Understanding Effectiveness and Equity of Conservation Policies using Economic Theory

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Abstract

Many Integrated Assessment Model (IAM) evaluate impacts of sustainability policies with high spatial granularity. Typically, though, the underlying economic mechanisms leading to those policy outcomes have limited emphasis. Yet, it is important to understand those mechanisms to design effective and equitable policies. In this paper, we build on a two-input theoretical model (Ray and Hertel 2023) to understand the impacts of a conservation policy at a spatially explicit scale which explains the economic behavior that determines the effectiveness of a conservation policy as well as its equity implications. We also highlight the role of uncertainty in parameters that translate to uncertainty in policy impacts using the Morris method (Morris 1991). In this paper we focus on a sustainable groundwater conservation policy targeting over-exploitation of groundwater resources in Western US (Haqiqi et al. 2023). In a previously published paper, Ray et al. (2023) shows that conservation policies that restrict the use of resources can lead to adverse distributional impacts where farmworkers who rely on those resources for their livelihoods absorb a wage-cut and job loss. So, we map the critical parameters that explain these equity implications as identified in Ray and Hertel (2023) to a more realistic multi-input production tree underlying the Simplified International Model for agricultural Prices, Land-use and the Environment at the Grid (SIMPLE-G) level. Using this method of analysis, we decompose the impacts of a conservation policy into the supply response comprising of the extensive and intensive margin response net of the conservation policy shock.

Key words: conservation policy, agricultural labor, groundwater,

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Introduction

Policies for long term sustainable management of the Earth's natural resources, while meeting the changing demands from the food production systems, requires in-depth understanding of the role of bio-physical and socio-economic processes and the multi-scale interactions between them. Local level impacts of global drivers of food production, such as climate change, technological changes and expected increase in population and income (O'Neill et al. 2014), is filtered through national and sub-national environmental and economic policies, cross-border linkages in food markets, community level institutions and site specific agro-ecological characteristics of natural resources (Hertel et al. 2019). At the same time, local or sub-national policy interventions, for example the biofuels mandate in OECD countries, can have far reaching impacts in geographically distant regions which are connected through commodity markets (Hertel, Tyner, and Birur 2010; Britz and Hertel 2011).

Integrated Assessment Model (IAMs), play the critical role of modelling impacts of global drivers of food production and their interaction with prospective environmental policies, by integrating biophysical and economic models. Incorporating economic behavior of agricultural producers with the geographic and bio-physical heterogeneity of natural systems, at a granular level, allows IAMs to evaluate important policy feedback loops in environmental policies at a spatially explicit scale. Global IAMs such as the Integrated Model to Assess the Global Environment (IMAGE, ref: Stehfest et al. 2014), Model of Agricultural Production and its Impact on the Environment, (MAgPIE, ref: Lotze-Campen et al. 2008) and the Global Biosphere Management Model (GLOBIOM, ref: IIASA 2018), incorporates complex interactions between specialized crop, climate, hydrology and market models to evaluate important sustainability questions in the food-energy-water nexus. However, the complexity of these models can obscure the understanding of human decision-making that lies at the crux of the success of environmental policies. In a review of IAMs, Kling et al. (2017) highlights the need to balance tractability with realistic representation of the complex links between human and natural systems at a high spatial resolution. Understanding the impacts of global drivers and policy responses using the foundational principles of producer and consumer behavior is essential to inform policy design for effective and equitable management of natural resources.

While the Global-Local-Global (GLG) interactions are essential in IAM style policy evaluation, they are often facilitated through the intervening 'meso' scale. Johnson et al. (2023) lists several meso scale phenomena such as management of water sheds, impacts on local labor sheds and changes in spatial pattern of land use cover, that cannot be overlooked for a complete understanding of prospective policy analysis. Further, meso scale analysis is particularly relevant to elicit the distributional impacts of environmental policies and the role of local governance in sustainable natural resource management.

In this paper, we build on a previously developed stylized two-input theoretical framework that models the impacts of conservation policies (Ray and Hertel 2023 & in review), to develop a new methodology that can be used to delve into the economic determinants of broad-based conservation policy impacts at a high spatial resolution. This novel 'bridging' methodology, makes the policy evaluations with IAMs more tractable by tracing the policy impacts back to foundational economic principles of producer and consumer behavior. We leverage the suite of Simplified International Models for agricultural Prices, Land use and the Environment (SIMPLE, ref: Baldos et al. 2020), to investigate the impacts of a sustainable groundwater policy in Western US on 75,000+ grids engaged in agricultural production across the country

(Haqiqi, Bowling, et al. 2023). We show that the policy impacts can be well understood using foundational principles of producer behavior grounded in economic theory.

We focus on understanding the drivers that explain policy effectiveness (measured in terms of change in resource use), labor markets (measured in terms of change in employment) and distributional impacts (measured in terms of changes in wages and resource rents). Policy effectiveness is decomposed into the slippage effect (Pfaff and Robalino 2017; Wu 2000) and the policy shock. Any conservation policy that restricts the use of resources, leads to an increase in commodity prices which incentivizes producers to increase production by bringing in previously unexploited resources into production. This leads to slippage in resource use that can partially (or even fully) offset the effectiveness of the policy in the targeted regions. The higher food prices also sparks spillover effects in regions not directly targeted by the policy where producers expand production in response to higher commodity prices.

The literature on the labor market impacts of environmental and conservation policies show that it is important to carefully consider the impacts on local employment (Deschênes and Greenstone 2012; Li and Ando 2023; Yip 2018; Hafstead, Williams, and Chen 2022; Carbone et al. 2020). Restrictions on resource exploitation, implicit in conservation policies, can lead to job losses and depressed wages which can persist over time in the presence of restrictions in labor mobility (Autor, Dorn, and Hanson 2021; Deschênes and Greenstone 2012). However, these can be offset by producer's supply response on both the extensive (bringing in more resources) and intensive (re-optimizing input-mix for cost minimization) margins. In this paper we decompose the policy impact on employment into these components and identify the site-specific parameters that underly each component.

The stylized theoretical framework (Ray and Hertel 2023 & in review) shows that conservation policies can lead to divergence in the distributional impacts on farmworkers and resource owners. One direct impact of a conservation policy leads to higher resource rents which reflects the increased resource scarcity as a first-order impact of the policy. On the other hand, farm wages can be dampened if the policy shock dominates the producer supply response. Again, this reiterates the need to better understand each component of the policy impact on wages and resource rents to design policy that can limit adverse distributional policy impacts. More generally, this paper also highlights the role that uncertainty in parameters play in the uncertainty in prospective policy impacts.

The rest of this paper is divided into four sections. In the next section, we provide a brief overview of the role of conservation policies in meeting the demands of an expanding and wealthier population with a limited stock of natural resources. We also describe the theoretical framework developed in Ray and Hertel (2023) and the numerical model we use in our application i.e., SIMPLEG-CZ (Ray et al. 2023). In the third section we develop our method of analysis. In the fourth section, we present its application to a sustainable groundwater conservation policy in Western US and decompose the impacts of the policy into intensive, extensive and policy shock. The concluding section highlights the need for better estimation of economic parameters that is necessary for effective and equitable policy design.

II. Theoretical Framework and Numerical Simulation Model

Theoretical Framework

This paper builds on a stylized two-input theoretical framework developed by Ray and Hertel (2023). It is a partial equilibrium framework for the agricultural sector, where crop output is produced with natural resources (R) and augmented-human (H) inputs with a Constant Elasticity of Substitution (CES) production function. Interaction of input supply, modelled with an upward sloping curve, and demand, derived from usual cost-minimization producer behavior, determine the equilibrium input use and prices. This framework is applied to two economic scales. At the aggregate scale, the optimized input supply function equates with aggregate demand to define output prices. At the disaggregate level, producers are 'price-takers'. This framework offers useful flexibility for modelling multi-scale GLG linkages. Global drivers such as projections of population and incomes changes and policy shocks are implemented as shifts in the aggregate demand curve. Conservation policies designed to protect natural resources are implemented as a backward shift in the recourse supply curve. Ray and Hertel (2023) summarize the changes in equilibrium outcomes at the different economic scales. The disaggregate economic scale offers additional flexibility since it can be implemented to study changes at the granular 'grid-cell' level as well as the meso scale, intervening local and global. Box 1 below summarizes the theoretical framework.

Numerical Simulation Model

This paper uses the SIMPLEG-US-CZ model (Ray et al. 2023), that is a numerical application of the theoretical framework, with a multi-input nested CES production function. SIMPLEG-US-CZ belongs to the Simplifies Model for agricultural Prices, Land-use and the Environment (SIMPLE) suite of models (Baldos et al. 2020; Hertel and Baldos 2016), that draws inspiration from the recent literature on quantitative trade modeling of climate and resource issues (Costinot, Donaldson, and Smith 2016; Gouel and Laborde 2021).

SIMPLEG-US-CZ models natural resource markets, i.e., land and water, that clear at the spatially explicit grid-cell level. It also incorporates local labor sheds that clear at the Commuting Zones (Fowler and Jensen 2020). The concept of CZs, widely used in labor economics, refers to a group of counties that defines a local labor shed where workers regularly commute between them (Carpenter, Lotspeich-Yadao, and Tolbert 2022; Autor, Dorn, and Hanson 2016). The output markets clear at the SIMPLE-region level. Output supply for the US is modelled at the grid-cell level which meets the total demand for the US including inter-regional trade in the commodity markets. The rest of the world is aggregated to 16 additional regions.

Box 1: Analytical solutions for the two-input theoretical model: Impact of conservation policies at the aggregate (country) and local (grid-cell) levels

Country level

(1) % Change in output price: $p^{*}=\phi_{R}^{C}\Gamma_{\phi}^{C}$

(2) % Change in supply: $q^{C*}=-\eta^{C}\phi_{R}^{C}\Gamma_{\phi}^{C}$

where, $\Gamma_{\phi}^{C}=\dfrac{1}{\dfrac{v_{R}^{C}}{\theta_{R}^{C}}+\eta^{C}\left[\dfrac{\theta_{H}^{C}\left(v_{R}^{C}+\sigma^{C}\right)}{\theta_{R}^{C}\left(v_{H}^{C}+\sigma^{C}\right)}+1\right]+\sigma^{C}\left[\dfrac{\theta_{H}^{C}\left(v_{H}^{C}-v_{R}^{C}\right)}{\theta_{R}^{C}\left(v_{H}^{C}+\sigma^{C}\right)}\right]}>0, when\, v_{H}^{C}>v_{R}^{C}$

(3) % Change in input L use: $q_{H}^{C*}=\dfrac{v_{H}^{C}\left(\sigma^{C}-\eta^{C}\right)}{v_{H}^{C}+\sigma^{C}}p^{*}$

(4) % Change in input A use: $q_{R}^{C*}=\dfrac{v_{R}^{C}}{\theta_{R}^{C}}\left[1-\dfrac{\theta_{H}^{C}\left(\sigma^{C}-\eta^{C}\right)}{v_{H}^{C}+\sigma^{C}}\right]p^{*}-\phi_{R}^{C}$

(5) % Change in price of input L: $p_{H}^{C*}=\dfrac{\sigma^{C}-\eta^{C}}{v_{H}^{C}+\sigma^{C}}p^{*}$

(6) % Change in price of Input A: $p_{R}^{C*}=\dfrac{\phi_{R}^{C}\Gamma_{\phi}^{C}}{\theta_{R}^{C}}\left[\dfrac{v_{H}^{C}+\theta_{R}^{C}\sigma^{C}+\theta_{H}^{C}\eta^{C}}{v_{H}^{C}+\sigma^{C}}\right]$

Grid Level (g index suppressed)

(7) % Change in input L use: $q_{H}^{*}=v_{R}\dfrac{p^{*}}{\theta_{R}}\Gamma_{H}+\sigma\dfrac{p^{*}}{\theta_{R}}\Gamma_{H}-\phi_{R}\Gamma_{H}$

(8) % Change in input A use: $q_{R}^{*}=p^{*}\dfrac{v_{R}}{\theta_{R}}\Gamma_{R}-\phi_{R}\Gamma_{\phi}$

(9) % Change in price of input L: $p_{H}^{*}=\dfrac{p^{*}}{\theta_{H}}\left(1-\Gamma_{R}\right)-\dfrac{\theta_{R}\phi_{R}}{denom}$

(10) % Change in price of input A: $p_{R}^{*}=\dfrac{p^{*}}{\theta_{R}}\Gamma_{R}+\dfrac{\theta_{H}\phi_{R}}{denom}$

(11) % Change in production: $q^{*}=p^{*}\dfrac{v_{R}}{\theta_{R}}\Gamma_{R}+p^{*}\dfrac{\sigma\theta_{H}}{\theta_{R}}\Gamma_{\sigma}-\phi_{R}\Gamma_{R}$,

where, $\Gamma_{R}=\dfrac{\theta_{R}\left(v_{H}+\sigma\right)}{denom},\Gamma_{H}=\dfrac{\theta_{R}v_{H}}{denom},\ \Gamma_{\phi}=\dfrac{\theta_{R}\left(v_{H}+\sigma\right)+\theta_{H}\sigma}{denom},\Gamma_{\sigma}=\dfrac{\theta_{R}\left(v_{H}-v_{R}\right)}{denom}$,

$denom=\sum_{j,k}\theta_{j}\left(v_{k}+\sigma\right),\ j,k=H,R$

All price and quantity variables denoted with a lower case represent percentage changes in the underlying indexes.

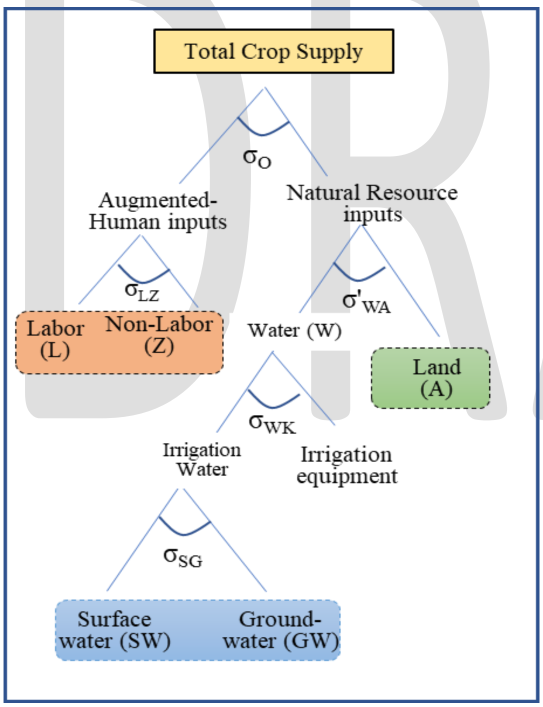
$\sigma\geq 0$: elasticity of substitution between two inputs

$v_{j}\geq 0,\theta_{j}\geq 0$: input supply elasticity and cost share of input *j*

$\phi_{H}=0,\phi_{R}>0$: backward supply shifter for input R, for example, due to a conservation policy

The SIMPLEG-US-CZ model is well suited to evaluate ex-ante, the interactions between global drivers of natural resource use and conservation policies, since it allows for multi-scale GLG interactions that can identify unintended policy consequences. The regional version of the model i.e., SIMPLE, has been validated against historical data over the period: 1961-2006 (Hertel and Baldos 2016). It has been applied to analyze the long run drivers of future food production, prices and land use change (Baldos and Hertel 2013; Hertel, Baldos, and van der Mensbrugghe 2016), adaptation to climate change (Lobell, Baldos, and Hertel 2013; Baldos, Fuglie, and Hertel 2020), and the role of R&D and productivity growth in ensuring food security and environmental sustainability (Fuglie et al. 2022; Hertel, Baldos, and Fuglie 2020). The gridded version of the model (SIMPLEG) is being used to water scarcity (Haqiqi, Bowling, et al. 2023), water quality (Liu et al. 2022) as well as the compounding impacts of pandemic and weather events (Haqiqi, Grogan, et al. 2023).

Figure 1: Nested, multi-input CES production tree in SIMPLE-G-US



III. Bridging Methodology:

The aim of the bridging methodology is to develop tools for a deeper understanding of the bio-physical and socio-economic processes that can explain the impacts of conservation policies at a granular scale. Though stylized, the theoretical framework from Ray and Hertel (2023) provides important insights about the impact of global shocks at the local level and the market mediated impacts of local level shocks i.e., spillover effects. However, the stylistic nature of the model restricts its direct application to the grid-cell level impacts, numerically simulated with the SIMPLEG-US-CZ and solved with non-linear optimization methods.

There are three key differences between the theoretical and numerical models used in this paper. This implies the bridging methodology, comprises of three components, that are designed to address each of these challenges in order to apply the insights from the theoretical framework to explain the results of the numerical simulation. In this section we describe each of them – components one and two comprise of Step 1 and the third component is Step 2.

IIIA. Data and parameters for Natural-Human CES Production Tree

The clear difference between the theoretical and numerical model is that SIMPLEG-US-CZ models multiple inputs (Figure 1), namely ground and surface water, cropland, labor and other inputs, in a nested CES production structure. The supply of each input (except the group of non-labor inputs) is modelled with an upward sloping curve and the substitutability between inputs within a composite input nest is modelled with a CES parameter. In comparison, the theoretical framework is developed with two composite inputs with a CES production function. Therefore, the first step of the bridging methodology is to aggregate the data and simulate composite parameters for composite inputs for the *two-input CES production function.*

This step consists of two components. One, aggregate the multi-input data to two composite inputs for each grid-cell. The total value of resources (VR) in the gridded production function is the sum of the value of land (VA), value of irrigation equipment (VWI), value of groundwater (VGW) and surface water (VSW). The total value of human inputs is the sum of the value of farmworker (VL) and value of other inputs (VZ) (Equation 12). The prices of the composite inputs are calculated as the cost-share weighted (θ) price of each of individual input (Equation 13). This allows us to calculate a quantity index for both the composite inputs (Equation 14). We can also calculate the cost shares of each of the composite inputs in total cost of production (Equation 15).

(12) $$\begin{aligned} V_R &= V_A + V_{WI} + V_{GW} + V_{SW} \\ V_H &= V_L + V_Z \end{aligned}$$

(13) $$\begin{aligned} &P_R = \theta_A P_A + \theta_{WI} P_{WI} + \theta_{GW} P_{GW} + \theta_{SW} P_{SW} \\ &P_H = \theta_L P_L + \theta_Z P_Z \\ &where\, \theta_k = \frac{V_k}{V_l}\, such\, that\, k \in l, l = R\, or\, H \end{aligned}$$

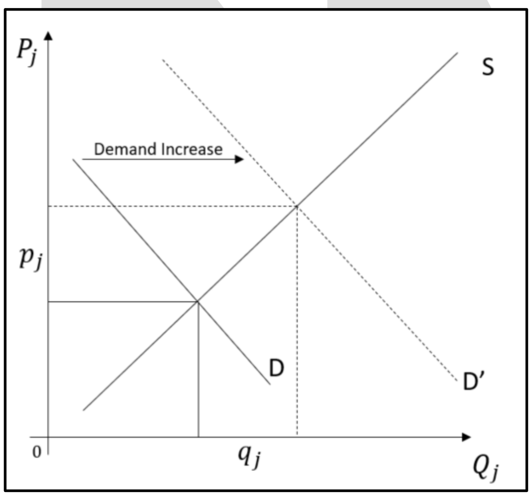
(14) $$Q_R = \frac{V_R}{P_R} \text{ and } Q_H = \frac{V_H}{P_H}$$

(15) $$\theta_R = \frac{V_R}{V_R + V_H} \text{ and } \theta_H = \frac{V_H}{V_R + V_H}$$

The second component in this step pertains to the simulation of parameters for composite inputs. Box 1 shows that the essential parameters in the two-input framework are the price elasticity of supply (v_j) and the CES substitution parameter (σ) for each grid in SIMPLEG-US-CZ. Intuitively, the price elasticity of supply for the composite inputs in the theoretical framework, is the change in supply of an input for a unit change in the price of the input i.e., the slope of the composite input supply curve (Figure 2). We simulate this gridded slope parameter for both composite inputs, H and R, by implementing a marginal shock on the demand for output in SIMPLEG-US-CZ and using Equation 6. This elicits producer behavior for each grid in the model when faced with the need to expand or contract production.

$$(16)\ v_j = \frac{q_j}{p_j} \text{ where j = H or R}$$

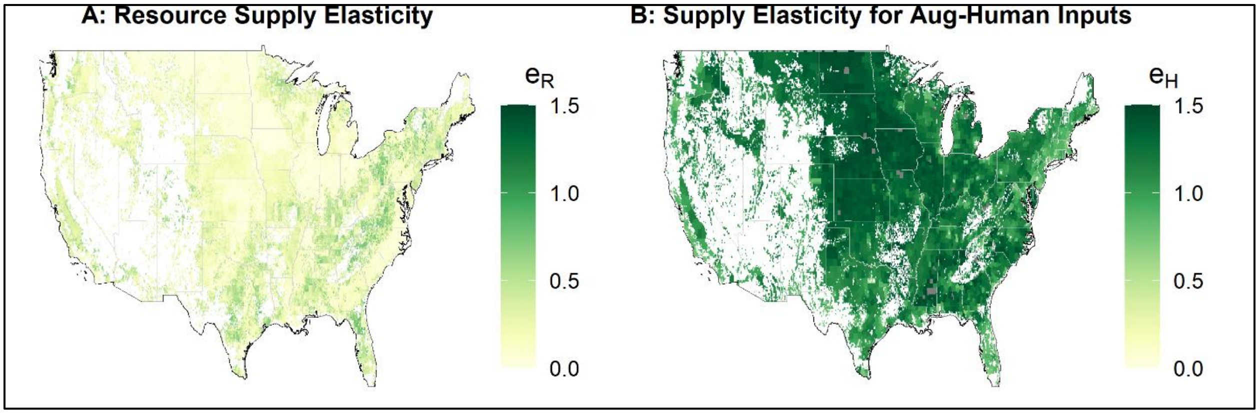
Figure 2: Simulation of Input Supply Elasticity for input j



The price elasticity of resource inputs captures the availability of land and water resources in each grid as well as the substitutability between inputs within a nest. The price elasticity of human resources is largely driven by the availability and mobility of labor within each grid-cell and the corresponding labor shed. Figure 3 shows the spatial distribution of the 2 composite input supply elasticities.

The two components of step 1 form the core of the bridging methodology. We can now transform the *multi-input two-sector CES production function* in SIMPLEG-US-CZ into a *two-input single-sector CES production function* which is used in the theoretical framework. While this transformation glosses over useful details in producer behavior, it also allows us to retain enough richness to delve deep into producer behavior in each grid-cell that undertakes agricultural production in the US when faced with an exogenous shock. To study the impacts of a conservation policy in particular, we need the additional step described below.

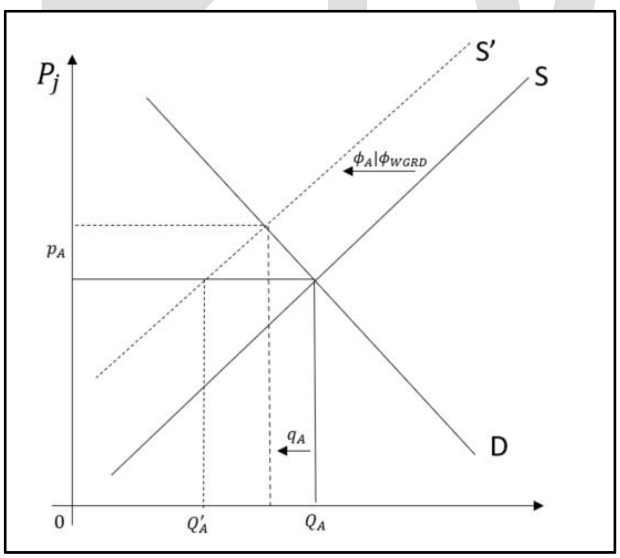
Figure 3: Simulated composite resource supply elasticity for 5-arcmin grid-cells in the US



III B. Simulate shock in 2 input-framework

A conservation policy, targeting protection of a natural resource, can be considered to be backward shift in the supply schedule of the specific input in both the theoretical framework and numerical model. For example, a policy that targets sustainable use of groundwater resources, would be implemented as a backward shift in the supply curve groundwater that is embedded within the Land+Water nest in SIMPLEG-US-CZ (Figure 1). While it can be expected that a restriction on the supply of one of the embedded inputs would lead to a backward shift in the supply of the composite input, in the theoretical framework, the magnitude of the shift in the latter is unclear without further analysis.

Figure 3: Graphical Illustration of Step II



When faced with a conservation policy that restricts the use of one of the resource inputs, it leads to an increase in the cost of that input, since the policy induces relative resource scarcity. Therefore, when faced with an increase in cost of irrigation producers use the margins of response discussed in Step 1 to minimize their cost of production. Further, if groundwater use is restricted in particular, producers can switch to the use to surface water depending on its availability. In the case that the policy targets land conservation, producers can respond by increase the intensity of irrigation to achieve higher yields to offset the lost production. Therefore, a shock to the supply of one of the inputs in the Land+Water nest can be traced to the top of the same nest after accounting for each margin of response. In the final step of the bridging methodology, we *elicit the magnitude of a policy shock to the composite input* due to a conservation policy shock to one of the embedded inputs.

We simulate this by implementing the conservation policy shock in the numerical model, while restricting any change in production and substituting Resource inputs with Augmented-Human inputs. This forces the model to simulate the change in Resource use, when faced with a conservation policy to one of the embedded inputs, while maintaining the total output supply from each grid without substituting with any other inputs. Note, that the change in Resource use simulated here, is not the magnitude of the policy shock, rather the expected change in resource use (i.e., LHS of Equation 8 in Box 1) under this hypothetical scenario. Finally, we use Equation 8 (in Box 1), to derive the magnitude of the shock to the composite input use if a conservation policy targets one of the embedded inputs. This elicits the *magnitude of the policy shock to the composite input,* which can be directly used in the theoretical framework $\left(\phi_R\right)$. Figure 4 compares the magnitude of the policy shock to groundwater (4A) and when implemented at the top of the resource nest (4B). Note that the magnitude of shock to the composite input is much smaller in the Ogallala aquifer due to the higher slippage effect in this watershed (Figure 5B). This is primarily driven by hydrological differences between the watersheds as well as institutional differences that govern water rights leading to the economic behavior by producers (Jame and Bowling 2020). In essence farm owners in Central US have greater flexibility in accessing groundwater from the Ogallala aquifer by increasing the depth of their wells or drilling new ones relative to the Central Valley and Snake River basin.

This has important implications for applying the theoretical framework to the numerical simulations results which focuses on the composite input level ie., Resources and Augmented-Human inputs. In the following section, we focus on Western US where the policy is effective in limiting composite resource use.

Figure 4: Groundwater policy shock (4A) and the implied shock at the composite resource nest (4B)

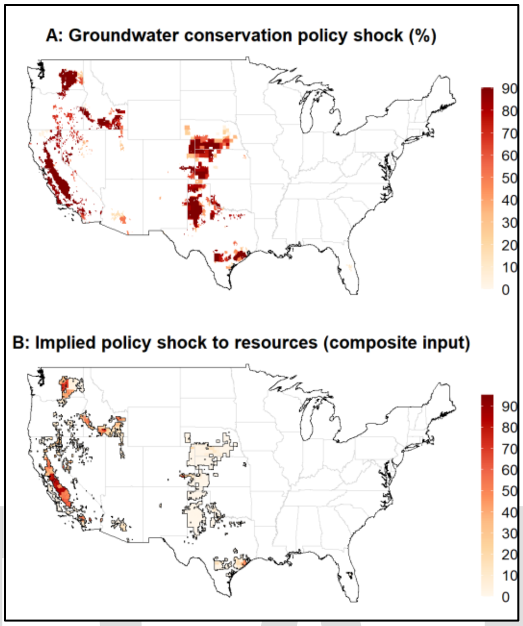
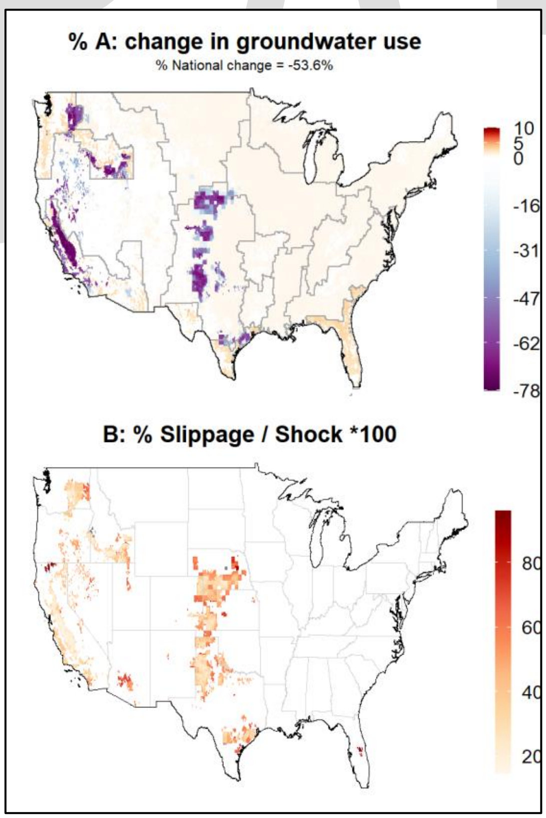


Figure 5: Grid-cell level impact of groundwater policy (5A) and the slippage effect relative to the policy shock (5B).



IV. Results

IV A. National level impacts

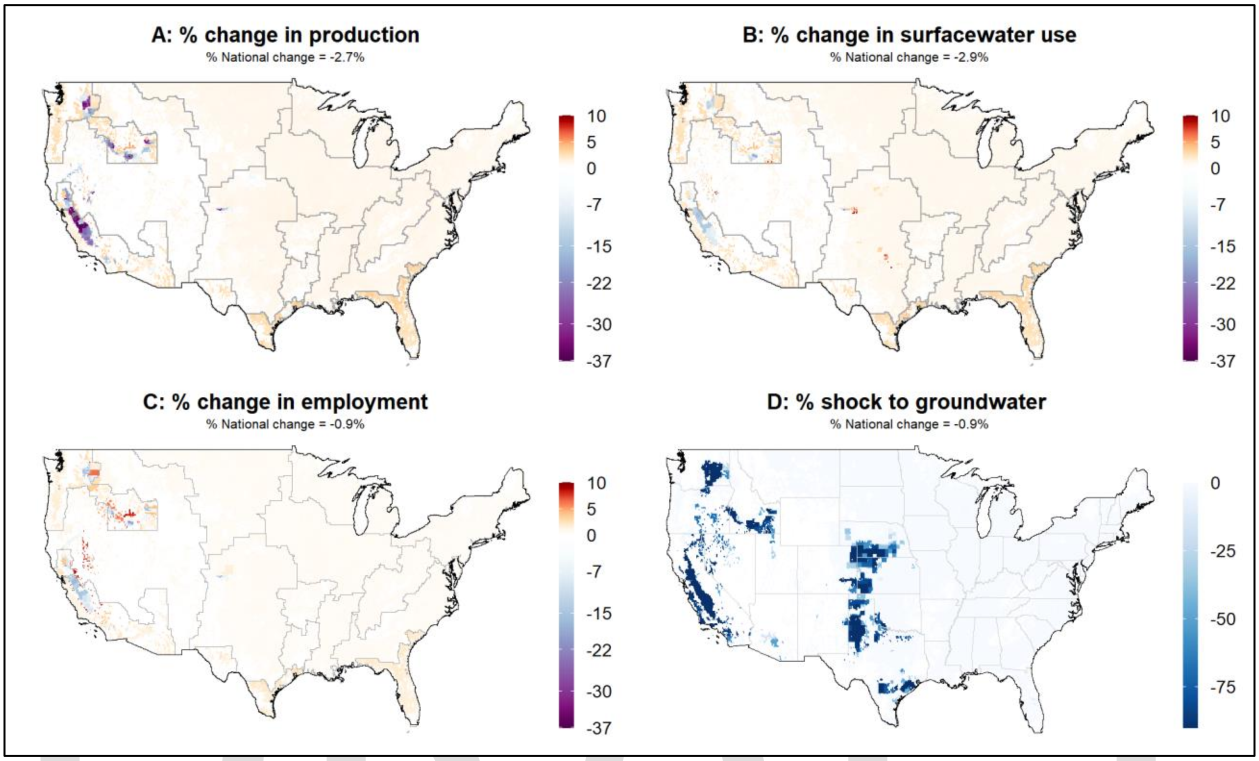
Table 1 summarizes the impacts of the groundwater conservation policy. At the national level, the groundwater conservation policy leads to a reduction in crop production by just about 3 percent and an accompanying increase in crop price of 2 percent. Natural resources comprise of cropland, ground and surface water as well as irrigation equipment. Augmented-Human input comprises of farmworkers as well as machinery that augment human labor productivity on the farm. The effectiveness of the conservation policy, in terms of the magnitude of irrigated land (along with the underlying groundwater) conserved, drives the changes in employment and production in the irrigated sector. The conservation policy leads to a reduction in aggregate Natural Resource use by 14 percent and a 54 percent reduction in groundwater use under both models. The change in groundwater use, under both models, is smaller than the magnitude of the shock at 66.7 percent. The difference is due to the slippage effect ranging between 12 – 13 percent.

Table 1: National impact of the US Sustainable Groundwater Conservation Policy (%) on Irrigated and Rainfed Agriculture

Outcomes	Irrigated	Rainfed	Overall
Crop Production	**-10.8**	**2.1**	**-2.7**
Natural Resources	**-24**	**0.3**	**-13.9**
Cropland under production	-0.6	0.4	0.2
Groundwater withdrawal			-53.6
Slippage effect			13.1
Augmented-Human input	**-5.9**	**2.3**	**-0.3**
Employment	-2.6	1.2	-0.9
Commodity Price	**--**	**--**	**2.1**
Natural Resource Rent	**32.2**	**5.8**	**19.6**
Land Rent	--	--	-0.4
Irrigation Cost			60.1
Augmented-Human Wages			**-0.8**
Wages			-3.8

The country level impacts of the conservation policy masks the stark spatial heterogeneity in the policy impact shown in Figure 6. We observe that the conservation policy can reduce production in Western US by upto 37 perfect and reduce employment by upto 19 percent. Note, that the spillover effects of the policy are is limited within the Fruitful Rim farm resource region, that comprises of the Western rim of the US includes parts of Texas and South-eastern regions. The spillover effects in the Ogallala aquifer is limited.

Figure 6: Grid-level impacts of the conservation policy (D) on production (A), surface water use (B) and employment (C).



Note: The lighter grey lines show the delineations of the USDA farm resource regions that are defined based on common cropping patter, crop-livestock production and farm typologies.

IV B. Applying theoretical framework to numerical simulation of conservation policy

In this section we apply the insights derived from the theoretical framework to delve deeper into understand the conservation policy impact at each grid-cell at the composite input level. We focus on three aspects of the policy impact: (i) effectiveness of the policy (change in resource use) (Figure 7), (ii) employment (change in employment) (Figure 8) and (iii) distributional impacts (changes in wages and rents) (Figures 9 and 10). Each figure decomposes policy impact using its corresponding analytical equation from Box 1. For instance, the Figure 7, decomposes the change in resource use using Equation 8 that shows the change in resource use includes the slippage effect (spillover in indirectly affected grid-cells) that increases resource use and the impact of the (effective) policy shock that conserves resource use.

To better understand the role of the parameters (focusing on the composite input supply elasticities) we also estimate the linear regression equation (16) for each component of Equations 7, 8, 9 and 10 in Box 1 decomposed here. For example, the regression results reported in Table 2, $Y = slippage/spillover$ effect (col 1) and $Y = abs(effective\ policy\ shock)$ (col 2).

$$(17) Y = \alpha + \beta * v_R + \gamma v_H + \delta(v_R * v_H) + \omega * Controls$$

Broadly the combination of Figures and regression Tables below help us to decipher the policy impacts at each grid-cell using economic theory. Further research is required to understand these results. Here we summarize some key observations:

1. Higher resource supply elasticity is associated with larger spillover and slippage effects as well as reduced impact of the shock on resource use (Figure 7 and Table 2)
2. Grid-cells with resource scarcity exacerbates the negative impact on job losses (Figure 8 and Table 3).
3. The conservation policy leads to divergence in wages and resource rents (Figures 9 and 10)
4. Scare factor captures a greater increase in returns. This implies farmworkers in grid-cells with high relative resource scarcity are susceptible to higher wage losses (Table 4).

Figure 7: Decompose change in resource use using Equation 8.

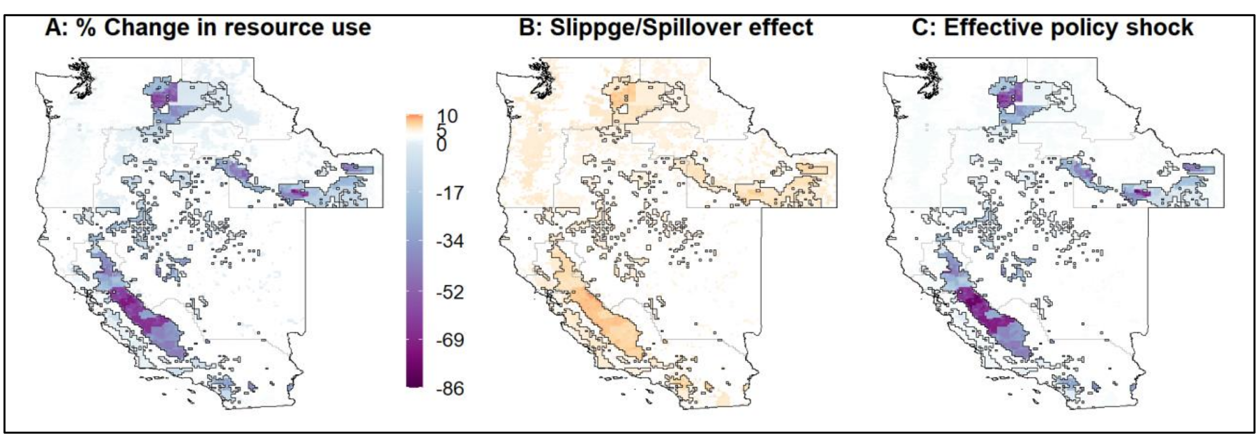


Table 2: Regression results (Eq 17) to show the role of (composite) input supply elasticity on each element of Eq. 8

	Slippage/Spillover effect	**Effective policy shock**
	(1)	**(2)**
v_R	2.635***	-27.885***
	(0.043)	(0.873)
v_H	0.023**	-3.41***
	(0.011)	(0.206)
$v_R * v_H$	0.311***	5.541***
	(0.024)	(0.317)
Adj-R2	0.83	0.99

Controls: Value of production, resource cost share, magnitude of policy shock in a grid cell

Figure 8: Decompose change in employment using equation 7

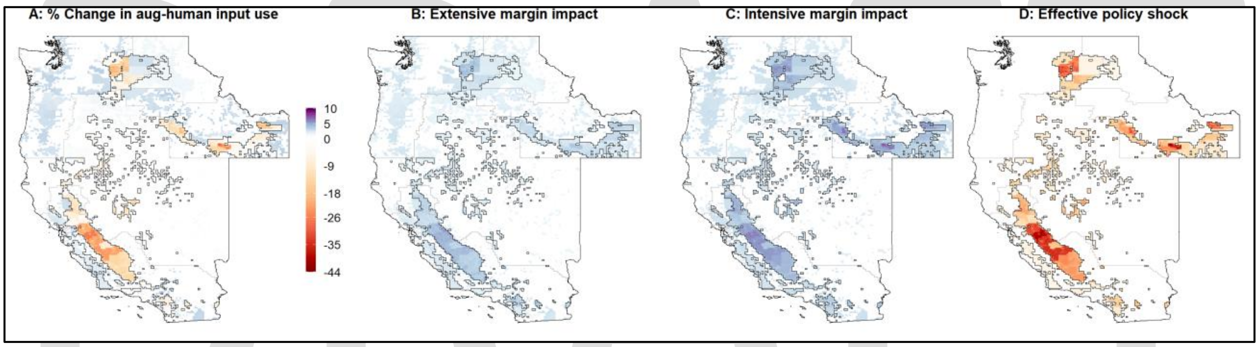


Table 3: Regression results (Eq 17) to show the role of (composite) input supply elasticity on each element of Eq. 7

	Extensive Margin	**Intensive Margin**	**Effective policy**
	(1)	**(2)**	**(3)**
v_R	1.334***	0.023	-14.538***
	(0.029)	(0.05)	(0.981)
v_H	0.032***	0.298***	1.009***
	(0.008)	(0.013)	(0.231)
$v_R * v_H$	0.233***	0.56***	12.74***
	(0.016)	(0.028)	(0.356)
Adj-R2	0.83	0.74	0.96

Controls: Value of production, resource cost share, magnitude of policy shock in a grid cell

Figure 9: Decomposition of change in price of (composite) human inputs using Eq 9

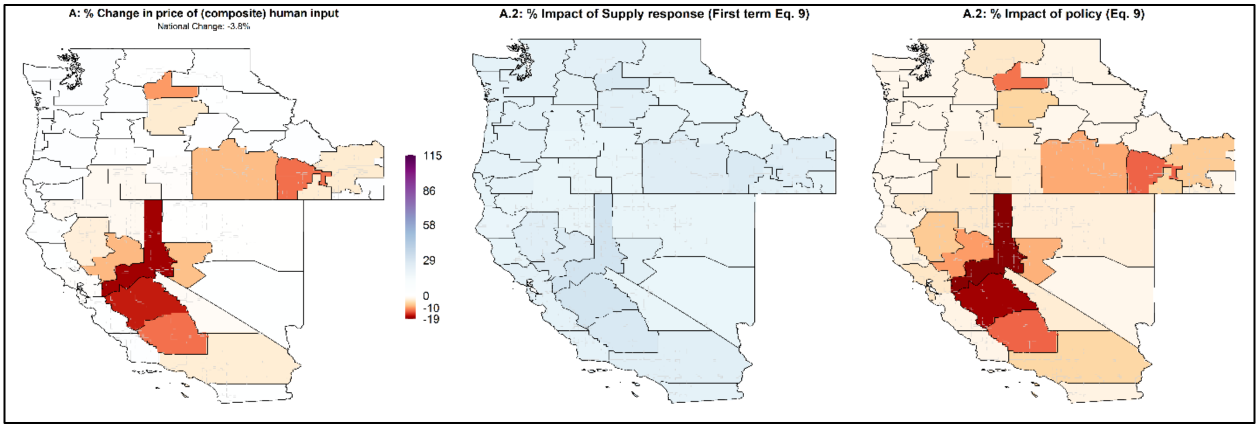


Table 4 Regression results (Eq 17) to show the role of (composite) input supply elasticity on each element of Eq. 9		
	Slippage/Spillover effect	**Effective policy shock**
	(1)	**(2)**
v_R	2.36*** (0.067)	-6.654*** (0.799)
v_H	-0.551*** (0.018)	0.034*** (0.188)
v_R/v_H	-1.768*** (0.056)	3.453*** (0.711)
Adj-R2	0.8	0.8
Controls: Value of production, resource cost share, magnitude of policy shock in a grid cell		

Figure 10: Decompose change in rents of (composite) resource inputs

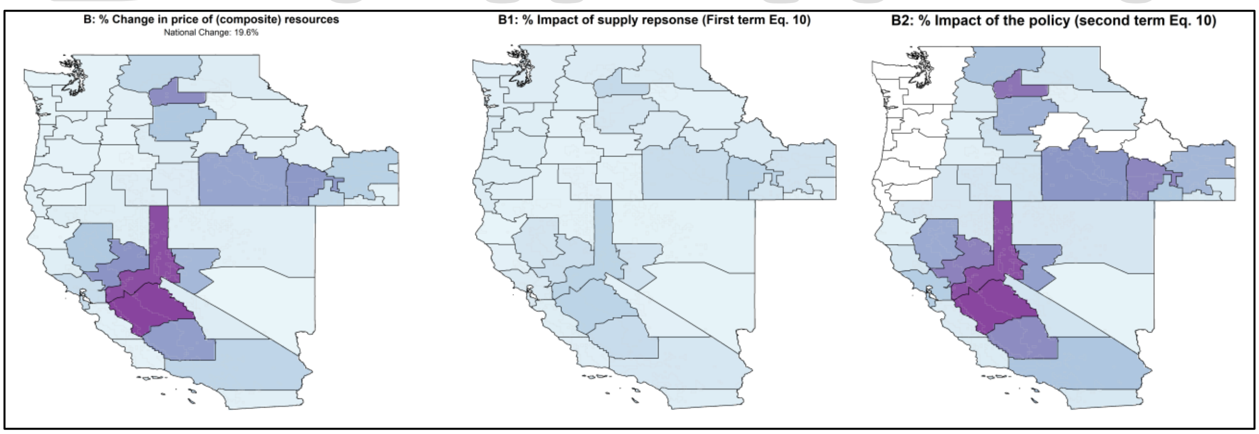


Table 5: Regression results (Eq 17) to show the role of (composite) input supply elasticity on each element of Eq. 10

	Slippage/Spillover effect	Effective policy shock
	(1)	**(2)**
v_R	-0.195	-20.046***
	(0.144)	(1.703)
v_H	0.061	-8.877***
	(0.037)	(0.401)
v_R/v_H	-1.969***	12.998***
	(0.12)	(1.513)
Adj-R2	0.74	0.96
Controls: Value of production, resource cost share, magnitude of policy shock in a grid cell		

Conclusion and Next steps

In this paper we build on the SIMPLE-G-CZ (Ray et al. 2023) model and a stylized theoretical framework for conservation policy analysis (Ray and Hertel 2023) to develop a method of analysis that can deepen our understanding of conservation policy simulations using IAM. It makes key contributions:

1. IAM style analysis aims to model complex links between human and natural systems. Such analysis is able to generate maps highlighting the spatial heterogeneity in policy impact. However, in-depth understand of what is driving the policy impact is often missing. However, it is critical to understand the underlying mechanisms policy impacts for research and policy design.
2. This method of analysis allows us to deepen our understanding of prospective policy evaluation using foundational principles of economic theory. We are able to extract any spatial region of interest, at a high resolution, and identify the drivers of the impacts. This is useful in designing effective and equitable policies.
3. This also sets us up to evaluate the uncertainty in parameters and shocks and its impact on uncertainty in policy impacts ex-ante. In the next steps of this analysis we will apply the Morris Method (Morris 1991) to identify the key drivers of uncertainty in conservation policy evaluation.
4. This will be further useful to inform future research agenda by identifying parameters that are critical in driving policy impacts (econometric estimations) and improving our modelling of human-natural system interactions (biophysical modelling).

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