Spatial Management of Invasive Alien Species

An Application to Cheatgrass Management in the Great Basin

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Motivation

- IS management is a complex problem with many dimensions
- Evaluating options requires understanding not only these features but how they interact
- Previous literature has focused on other combinations; we focus on the spatial aspects.

- *Biological*
- *Economic*
- *Spatial*
- *Intertemporal*
- *Stochastic*

Two Spatial Models

- Model 1: Transmission Pathways and Policy Options
- Model 2: Native rangeland and invasive weeds

Key Research Questions

- What are the crucial feedbacks that influence the relative effectiveness of IS policies?
  - "Spatial Management of Invasive Ecosystem Engineers"
- What if the scope of IS policies does not match the ecosystem/economic scale of the problem?
  - "Invasive Species Management in a Spatially Heterogeneous World: Spatial vs. Uniform Policies"
- How does spatial connectivity, including fire hazards, affect cheatgrass management?
  - "Sagebrush vs. Cheatgrass in the Great Basin"

Transmission Pathways

- IS can enter a local ecosystem in several ways
- Economic
  - "Foreign" trade: transportation and commerce from outside the larger system (e.g., foreign container ships)
  - "Domestic" trade: transportation and commerce between two patches (e.g., inland river, air, and road travel)
- Ecological
  - Natural dispersal of the invasive species (e.g., currents, fish, birds)
  - Fire risk

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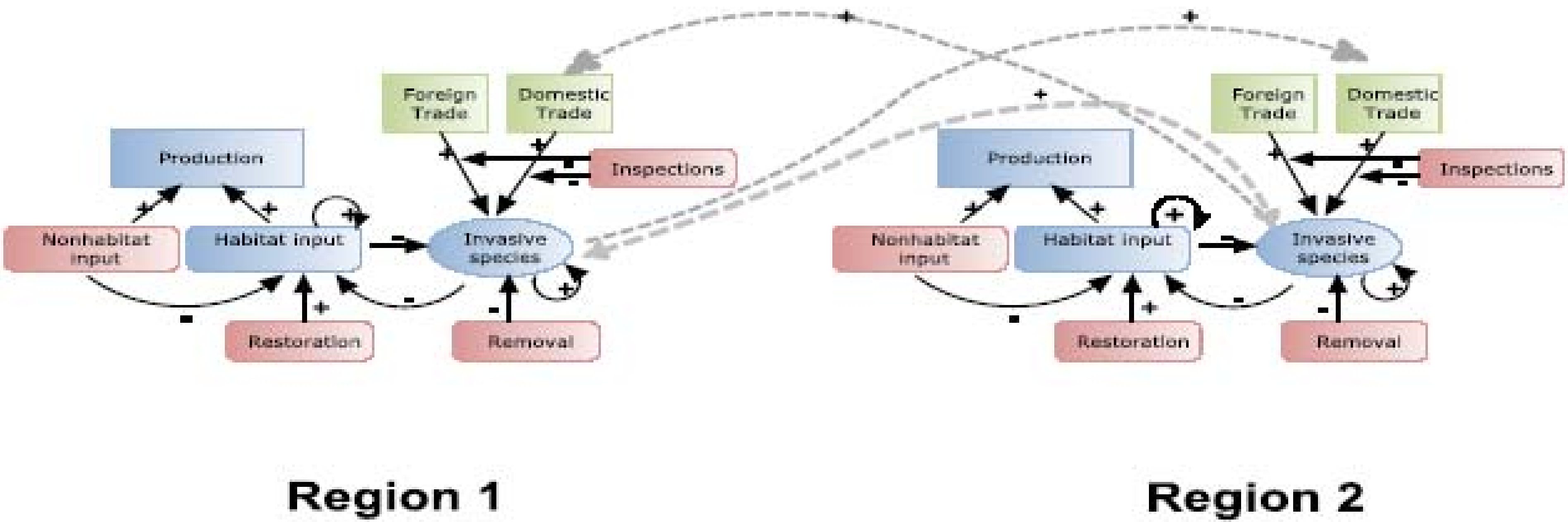
Policy Options

- Reduce likelihood of entry by inspections, quarantines, and reducing the volume of trade
- Prevent long-term establishment and spread with better land or water management practices and/or mitigate damages by changing land use or grazing patterns
- Restore habitat for native species
- Remove or eradicate existing infestations, including use of biological controls
- Physical barriers to fire dispersal (in 3rd paper)
- *How much and where?*

Stylized Description of Model 1



Ecological Features of the Model: Invasive species

- Probability of invasive taking hold depends on
  - Transmission pathways and magnitudes
  - Level of inspections of trade going into each patch (greater inspections lower probability)
  - Stock of invasives in source patch
  - Quality of the habitat in the patch (impedes entry)
- IS growth depends on
  - Quality of the habitat in the patch (impedes growth)
  - Natural growth rate
  - Removal efforts (directly decreases invasive stock)

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Ecological Features of the Model: Habitat

- Habitat quality (stock variable) improves with
  - Natural regeneration
  - Investments in restoration
- Habitat is damaged/depleted by
  - Agricultural (non-habitat) inputs
  - Increase in invasive population

Economic features of the model

- Agricultural production depends on
  - Habitat quality and ecosystem services from the habitat
  - Use of non-habitat inputs
- Social planner maximizes agricultural revenues net of input costs, and net of policy costs of inspections, removal, and remediation
  - Dynamic model; we focus on steady states

Numerical Analysis

- We investigate the spatial aspects of the invasive species problem from two angles.
  - How do the patch-specific controls change when new transmission (spatial) pathways are introduced?
  - How do aspatial (uniform) policies differ from their spatial counterparts, and how are they affected when new pathways are introduced?
- Stylized example

Spatial homogeneity, spatial processes, and control problems

Percentage change from no connectivity steady state (symmetric case)

	Either Patch				
	Invasive	Removal	Restoration	Commodity Input use	Commodity Output
Ecol. Disp.	1.77	5.82	-0.69	-1.30	-.62
Dom. Trade	-.20	.92	-.17	-0.22	-.31
Foreign Trade	387.39	16.32	42.30	8.79	2.83
Dom. & For.	392.40	17.15	42.77	8.78	2.83
Disp., Dom. & For.	403.26	21.83	43.60	8.26	2.83

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Adding Asymmetries

- Port-Inland Case: No exogenous flows from outside the system into the inland patch
- Cost of agricultural inputs are cheaper in the inland patch, all else equal
- Both

Sensitivity to relative cost of non-habitat input (full connectivity)

Invasive

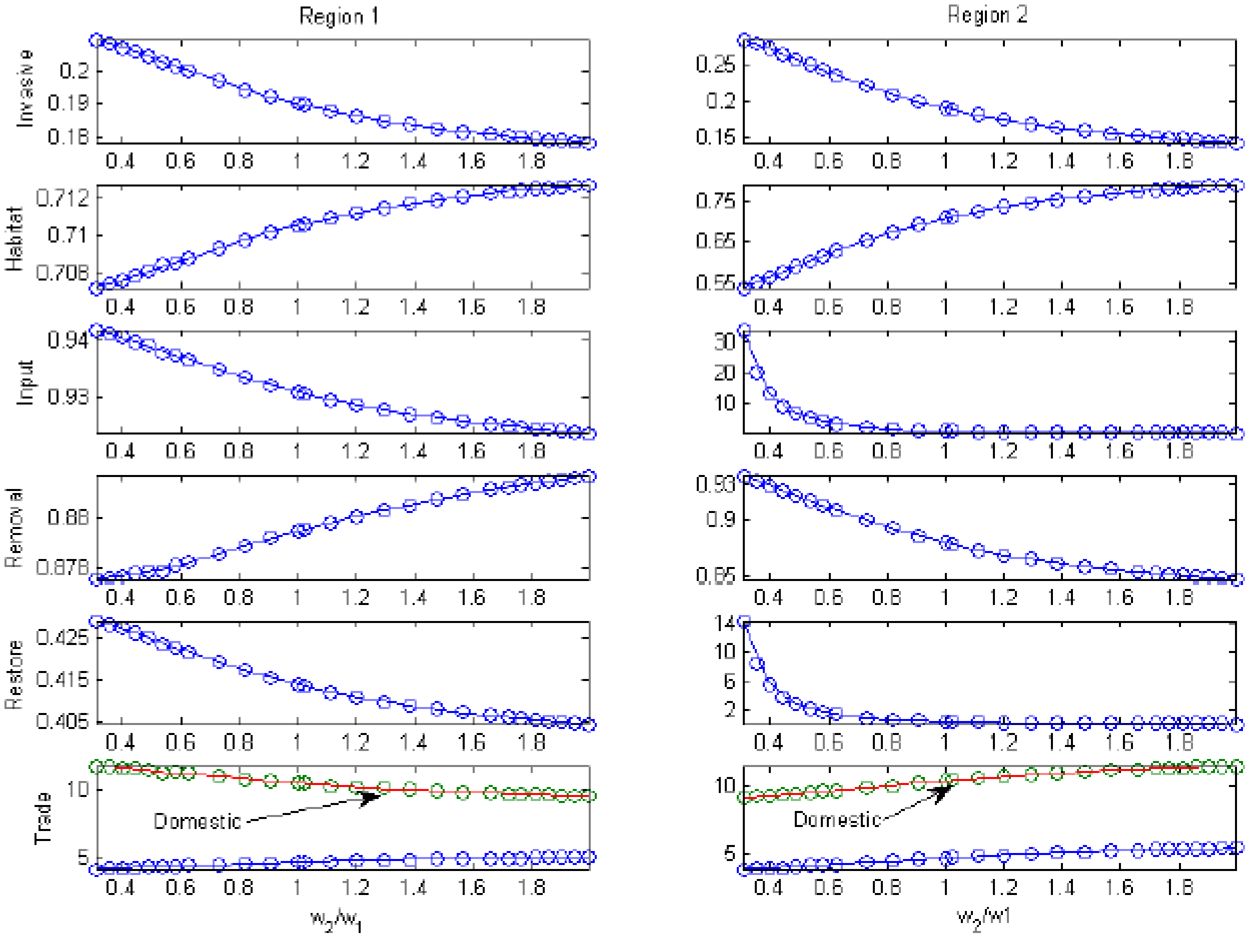
Habitat

Input use

Removal

Restore

Trade



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Sensitivity to spatial linkage

- Percentage change from the case with no linkages that is due to the connectivity in the model.
- A positive (negative) level implies that the case with the linkages is changing faster (slower) than the case without the linkages.

j is the parameter set over which the sensitivity analysis is run,

o is symmetric case

k is model run

K is model run w/ no linkages

Percent change due to spatial linkage

$$=100*\left(\frac{Y(j,k)/Y(o,k) - Y(j,K)/Y(o,K)}{Y(j,K)/Y(o,K)}\right)$$

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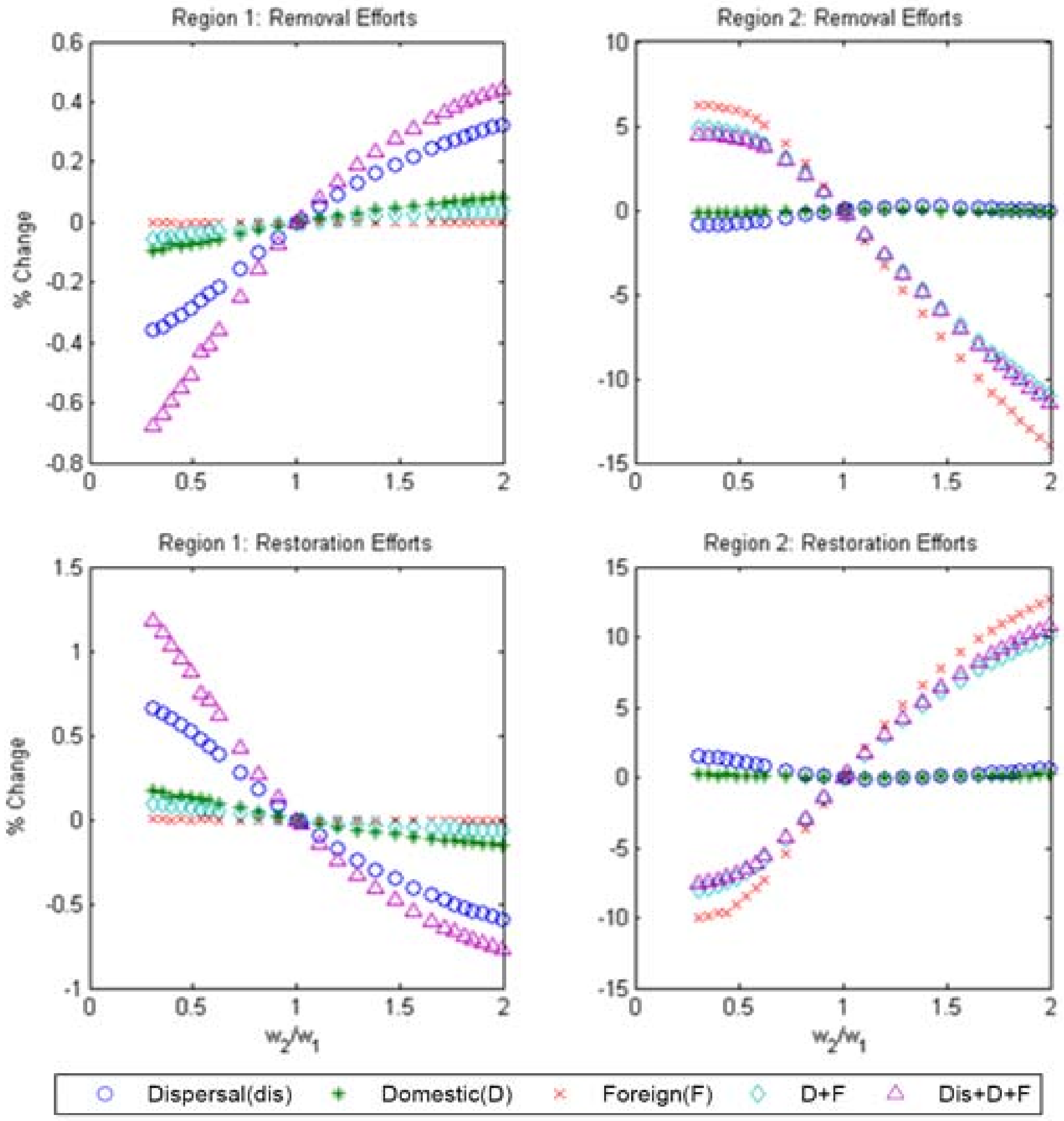
Sensitivity to relative input costs

Removal Effort

Restoration Effort



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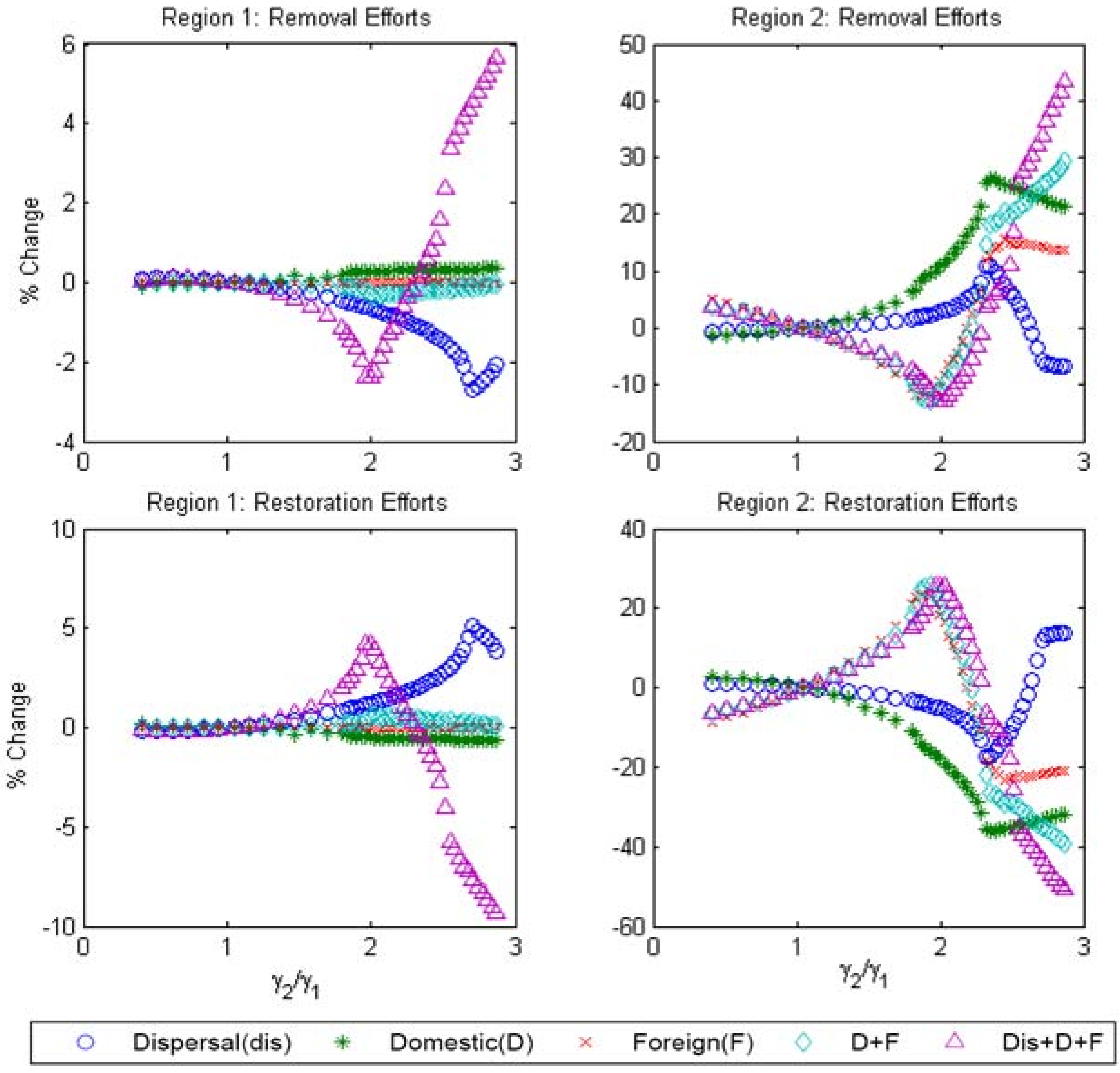
Sensitivity to relative removal costs

Removal Effort

Restoration Effort



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Spatial Discussion

- Foreign trade’s impact appears larger than other pathways
- Control strategies are not simply additive or average combinations of the results with a limited set of pathways because system-wide interactions are non-linear.
  - policy recommendations from modeling efforts that only consider one of the dimensions and/or control strategies may be far from efficient.
- Control strategies interact in a non-linear way with the degree of spatial heterogeneity.

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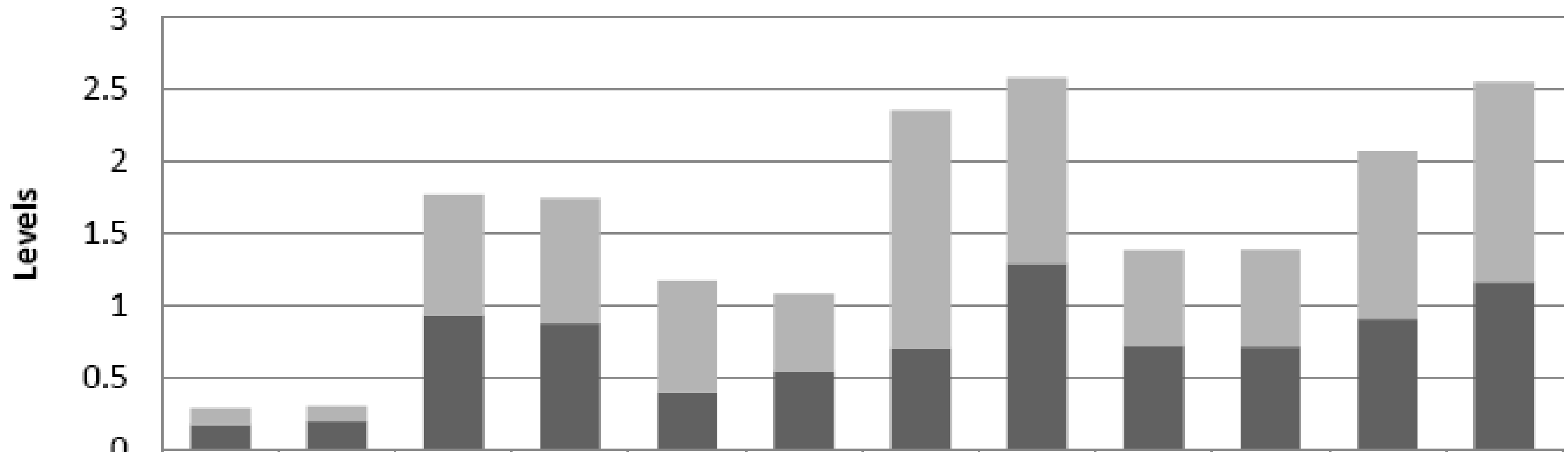
Spatial Policies vs. Uniform Ones



	Invasive		Removal		Restore		Domestic		Habitat		Non-Habitat	
	Space	Uni.	Space	Uni.	Space	Uni.	Space	Uni.	Space	Uni.	Space	Uni.
Inland	0.1113	0.103	0.8414	0.8742	0.7726	0.5402	1.6622	1.2926	0.669	0.6778	1.165	1.3922
Port	0.1728	0.1963	0.9323	0.8742	0.3983	0.5402	0.6994	1.2926	0.7168	0.7121	0.9098	1.165

Figure 9 Steady-state controls at the spatial and uniform optimal

Note: Domestic inspection levels are divided by ten for expositional reasons.

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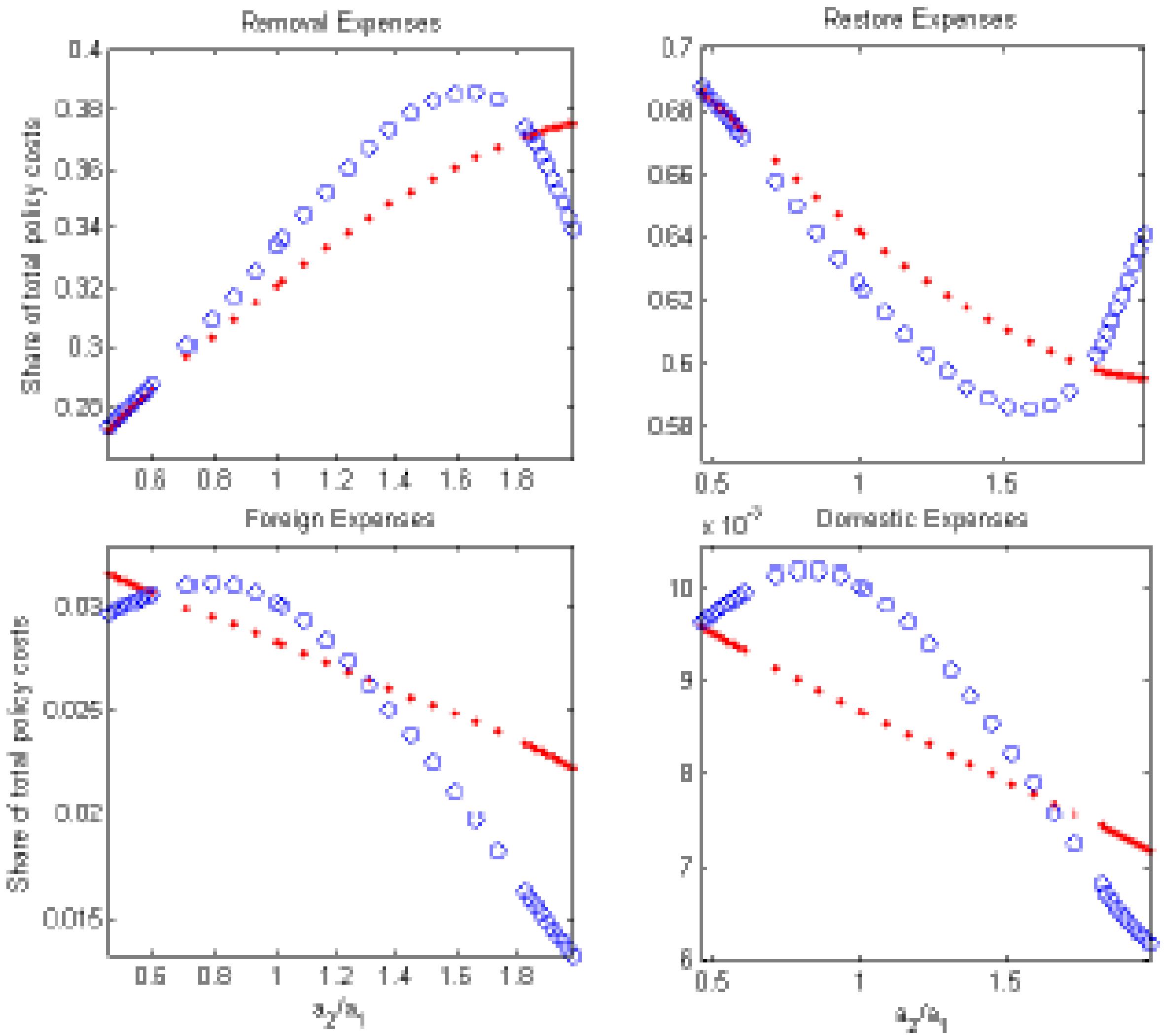
Policy Expenditure Shares: Sensitivity to relative IS growth rates



Spatial: ••• & Uniform: ooo

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Uniform Discussion

- Policy levels reflect some averaging of the spatially optimal strategies.
- Policy mixes—and their responses to additional asymmetries across space—can differ substantially.
- Net effect on welfare seems small
  - shift from the agricultural sector (lower profits) to government stakeholders (lower IS policy expenditures)

Application to Cheatgrass in the Great Basin

- Over 40 million hectares of rangelands suffer loss of perennial native vegetation, grazing and watershed values, habitat, and aesthetics
- Invaded where native plants did not evolve with significant grazing pressure
- Less nutritional content for cattle

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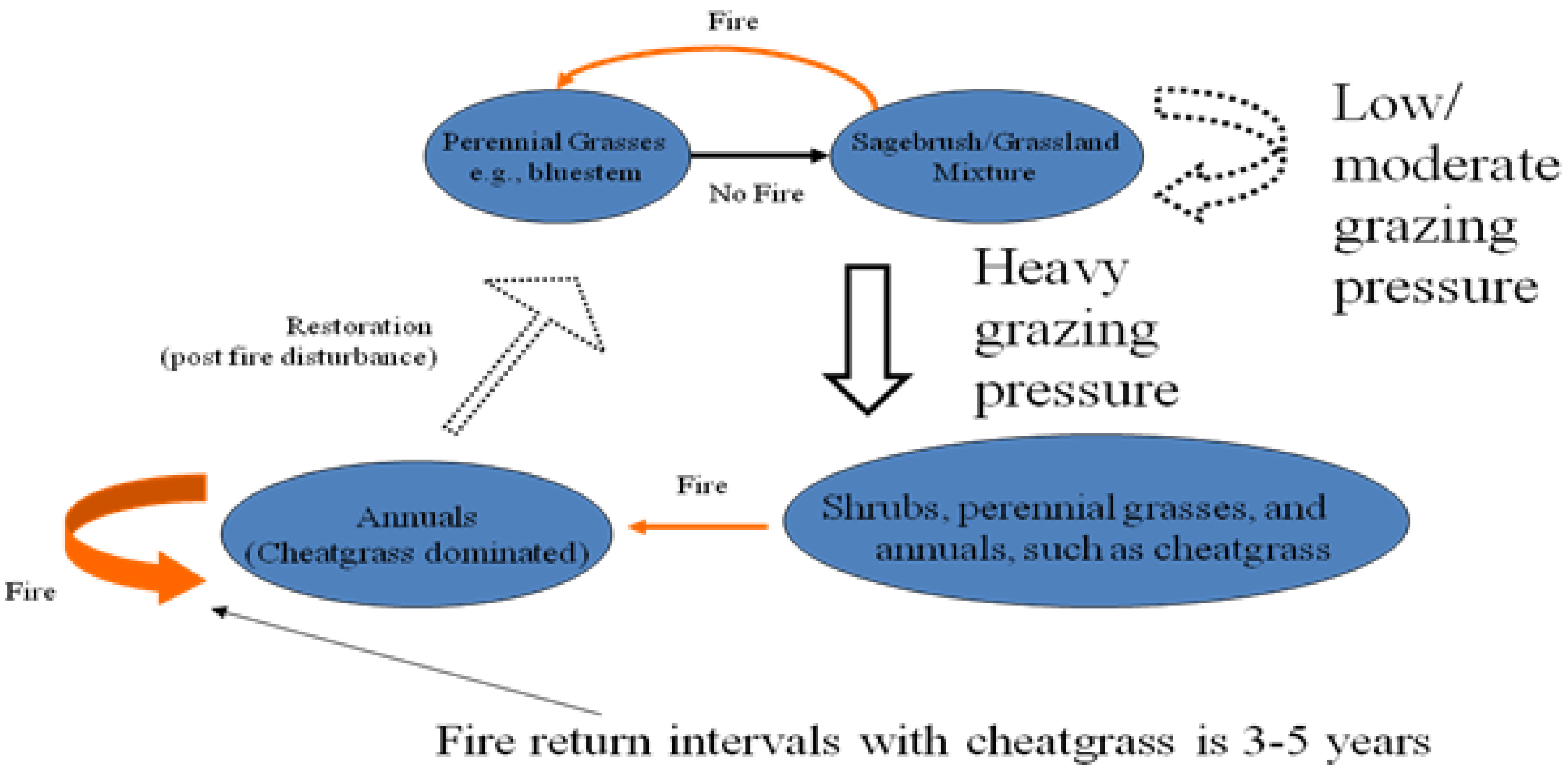
Cheatgrass and Fire

- Shortened and intensified wildfire cycle, as cheatgrass grows earlier and loses moisture content earlier.
- Cheatgrass has increased success rate against native species following wildfires, creating positive feedback loop and preventing recovery

Sagebrush-grassland ecosystem with cheatgrass



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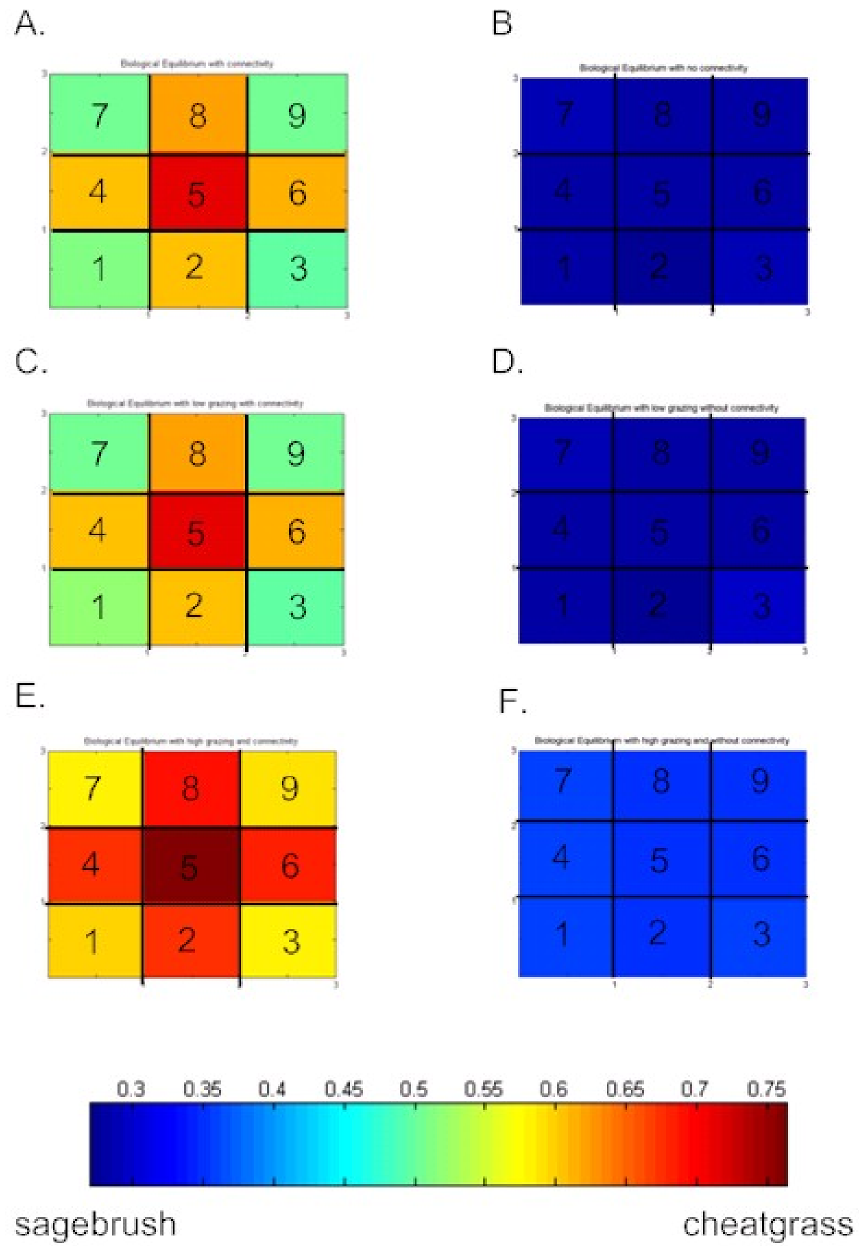
With Connectivity | No Connectivity

No Grazing

Low Grazing

High Grazing



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Cheatgrass Discussion

- Spatial component matters
  - frequency with which one might predict the system to switch to a cheatgrass-dominated landscape increases.
- Lower grazing rates in the interior patches relative to the outer edges to reduce the spatial externality.
- Greenstripping reduces spatial externalities, increasing the level of grazing within each patch

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Future work

- Consider decentralized commodity production decisions
- Consider (2) separate regional planners that might or might not cooperate

Thanks!

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