\right)\left(FV_i + \theta_t - p_{it}\right) \geq 0$$

Full Model Formulation

$$Max\left[\sum_i a_i div_i \sum_t x_{it} + \alpha \sum_i a_i div_i \left(1-\sum_t x_{it} - \sum_t z_{it}\right)\right]$$

$$Subject\,to:$$

Logical constraint

$$\sum_t \left(x_{it} + z_{it}\right) \le 1 \qquad \forall\ i \in I$$

Budget constraint

$$\sum_i \underline{p_{it} x_{it}} \le B_t \qquad \forall\ t \in T$$

Pricing

$$p_{it} = \underline{p_{i(t-1)}}\left[1+\left(r+e\underline{y_{it}}\right)\right] + a_i \frac{\tan\varphi \cdot \tan\beta}{\tan\varphi + \tan\beta} \sum_{j\in\{I\setminus i\}} a_j x_{j(t\text{-}1)} \qquad \forall\ i \in I,\ \forall\ t \in \{T\setminus 1\}$$

Amenity triggers

$$\sum_{k\in S_i} x_{k(t-1)} \ge y_{it} \qquad \forall\ i \in I,\ \forall\ t \in \{T\setminus 1\}$$

$$\sum_{k\in S_i} x_{k(t-1)} \le |S_i| y_{it} \qquad \forall\ i \in I,\ \forall\ t \in \{T\setminus 1\}$$

Development triggers

$$p_{it} \ge \left(FV_i + \theta_t\right) z_{it} \qquad \forall\ i \in I,\ \forall\ t \in T$$

$$\left(1-\underline{\sum_{t'=1}^{t} z_{it'}} - \underline{\sum_{t'=1}^{t} x_{it'}}\right)\left(FV_i + \theta_t - \underline{p_{it}}\right) \ge 0 \qquad \forall\ i \in I,\ \forall\ t \in T$$

$$x_{it}, y_{it}, z_{it} \in \{0,1\},\ \ p_{it} \in \mathbb{R}^+$$

Non-Linearities

$$\sum_i p_{it} x_{it} \leq B_t \qquad \forall\ t \in T$$

Let $\varepsilon_{it} = p_{it} x_{it}$

We want that $\varepsilon_{it} = 0$ if $x_{it} = 0$, otherwise: $\varepsilon_{it} = p_{it}$.

large constant

$$\varepsilon_{it} - M x_{it} \leq 0$$

$$\varepsilon_{it} \leq p_{it}$$

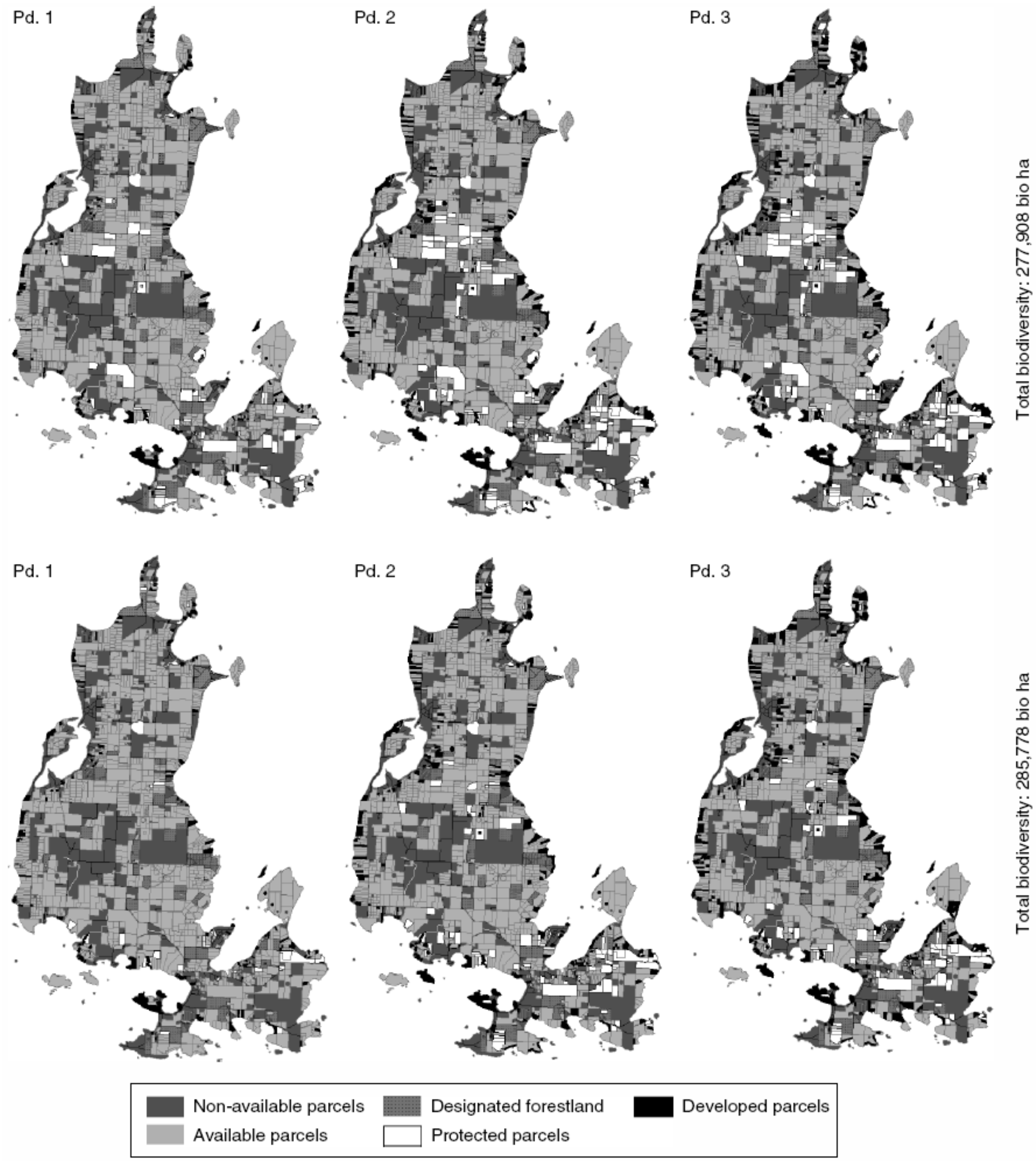
$$p_{it} - \varepsilon_{it} + M x_{it} \leq M$$

Results 1

Table 2. Objective values under different market scenarios and budget constraints.

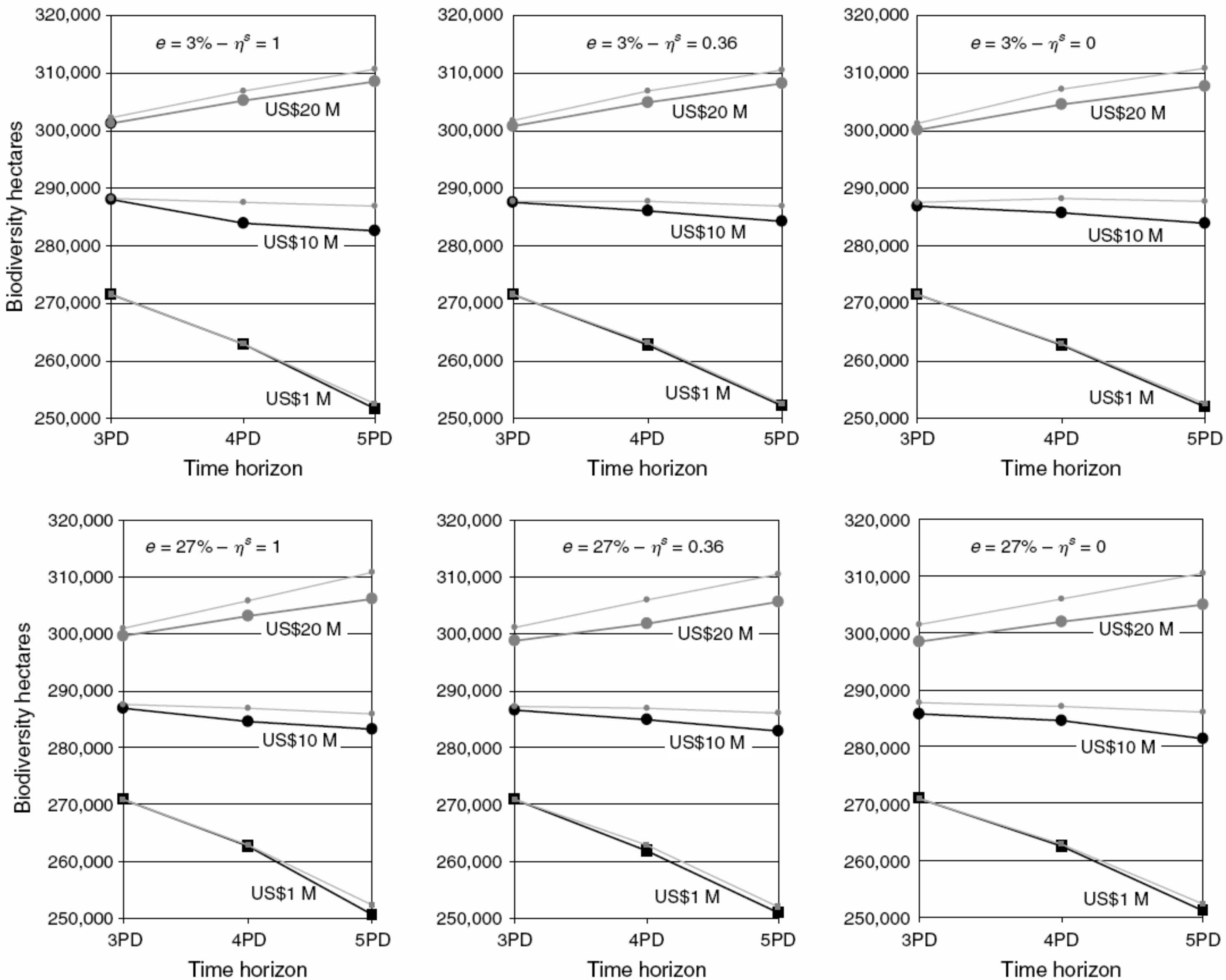
Budget	Price elasticity of supply	Amenity premium (%)	Naïve purchases (no anticipation of price feedbacks): Objective func. values (total biodiversity hectares)	Naïve purchases: Optimality gaps (%)	Smart purchases (price feedbacks are anticipated): Objective func. values (total biodiversity hectares)	Smart purchases: Optimality gaps (%)	Loss in objective function values due to ignoring the price feedbacks (%)
US$1 M	1	3	271,525	0.00	271,537	0.00	0.004568
	0.36	3	271,496	0.00	271,512	0.00	0.01
	0	3	271,484	0.00	271,500	0.00	0.01
	1	27	270,168	0.00	270,927	0.00	0.28
	0.36	27	270,002	0.00	270,924	0.00	0.34
	0	27	268,958	0.00	270,911	0.00	0.72
US$10 M	1	3	286,007	0.00	288,030	0.07	0.70–0.78
	0.36	3	286,509	0.00	287,607	0.05	0.38–0.43
	0	3	286,230	0.00	286,895	0.21	0.23–0.44
	1	27	278,586	0.00	286,966	0.04	2.92–2.96
	0.36	27	278,051	0.00	286,511	0.23	2.95–3.19
	0	27	277,908	0.00	285,778	0.68	2.75–3.41
US$20 M	1	3	299,773	0.00	301,267	0.32	0.50–0.81
	0.36	3	299,527	0.00	300,816	0.32	0.43–0.75
	0	3	298,167	0.00	300,221	0.38	0.68–1.06
	1	27	289,092	0.00	299,655	0.44	3.52–3.95
	0.36	27	288,284	0.00	298,729	0.78	3.50–4.24
	0	27	287,452	0.00	298,487	1.02	3.70–4.67

Results 2



Pd. 1
Pd. 2
Pd. 3
Total biodiversity: 277,908 bio ha
Pd. 1
Pd. 2
Pd. 3
Total biodiversity: 285,778 bio ha
Non-available parcels
Available parcels
Designated forestland
Protected parcels
Developed parcels

Results 3



e = 3% – η^s = 1
e = 3% – η^s = 0.36
e = 3% – η^s = 0
e = 27% – η^s = 1
e = 27% – η^s = 0.36
e = 27% – η^s = 0
US$20 M
US$10 M
US$1 M
Biodiversity hectares
Time horizon
3PD
4PD
5PD
250,000
260,000
270,000
280,000
290,000
300,000
310,000
320,000