Labor market rigidities mediate the effectiveness and distributional impacts of conservation policies

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Abstract

The drawbacks of ignoring labor markets when assessing the effectiveness and impacts of conservation policies are highlighted in a recent paper by Ray et al. (2023), who published the SIMPLE-G-CZ model that incorporates spatially explicit labor markets in the analysis of conservation policies. In this paper, we develop the underlying theoretical framework for the evaluation of conservation policies under contrasting assumptions about labor markets. We use a stylized two-input framework to identify key parameters that determine the success (in terms of resources conserved) and distributional effects of a conservation policy (amongst consumers, resource owners and farmworkers) depending on the representation of agricultural labor markets. Using this framework, we identify several important new propositions pertaining to the interplay between labor market functioning and the consequences of conservation policies at the national and local levels. Next, we propose a novel 'bridging' methodology, that maps the multi-input production function underlying the SIMPLE-G-CZ model to the 2-input analytical framework. This allows us to leverage our theoretical framework, to investigate the impacts of a conservation policy (sustainable groundwater use in the Western US) at a high spatial resolution of 75,000+ grid-cells. We further decompose the impacts of the policy on resource use, employment and production, into extensive and intensive margin producer responses, at the grid cell level. This rigor is currently missing in IAM (Integrated Assessment Model) style policy evaluation, where the model generated results are typically displayed in maps of potential impacts of the policy but lack clarity in terms of the underlying economic and bio-physical processes contributing to those results. The novel methodology developed in this paper, allows us to characterize the distributional impacts of a natural resource conservation policy and identify the specific parameters that drive these results. These are useful insights for conservation policy design which allow identification of hitherto unforeseen adverse impacts on members of rural communities.

JEL Codes: Q12, Q25, Q56, J43, C6

Key words: Integrated Assessment Models (IAMs), SIMPLE-G-CZ, labor-sheds, agricultural labor mobility, producer theory.

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1. Introduction and Motivation

The agriculture-environment interface is at the heart of many of the greatest conservation challenges facing the world today, including deforestation and biodiversity loss (Busch and Ferretti-Gallon 2017), nutrient pollution of waterways (Steffen et al. 2015), greenhouse gas emissions (IPCC 2022) and unsustainable groundwater drawdown (Wada and Bierkens 2014). Lessening this pressure on the environment invariably involves changing agricultural production and withdrawing critical natural resources from farming. For example, the recently concluded Kunming/Montreal protocol has proposed setting aside 30% of the earth to preserve biodiversity (CBD 2022). The recently elected Brazilian government's plan to target net-zero deforestation to conserve the Amazon rainforest (Rodrigues 2023) will restrict expansion of agricultural land in that country. Such policies can have important implications for food security, expose rural communities to economic disruption, creating tensions in the face of rising demand for agricultural products due to projected increases in population and income (O'Neill et al. 2014). The primary tools for investigating these tradeoffs at global scale are Integrated Assessment Models (IAMs) -- more specifically, IAMs that incorporate geographic and bio-physical heterogeneity at a granular level, which is critical for assessing conservation policies. These include the IMAGE model (Stehfest et al. 2014), GLOBIOM (Global Biosphere Management Model, ref: IIASA 2018), MAgPIE (Model of Agricultural Production and its Impact on the Environment, ref: Lotze-Campen et al. 2008) and SIMPLE-G (Simplified International Model of agricultural Prices, Land use and the Environment – Gridded version, ref: Baldos et al. 2020). Yet these frameworks have largely neglected the importance of labor as a mediating factor, instead assume workers adjust costlessly to any policy change.

The dangers of ignoring labor markets when assessing the effectiveness and impacts of conservation policies are highlighted in a recent paper by Ray et al. (2023). Those authors show that in the context of increasing rigidities in agricultural labor markets, the structure of labor markets plays a critical role in mediating the impact and success of conservation policies. The perfect labor mobility assumption, embedded in IAM style analysis, biases the spatial impact of conservation policies, in the presence of labor market rigidities. Further, it completely overlooks the negative wage impacts on farmworkers. This is demonstrated by comparing the grid level impacts of a groundwater conservation policy in Western US, under the two cases of perfect and restricted labor mobility using the SIMPLE-G-CZ model (Ray et al. 2023). The SIMPLE-G-CZ model, builds on the SIMPLE-G model and Commuting Zones (CZ) literature (Fowler, Rhubart, and Jensen 2016), to incorporate spatially explicit labor markets.

In this paper, we develop the underlying theoretical framework for the evaluation of conservation policies under contrasting assumptions about labor markets. The focus on labor market structure, in the context of conservation policies, is important given the evolution of agricultural labor markets (Charlton, Rutledge, and Taylor 2021). In migration-source countries, as agricultural transformation progresses, fewer workers enter the migrant stream which is the primary source of farmworkers in neighboring high-income countries such as the United States (US) and EU members. Evidence from the US suggests that the era of farm labor abundance is coming to an end, reflected in relatively rapid increases in farm wages and expanding guest worker programs to source farmworkers from a shrinking pool of rural Mexicans willing to work in agriculture (Hamilton et al. 2021; Zahniser et al. 2018). In developing countries, as markets mature, rural labor becomes less agricultural and farmers rely on within-country migration from labor surplus regions. As these economies evolve, labor shortages play an increasing role in farmers' decision making. Shortages of agricultural labor have been associated with fallowing of cropland in India (Meiyappan et al. 2017), adoption of labor-saving technologies in Sub-Saharan Africa (Tiffen 2003) and a rising capital-labor ratio in China's crop sector (Meiyan 2010).

While research on the interaction between agricultural labor markets and conservation policies is limited, evidence from related areas of research highlight the need to focus greater attention on the interplay between labor markets and local level implications of policy interventions. Impacts of trade policy changes – most notably China's entry into the WTO – have led to locally concentrated unemployment and depressed wages (Autor, Dorn, and Hanson 2016; Caliendo, Dvorkin, and Parro 2019) which have persisted for more than a decade due to geographic rigidities in local labor markets (Autor, Dorn, and Hanson 2021). Anecdotal evidence from New Zealand (Solomon 2022) and China (Liu et al. 2008) show that conservation policies, that remove over-exploited natural resources from production, can limit employment opportunities for farmworkers whose livelihoods rely on the exploitation of the same natural resources. More formally, Ray et al. (2023), show that California's Central Valley, if targeted by a groundwater conservation policy, could face up to 25 percent agricultural wage reductions under the restricted labor mobility scenario. Further, they highlight the stark differences in the spatial impact of the conservation policy under alternative labor mobility assumptions at a resolution of 75,000+ grid-cells undertaking agricultural production in the US.

In this paper we develop a novel 'bridging' methodology to analyze the impact of conservation policies at a high spatial resolution. This bridging exercise allows us to investigate the simulation results for 75,000+ grid-cells, as presented in Ray et al. (2023), using tractable postulates of economic theory. This level of rigor is currently missing in IAM style policy evaluation, where the model generated results show maps of potential impacts of the policy but lack clarity in terms of the underlying economic and bio-physical processes contributing to those results.

We begin by developing a stylized 2-input analytical framework to identify key parameters that determine the distributional effects of a conservation policy (amongst consumers, resource owners and farmworkers) depending on the representation of agricultural labor markets. We use this framework to consider the policy impacts, at the national level, as well as at a spatially disaggregated (local) scale – in this case a 'grid-cell' i.e., the geo-referenced parcel of land commonly used in IAMs. The theoretical model allows us to identify several important new propositions pertaining to the interplay between labor market functioning and the consequences of conservation policies at national and local levels. At an aggregate (national) scale, we find that the relative magnitude of food price elasticity of demand (on the consumption side) and elasticity of input substitution (on the production side) interacts with the supply elasticity of agricultural labor to determine the distributional effects of the policy. At the local (grid) level, we find that the magnitude of the conservation policy shock relative to the producers' response at the extensive and intensive margins, as well as local labor mobility play a crucial role in governing the distributional effects of the policy as well as the success of the conservation policy.

With this theoretical framework in hand, we revisit the impacts of the groundwater conservation policy analysis provided by the SIMPLE-G-CZ model (Ray et al. 2023). Specifically, we map the multi-input production function underlying the SIMPLE-G-CZ model to the 2-input analytical framework (our novel 'bridging' methodology). This allows us to use the insights derived from theory to decompose the simulation results for 75,000+ grid-cells into extensive and intensive margin producer response to the conservation policy shock that withdraws over-exploited resources from production. We highlight the importance of better understanding the structure of agricultural labor markets, by clearly contrasting the impacts of the policy at a high resolution under different assumptions about the labor markets. This novel bridging methodology allows us to distinguish between the 'winners' and 'losers' from a natural resource conservation policy and identifies the specific parameters that drive these results. These are useful insights for conservation policy design to limit unforeseen adverse impacts on members of rural communities.

The rest of this paper is divided into four sections. The next section introduces the theoretical model and develops key propositions. The third section describes the SIMPLE-G-CZ model with a focus on the introduction of spatially explicit labor markets that sets it apart from the SIMPLE-G (Baldos et al. 2020) model. We also describe the novel bridging methodology between the theoretical model and the numerical model results and a sustainable groundwater conservation policy that motivates our numerical analysis. This is followed by a discussion of model results using the insights developed in the theoretical model. The final section concludes by highlighting the importance of modelling agricultural labor markets in the context of assessing the effectiveness and distributional impacts of conservation polices as well as a discussing next steps in this line of research.

2. Theoretical Model

In this section we introduce a partial equilibrium model of agricultural production (ref: Box 1) to shed light on the interplay between the impact of conservation policies and labor markets. We design the theoretical framework to be amenable to any policy that restricts the use of land and water resources in the agricultural sector such as groundwater conservation, retiring agricultural land to protect bio-diversity or to provide other non-market eco-system services. We implement this framework at two spatial scales: country level aggregates and disaggregated 'grid-cells' where the 'grid-cell' level modeling takes output prices as exogenous. This allows for the development of important insights into the distributional consequences of conservation policies and how they depend on the functioning of agricultural labor markets.

BOX 1: A PARTIAL EQUILIBRIUM TWO-INPUT THEORETICAL MODEL FOR AGRICULTURAL PRODUCTION: IMPACT OF CONSERVATION POLICIES

Agricultural production (Q) is a constant elasticity of substitution (CES) function of two inputs, agricultural labor (Q_L) and irrigation-augmented land (Q_A) comprising non-labor inputs such as land and water resources as well as seeds, fertilizer and machinery, in a relevant spatial unit.

(1) % Change in conditional input demand: $q_j^D = q - \sigma\left(p_j - p\right)\ for\ j = L\ or\ A$

(2) % Change in supply of input *j* with supply shifters: $q_j^S = v_j p_j - \phi_j$

(3) Zero-profit condition in % change terms: $p = \sum_{j=L,A} \theta_j p_j, where \sum_{j=L,A} \theta_j = 1:$

(4) % Change in optimized agricultural supply: $q^S = \varepsilon p - \Gamma_A \phi_A$ (Appendix A1)

where, $\varepsilon = \left[\sum_{j=L,A} \theta_j \left(v_j + \sigma\right)^{-1} \right]^{-1} - \sigma,\ \Gamma_A = \theta_A\left(v_L + \sigma\right)\left[\sum_{j,k=L,A} \theta_j \left(v_k + \sigma\right) \right]^{-1}.$

Using (1) – (4) the equilibrium changes in input use and output for a given $p = p^*$ (Appendix B1) follow:

(5) % Change in input L use: $q_L = p^* \frac{v_A}{\theta_A}\Gamma_L + p^* \frac{\sigma}{\theta_A}\Gamma_L - \phi_A\Gamma_L$

(6) % Change in input A use: $q_A = p^* \frac{v_A}{\theta_A}\Gamma_A - \phi_A\Gamma_\phi$

(7) % Change in price of input L: $p_L = \frac{p^*}{\theta_L}(1-\Gamma_A) - \theta_A\phi_A\left[\sum_{j,k=L,A} \theta_j \left(v_k + \sigma\right) \right]^{-1}$

(8) % Change in price of input A: $p_A = \frac{p^*}{\theta_A}\Gamma_A + \theta_L\phi_A\left[\sum_{j,k=L,A} \theta_j \left(v_k + \sigma\right) \right]^{-1}$

(9) % Change in production: $q = p^* \frac{v_A}{\theta_A}\Gamma_A + p^* \frac{\sigma\theta_L}{\theta_A}\Gamma_\sigma - \phi_A\Gamma_A.$

where, $\Gamma_L = \frac{\theta_A v_L}{\sum_{j,k=L,A} \theta_j \left(v_k + \sigma\right)},\ \Gamma_\phi = \frac{\theta_A\left(v_L + \sigma\right) + \theta_L\sigma}{\sum_{j,k=L,A} \theta_j \left(v_k + \sigma\right)},\Gamma_\sigma = \frac{\theta_A\left(v_L - v_A\right)}{\sum_{j,k=L,A} \theta_j \left(v_k + \sigma\right)}$

For $v_A < v_L, 0 < \Gamma_\sigma < \Gamma_L < \Gamma_A < 1.$

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

p, p_j : % change in the price of output and input *j*

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

$v_j \geq 0, \theta_j \geq 0:$ elasticity of supply to agriculture and cost share of input *j*

$\phi_L = 0, \phi_A > 0$: backward supply shifter for input A, for example, due to a conservation policy

While there are different ways to conceptualize a conservation policy within our theoretical framework, we implement it as a backward shift in the supply of natural resources (irrigation-augmented land denoted by the A subscript) available to the agriculture sector, i.e. $\phi_A > 0$. This approach captures the voluntary nature of most conservation policies in the US. Importantly, this leaves the equilibrium employment of irrigation-augmented land as an endogenous variable, not directly under government control, but rather to be determined within the model. This formulation of the conservation policy unambiguously bids up food prices (discussed below) as well as the rental rate on irrigation-augmented land so that, for any given quantity of land employed, higher rents must be paid to retain the irrigated land in agriculture.

The theoretical framework introduced here investigates the long-term (zero profit) impacts of a conservation policy which implies that any increase in revenue, due to a positive (negative) change in output price p, must be offset by an equivalent change in unit cost (3). The change in unit cost, is determined by the interaction of supply and demand in the factor markets. In general, the benefits of a commodity price rise will be distributed to the two inputs in inverse proportion to their factor supply elasticities (2) i.e., the relatively inelastic factor will attract more of the output price rise, and it will bear relatively more of the burden of a decrease in output price.

Equation 4 shows that the impact of a conservation policy on supply is the combined effect of any output price change (p) depending on the price elasticity of crop supply (ε) and the policy shock (ϕ_A) as mediated through input market adjustments (Γ_A). Both ε and Γ_A are functions of the two input supply elasticities (v_A and v_L), the elasticity of input substitution (σ) and the cost shares (θ_A and θ_L). The first term in (4), εp, captures the sensitivity of the output supply curve to output price changes. We show in the following section, that a conservation policy leads to an increase in output price. Ceteris paribus, with the presence of a relatively elastic input supply results in a more elastic crop supply curve $(\partial\varepsilon/\partial v_i > 0)$, and therefore a larger increase in production due to the given output price increase. Thus, as the labor supply elasticity increases, so does the aggregate supply response, since adjustments to output price changes is easier for more elastically supplied inputs.

The second term in (4), $-\Gamma_A\phi_A$, captures the backward shift in the aggregate supply function in response to a natural resource supply shock. The magnitude of the shift in q^S is adjusted by a scaling factor Γ_A, which accounts for the adjustments in the two factor markets to the aggregate conservation policy. If the magnitude of Γ_A is smaller than 1, the backward shift in q^S is smaller than the magnitude of the conservation shock. As the labor supply elasticity increases, the magnitude of the scaling factor increases ($\partial\Gamma_A/\partial v_L > 0$, ref Appendix B2.5) and approaches 1 in the limit $(v_L \to \infty)$. A similar policy shock will lead to a larger shift in the aggregate supply curve in the case of a relatively elastic labor supply, because fewer labor market rigidities enable producers to adjust freely to the policy shock. Therefore, if we incorrectly assume the agricultural labor supply is perfectly elastic, we will over-estimate the resulting backward shift in agricultural supply.

2.1 National Market Model with Endogenous Output Price

In this section, we implement the theoretical model at an aggregate i.e., country level, and therefore index the parameters with a 'C'. We introduce the country level agricultural demand curve (10) which is a function of output price changes, the absolute value of the price elasticity of demand $\left(\eta^{C}\right)$ and exogenous demand shifters $\left(z\right)$ such as population and income growth (Appendix A2). The equilibrium changes in aggregate commodity production $\left(q^{*}\right)$ and price $\left(p^{*}\right)$ due to the groundwater conservation policy $\left(\phi_{A}^{C}>0\right)$ is determined by the intersection of (4) and (10) in (11) and (12) respectively. (Appendix A3).

A conservation policy unambiguously leads to an increase in national level output price $\left(p^{*}>0\right)$ and aggregate agricultural production $\left(q^{*}>0\right)$.[1] As expected, a more restrictive conservation policy leads to a larger increase in output price and consequently a greater fall in production. Other aggregate level impacts of the policy, i.e., changes in employment, resource use, wages and resource rents, are derived from (5) – (8), where the notation (with index 'C') pertain to the aggregate scale. In Section 2.2 we use these country level outcomes to discuss the distributional effects of a conservation policy at the aggregate level.

(10) $q^{D}=-\eta^{C}p+z$

(11) $p^{*}=\phi_{A}^{C}\Gamma_{\phi}^{C}$ where $\Gamma_{\phi}^{C}=\dfrac{1}{\dfrac{v_{A}^{C}}{\theta_{A}^{C}}+\eta^{C}\left[\dfrac{\theta_{L}^{C}\left(v_{A}^{C}+\sigma^{C}\right)}{\theta_{A}^{C}\left(v_{L}^{C}+\sigma^{C}\right)}+1\right]+\sigma^{C}\left[\dfrac{\theta_{L}^{C}\left(v_{L}^{C}-v_{A}^{C}\right)}{\theta_{A}^{C}\left(v_{L}^{C}+\sigma^{C}\right)}\right]}>0\; when\; v_{L}^{C}>v_{A}^{C}$

(12) $q^{*}=-\eta^{C}\phi_{A}^{C}\Gamma_{\phi}^{C}$

[1] Throughout this discussion, we will assume that the augmented-land supply elasticity is smaller than the labor supply elasticity $\left(v_{A}^{C}<v_{L}^{C}\right)$, given the fact that land and water resources, constituting the largest share of A, are generally not geographically mobile. The aggregate land supply elasticity for the US $\left(v_{A}^{C}\right)$ has been estimated to be between 0.01 and 0.06 (Barr et al. 2011) while the most recent estimates of extensive margin agricultural labor supply elasticity for the US suggests v_{L}^{C} ranges between 0.2 and 1.1 (Hill, Ornelas, and Taylor 2021). Appendix A3 shows $\begin{cases}\Gamma_{\phi}^{C}>0\Rightarrow p^{*}>0\,\&\,q^{*}<0\; if\; v_{L}^{C}-v_{A}^{C}>0\\ \Gamma_{\phi}^{C}>0\Rightarrow p^{*}>0\,\&\,q^{*}<0\; if\; v_{A}^{C}-v_{L}^{C}<\overline{v}\end{cases}$

The national level model introduced here is distinguished from the spatially disaggregated model presented in Section 2.3. One important factor that distinguishes the two is that at the country level we allow output price to be endogenously determined. The demand elasticity, η^C determines the absolute quantity of production required given a price change. Therefore, we find that the relative magnitudes of the aggregate consumers' response to a price change η^C relative to the aggregate producers' response to a price change σ^C (in terms of input mix) plays a critical role in Propositions 1, 2 and 3 which are summarized in Table 1. Later (Section 2.3) we assume output prices changes are exogenous to any given grid-cell, when we implement the model at a spatially resolved scale.

Table 1: Summary of the interactions between labor supply elasticity, input substitutability and demand elasticity underlying the implications of a natural resource conservation policy for prices, wages, employment and policy effectiveness

		$\sigma^C > \eta^C$	$\sigma^C < \eta^C$
(1)	(2)	(3)	(4)
A.	Food price $\left(p^*\right)$	Increase	Increase
	Smaller v_L^C	Magnifies	Dampens
B.	Agricultural Wages $\left(p_L^*\right)$	Increase	Decrease
	Smaller v_L^C	Magnifies	ambiguous
C.	Employment $\left(q_L^*\right)$	Increase	Decrease
	Smaller v_L^C	ambiguous	Dampens
D.	'Slippage' effect $\left(v_A^C\left[\frac{v_L^C+\theta_A^C\sigma^C+\theta_L^C\eta^C}{v_L^C+\sigma^C}\right]\frac{p^*}{\theta_A^C}\right)$	Non-negative	Non-Negative
	Smaller v_L^C	Dampens	Dampens

2.2 Distributional Consequences of the Groundwater Conservation Policy

The interplay between labor supply and other production parameters, such as aggregate input substitutability and consumption parameters, determines the effectiveness of a conservation policy and its impact on key stakeholder groups, i.e., consumers, resource owners and agricultural workers. At the crux of the intersection between these different economic parameters is the decision making of the producer in response to a conservation policy shock, which deserves further examination. The groundwater conservation policy generates a backward shift in the supply of irrigation-augmented land, and therefore leads to an increase in the rental price of A. Producers respond to higher rental prices, through two different channels.

The first channel of producer response is the *extensive* margin, which is determined by the supply elasticity of natural resources $\left(v_A^C\right)$. The higher rental rate of A, induces a slippage effect, whereby producers are incentivized to draw more natural resources into production, for example by bringing in irrigable marginal land into agricultural production. A higher v_A^C will generate a greater extensive margin response. The second channel of producer response to higher rental rates occurs at the *intensive* margin. In this two-input framework, this entails increasing management intensity by hiring more labor in order to make better use of the resources already under production. A higher v_L^C and larger σ^C will generate a greater response at the intensive margin.

2.2.1 Impact on consumers

We measure the welfare impact of a conservation policy on consumers in terms of change in agricultural output prices. In addition to the exogenous policy shock, the magnitude of the output price increase is determined by Γ_ϕ^C (in 11). If Γ_ϕ^C is relatively large, the magnitude of reduction in aggregate output will be larger and the increase in output price will also be larger. While Γ_ϕ^C is a function the consumption and production side parameters, the marginal impact of v_L^C on Γ_ϕ^C, depends on the relative magnitudes of aggregate input substitutability and price elasticity of demand parameters (Proposition 1).

Proposition 1: *The aggregate labor supply elasticity interacts with production and consumption side parameters to determine the magnitude of increase in output price paid by consumers following the conservation policy. A lower supply elasticity of labor leads to a higher output price increase when the substitution elasticity between aggregate inputs is higher than the price elasticity of demand* $\left(\sigma^C < \eta^C\right)$ *. A higher supply elasticity of labor leads to a higher output price increase when substitution elasticity between aggregate inputs is lower than the price elasticity of demand* $\left(\sigma^C > \eta^C\right)$.

(13) $\frac{\partial p^*}{\partial v_L^C}\begin{cases} < 0\, if\ \sigma^C > \eta^C \\ > 0\, if\ \sigma^C < \eta^C \end{cases}$ (Appendix A3.1)

This proposition highlights the qualitative importance of the relative magnitudes of σ^C and η^C in determining how labor market functioning affects the incidence of a conservation policy. While η^C refers to the slope of the aggregate demand curve, σ^C is one of the parameters underlying the slope of the aggregate supply curve (4). When $\sigma^C > \eta^C$, substitutability between aggregate inputs is more elastic relative to the price elasticity. In this case, producers find it easier to intensify production by hiring more labor, thereby bidding-up wages, to offset the negative effect of the conservation policy. A *reduction in the labor supply elasticity* limits the producers' ability to intensify production. This *leads to a larger increase in output price* and a larger reduction in total consumption compared to the case of greater labor mobility.

In the opposite case, where the substitutability between aggregate inputs is smaller than the demand elasticity $\left(\sigma^C < \eta^C\right)$, a *higher* labor supply elasticity *leads to stronger output price* increase. With fewer labor market rigidities, producers have access to cheap labor. However, with limited substitutability between aggregate inputs, producers' ability to offset the negative policy shock at the intensive margin is limited. Rather, producers respond on the extensive margin, further bidding-up the rental price of resources. This leads to a higher output price increase compared to the case where labor supply is relatively less elastic.

2.2.2 Agricultural Workers

As we have seen in equation (11), the immediate effect of a conservation policy is to reduce production and raise the price of agricultural output. The magnitudes of these changes depend on the price elasticity of demand. *Ceteris paribus*, a conservation policy leads to diminished labor demand in agriculture and lower wages. However, the possibility to substitute (producer's intensive margin response) the more expensive irrigation-augmented land with labor can offset some of the reduction in labor demand and wages. The strength of this effect is governed by the elasticity of substitution $\left(\sigma^C\right)$. On the consumption side, η^C determines the fall in consumption due to commodity price increase. Therefore, the relative size of these two parameters is once again critical. In this case it determines the impact of the conservation policy on wages (14) and employment (15)[2] and gives rise to Proposition 2.

Proposition 2: *If* $\sigma^C > \eta^C$ *, a conservation policy leads to an increase in wages and employment. If* $\sigma^C < \eta^C$*, the resource conservation policy leads to a reduction in wages and employment.*

(14) $p_L^* = \dfrac{\sigma^C - \eta^C}{v_L^C + \sigma^C} p^*$

(15) $q_L^* = \dfrac{v_L^C\left(\sigma^C - \eta^C\right)}{v_L^C + \sigma^C} p^*$ (Appendix A4)

If the elasticity of substitution is greater than the price elasticity of demand $\left(\sigma^C > \eta^C\right)$, intensification of production by hiring more labor leads to higher wages (14) and employment

[2] Note that we have substituted in equation (9) which determines the output price change as a function of the conservation policy (Appendix A4). This price effect, in turn, depends on all of the model parameters as well

(15). The extent of increase in wages and employment depends on labor supply elasticity. When labor supply is relatively less elastic, there is a greater increase in wages (16) and employment (17).

$$(16)\ \frac{\partial p_L^*}{\partial v_L^C}=\frac{\sigma^C-\eta^C}{v_L^C+\sigma^C}\left[\frac{\partial p^*}{\partial v_L^C}-\frac{p^*}{v_L^C+\sigma^C}\right]\begin{cases}<0\, if\ \sigma^C>\eta^C\\ ambiguous\, if\ \sigma^C<\eta^C\end{cases}$$

$$(17)\ \frac{\partial q_L^*}{\partial v_L^C}=\frac{\sigma^C-\eta^C}{v_L^C+\sigma^C}\left[\frac{\sigma^C p^*}{v_L^C+\sigma^C}+v_L^C\frac{\partial p^*}{\partial v_L^C}\right]\begin{cases}>0\, if\ \sigma^C>\eta^C\\ <0\, if\ \sigma^C<\eta^C\end{cases}$$

In the opposite case, when elasticity of substitution is smaller than price elasticity of demand $\left(\sigma^C<\eta^C\right)$, the extensive margin response by producers is more pronounced, since producers' ability to substitute irrigated-augmented land with labor is limited. Therefore, there is a fall in wages (14) and employment (15). In this case, a less elastic labor supply leads to a smaller reduction in employment (17)[3], while the impact on wages is ambiguous and depends on the sign of $\left[\frac{\partial p^*}{\partial v_L^C}-\frac{p^*}{v_L^C+\sigma^C}\right]$ (Appendix A4).

2.2.3 Resource conservation and resource owners

Economic intuition dictates that returns to the irrigated land resource $\left(p_A^*\right)$ must rise in response to a conservation policy which shifts its supply curve backwards. This is indeed the case in (18) (Appendix A4). The impact of the conservation policy on irrigated land $\left(q_A^*\right)$ is more complex (19). It depends first on how aggressive the policy is, i.e., $-\phi_A^C$. It also depends on the extensive margin, as there is potential for a 'slippage effect' whereby additional natural resources are brought into production in response to the higher rents. This is captured in, $v_A^C\left[1-\frac{\theta_L^C\left(\sigma^C-\eta^C\right)}{v_L^C+\sigma^C}\right]$, the first term on the right-hand side of (19).

$$(18)\ p_A^*=\frac{p^*}{\theta_A^C}\left[1-\frac{\theta_L^C\left(\sigma^C-\eta^C\right)}{v_L^C+\sigma^C}\right]=\frac{p^*}{\theta_A^C}\left[\frac{v_L^C+\theta_A^C\sigma^C+\theta_L^C\eta^C}{v_L^C+\sigma^C}\right]>0$$

[3] Note: $\frac{\partial q_L^*}{\partial v_L^C}<0\Rightarrow$ when there is a fall in v_L^C, q_L^* increases. Since $q_L^*<0$, increase in q_L^* implies a smaller reduction in employment.

(19) $q_A^* = v_A^C \left[1 - \frac{\theta_L^C \left(\sigma^C - \eta^C \right)}{v_L^C + \sigma^C} \right] \frac{p^*}{\theta_A^C} - \phi_A^C = v_A^C \left[\frac{v_L^C + \theta_A^C \sigma^C + \theta_L^C \eta^C}{v_L^C + \sigma^C} \right] \frac{p^*}{\theta_A^C} - \phi_A^C$

Given its importance to the ultimate success of the conservation policy, it is worth exploring this slippage effect in greater depth. Note that in the case where labor supply is perfectly elastic, the 'slippage' effect: $v_A^C \left[1 - \frac{\theta_L^C \left(\sigma^C - \eta^C \right)}{v_L^C + \sigma^C} \right] \frac{p^*}{\theta_A^C}$ collapses to: $v_A^C \frac{p^*}{\theta_A^C}$, which is just the supply elasticity for irrigation-augmented land, multiplied by the rise in land rents due to the conservation-induced output price increase. But when labor supply is less than perfectly elastic, the slippage effect is modified by a non-negative term i.e., $\left[1 - \frac{\theta_L^C \left(\sigma^C - \eta^C \right)}{v_L^C + \sigma^C} \right]$. The magnitude of this term, relative to unity, once again hinges critically on the relative size of the input substitution elasticity and the price elasticity of demand. If the elasticity of substitution is relatively large $\left(\sigma^C > \eta^C \right)$, then $\left[1 - \frac{\theta_L^C \left(\sigma^C - \eta^C \right)}{v_L^C + \sigma^C} \right] < 1$, and slippage is moderated due to the propensity to substitute labor for the scarce irrigation-augmented land input. However, if there is little potential for such substitution $\left(\sigma^C < \eta^C \right)$, then $\left[1 - \frac{\theta_L^C \left(\sigma^C - \eta^C \right)}{v_L^C + \sigma^C} \right] > 1$, and the slippage effect is magnified in response to output price change. The labor supply elasticity also plays a role in determining the absolute size of the output price increase, so the overall impact on resource use is ambiguous (Proposition 3).

Proposition 3: *The net effect of the conservation policy on resource use depends on the relative magnitude of the conservation policy shock itself i.e.,* $-\phi_A^C$, *and 'slippage' effect i.e.,* $v_A^C \left[1 - \frac{\theta_L^C \left(\sigma^C - \eta^C \right)}{v_L^C + \sigma^C} \right] \frac{p^*}{\theta_A^C}$. *The slippage effect is equal to the extensive margin response to the crop price change i.e.* $v_A^C \frac{p^*}{\theta_A^C}$, *under the assumption of perfect labor supply elasticity. If labor supply is less than perfectly elastic, the slippage effect depends critically on the relative magnitudes of input substitution elasticity and price elasticity of demand as well as the labor supply elasticity.*

If the policy shock is dominant in (20), there will be a fall in natural resource use. However, if the 'slippage' effect is dominant, resource use will increase. Theoretically, a dominant 'slippage' effect may be observed in the case of a large output price increase (under conditions discussed in

Proposition 1) and a combination of parameters leading to a larger slippage effect (20). In practice, a dominant 'slippage' effect implies that there are sufficient untapped resources available locally which can be diverted to production in the affected area to offset the conservation policy shock, leading to a boost in aggregate resource use in response to the higher commodity prices.[4] Given the increase in commodity prices, the 'slippage' effects is always non-negative but it is dampened under restricted labor markets. Overlooking labor market restrictions lead to over-estimation of the 'slippage' effects

$$(20)\ q_A^* < 0\, if\ v_A^C \left[1 - \frac{\theta_L^C \left(\sigma^C - \eta^C \right)}{v_L^C + \sigma^C} \right] \frac{p^*}{\theta_A^C} < \phi_A^C$$

The impact on the resource owner's revenue stream will hinge importantly on how the policy is implemented. If resource owners are fully compensated for the resources removed from production, then they will unambiguously gain from this policy, since resource rents are bid up by the policy. However, the more interesting case is where the removal of resources is determined by regulation and resource owners are not compensated. In this case, it is relevant to focus on the change in market returns $\left(r_A^* = p_A^* + q_A^* \right)$ to resource owners.

$$(21)\ r_A^* \begin{cases} < 0\, if\ q_A^* < 0\, and\ p_A^* < \left| q_A^* \right| \\ > 0\, otherwise \end{cases}$$

The direction of change in r_A^* depends on the q_A^*, since we have shown in (18) that a conservation policy always bids up resource rents $\left(p_A^* > 0 \right)$. When the change in resource use is positive (where the slippage effect is dominant in 20), the change in returns to resource owners is necessarily positive (21). The necessary condition for a negative change in market returns to resource owners is a reduction in resource use. The sufficient condition for a fall in r_A^* requires that the absolute value of the reduction in resource use $\left(\left| q_A^* \right| \right)$ is greater than the rent increase $\left(p_A^* \right)$. This holds when the 'slippage' augmented extensive supply response of A is smaller than the conservation policy shock (22). Since the 'slippage' effect depends on the interaction between labor supply elasticity, input substitution elasticity and price elasticity of demand, the same factors influence the impact on resource owners in the context of a conservation policy shock. The distributional impact of the conservation policy depends on the interaction between the labor supply elasticity and the difference between input substitution elasticity and demand elasticity. This also implies that accurate parameterization of models assessing the impact of a conservation policy is critical to obtain valid assessments of the distributional consequences of such a policy.

[4] We discuss spatial heterogeneity in the impact of a conservation policy in a subsequent section.

$$(22)\ \ r_A^* < 0\, if\ \left(1+v_A^C\right)\frac{p^*}{\theta_A^C}\left[1-\frac{\theta_L^C\left(\sigma^C-\eta^C\right)}{v_L^C+\sigma^C}\right] < \phi_A^C$$

Two important insights from this discussion highlight the need for better understanding of the agricultural labor markets and how it mediates the impact of a conservation policy. First, the zero-profit equation (3) shows that any change in output price is distributed as returns to the two inputs in inverse proportion of the input supply elasticity for the relevant input. As a result of a conservation policy consumers always pay a higher price for food products. If substitutability between inputs is more elastic than the price-responsiveness of food demand, labor market rigidities accentuate this burden on consumers, magnifying the increase in wages but dampening the increase in employment opportunities. However, if substitutability between inputs is less elastic than the price-responsiveness of food demand, the burden on consumers in terms of higher food prices is dampened but there is a decrease in wages and employment opportunities for farmworkers. If we ignore labor market rigidities, we overlook the complexities in the distributional effects of a conservation policy mediated through the interactions between production (input substitutability) and consumption (price elasticity of demand) side parameters.

A second insight bears on the likely success of a voluntary resource conservation policy in achieving its goals. This outcome depends on the ability of producers to intensify management of the resources under production by hiring more labor and reducing the ‘slippage’ effect. When substitutability between inputs is easier the ‘slippage’ effect is smaller, leading to a more substantial conservation impact. Therefore, the success of the conservation policy depends on the interaction between the labor supply elasticity as well as input substitutability and price elasticity of demand. Under the perfect labor mobility assumption, we are likely to get an inaccurate assessment of the success of the conservation policy.

Thus far we have focused on a national level conservation policy and its aggregate level impacts. While this provides important insights, it also has practical limitations. First, effective conservation policies are likely to be targeted at specific localities with deteriorating natural resources. Therefore, site-specific factors will determine the local impacts of the policy shock. Second, the economic behavior of producers and agricultural workers in response to the policy shock is also likely to vary across different regions in a country. For example, the magnitude of the ‘slippage’ effect is expected to be larger in regions with relatively elastic land supply. A single labor or resource supply elasticity is unable to capture this heterogeneity across counties or regions. Third, a further complication is the fact that the entire agricultural sector in the United States is interconnected through markets. If some producers are not directly affected by the policy, they may be able to hire the workers laid off from the farms that are directly affected by the groundwater restrictions, thus absorbing some of the negative shock. This, in turn, depends on the functioning of local labor markets.

2.3 Theoretical Model at the Grid Level with Exogenous Output Prices

A useful characteristic of the model introduced in Box 1 is that it can be implemented at a highly resolved, spatial scale. In order to address the limitations of the national level model discussed above, in this section we implement the theoretical framework at a disaggregated level to capture spatially heterogeneous impacts of conservation policies. The price and quantity variables as well as the parameters should now be considered indexed at the 'grid-cell' level ('g' notation omitted). A 'grid-cell' in this paper is a geo-referenced 6-8 square kilometer parcel of land (or 5 arc-minutes). The main distinguishing feature of the analysis in this section is that the national commodity price is now assumed to be exogenous to localized production decisions. Therefore, producers at the grid level are 'price-takers' from the national level. As we will see, the uniform change in output price induces varied grid-cell specific responses in input use (5 and 6), input price (7 and 8) and production (9), due to differences in parameters as well as the intensity of the local conservation policy.

By implementing the theoretical model at the disaggregated level, we can distinguish between the 'direct' impact of a conservation policy in grid-cells that are targeted $\left(\phi_A > 0\right)$ and the 'indirect' impact on grid-cells where the producers solely respond to the market-mediated output price change $\left(\phi_A = 0\right)$. Both direct and indirect impacts of the conservation policy lead to an increase in resource rental rate (8) since the policy shock leads to relative resource scarcity. The direct impact of the policy on all other outcomes depends on the magnitude of the different terms in each equation. However, the indirect impacts are positive and referred to as 'spillover' effects. One can think of the national level impacts of a conservation policy discussed previously as an aggregate of all the grid level changes, direct and indirect, within the national market.

Consider the local change in employment when labor supply in a grid is perfectly elastic so that (5) collapses to condition C1. We find that the interaction between the labor supply elasticity and the impacts of a conservation policy at the grid level depends heavily on C1 and therefore requires further attention. The first and second terms in C1 refer to the extensive and intensive margins of supply response to the output price change under perfect labor mobility $\left(v_L \to \infty\right)$, and the third term refers to the magnitude of the conservation shock itself. When the grid level labor supply elasticity is less than perfectly elastic, each of these terms are scaled by $0 < \Gamma_L < 1$, as in (5). The direction of change in employment (5) and wages (7), as well as their interaction with the labor supply elasticity, depends on C1.

(C1) $p^* \frac{v_A}{\theta_A} + p^* \frac{\sigma}{\theta_A} - \phi_A$.

Proposition 4a summarizes the impact of labor market rigidities on wages, employment and resource rents in grids that are directly shocked. If C1 is positive, i.e., the total supply response is dominant $\left[p^* \frac{v_A}{\theta_A} + p^* \frac{\sigma}{\theta_A} > \phi_A \right]$, and there is an increase in wages and employment in the grid-cell.

Wages may increase if the direct impact of the shock is relatively small, the magnitude of the total supply response is relatively large, or a combination of both factors which interacts with labor supply elasticity. Agricultural workers in grids with a lower labor supply elasticity enjoy greater increase in wages, while the increase in resource rents is smaller. However, greater labor market rigidities limit producers' ability to hire workers leading to a smaller increase in employment (23).

If the conservation policy shock is dominant $\left[p^* \frac{v_A}{\theta_A} + p^* \frac{\sigma}{\theta_A} < \phi_A \right]$, then C1 is negative. In this case, the job losses due to the conservation policy shock leads to a fall in wages and employment in the grid. The reduction in employment (24) is lower in the grids with a lower labor supply elasticity since labor market rigidities limit producers' ability to adjust to the policy shock. However, agricultural workers who continue to be employed in grids with a lower labor supply elasticity absorb a greater reduction in wages, while the increase in resource rents is larger.

Condition C1 is critical in determining the direction of change on important labor market outcomes. Proposition 4 shows that condition C1 is also crucial in determining the interaction of the structure of agricultural labor markets and the impact of the conservation policy in terms of resource rents and labor market outcomes summarized in Table 2.

Table 2: Summary of the interactions between labor supply elasticity and the implications of a natural resource conservation policy on grid level outcomes

	Conservation Shock	$\phi_A > 0$	$\phi_A > 0$	$\phi_A = 0$
	Relative size of the Supply Response	$p^* \left[\frac{v_A + \sigma}{\theta_A} \right] < \phi_A$	$p^* \left[\frac{v_A + \sigma}{\theta_A} \right] > \phi_A$	
(1)	(2)	(3)	(4)	(5)
A	Resource Rents (p_A)	Increase	Increase	Increase
	Smaller v_L	Magnifies	Dampens	Dampens
B	Agricultural Wages (p_L)	Decrease	Increase	Increase
	Smaller v_L	Magnifies	Magnifies	Magnifies
C	Employment (q_L)	Decrease	Increase	Increase
	Smaller v_L	Dampens	Dampens	Dampens
D	'Slippage' Effect	Non-negative	Non-negative	Non-negative
	Smaller v_L	Dampens	Dampens	Dampens

The spillover effects of the conservation policy work through the commodity markets, leading to higher prices and increased employment in the indirectly affected grids (5). This leads to an increase in wages in these grids (7). However, labor market rigidities can restrict the movement of labor, leading to a smaller increase in employment and resource rents while magnifying the increase in wages (Proposition 4b).

Proposition 4a: *In directly affected grids, when the total supply response dominates the effect of the conservation policy, a smaller labor supply elasticity leads to a greater increase in wages, smaller increase in resource rental rates and moderates the reduction in employment (23). If the conservation policy shock is dominant, a smaller labor supply elasticity leads to a greater reduction in wages and greater increase in resource rental rates while deflating the increase in employment (24) (Appendix B2).*

(23) Given $\phi > 0$, $\frac{\partial p_L}{\partial v_L} < 0$, $\frac{\partial p_A}{\partial v_L} > 0$ *and* $\frac{\partial q_L}{\partial v_L} > 0$ *if* $p^* \left[\frac{v_A + \sigma}{\theta_A} \right] > \phi_A$

(24) Given $\phi > 0$, $\frac{\partial p_L}{\partial v_L} > 0$, $\frac{\partial p_A}{\partial v_L} < 0$ *and* $\frac{\partial q_L}{\partial v_L} < 0$ *if* $p^* \left[\frac{v_A + \sigma}{\theta_A} \right] < \phi_A$

Proposition 4b: *Spillover effects of the groundwater conservation policy shock through the commodity market lead to an increase in wages, employment and resource rents in those grids cells that are indirectly affected. Grids with less elastic labor supply elasticity observe a greater increase in wages while the increase in resource rents and employment is reduced (25).*

(25) Given $\phi = 0$, $\frac{\partial p_L}{\partial v_L} < 0$, $\frac{\partial p_A}{\partial v_L} > 0$ *and* $\frac{\partial q_L}{\partial v_L} > 0$

Similar to the country level, the final impact of a conservation policy on natural resource use at the grid-level (6) depends on the relative magnitude of the non-negative 'slippage' effect (first term) and the 'effective' incidence of the shock (second term). Again, it is insightful to consider the case where the labor supply is perfectly elastic so that (6) collapses to $\left[p^* \frac{v_A}{\theta_A} - \phi_A \right]$. This shows that if labor supply is perfectly elastic, the change in resource use due to a conservation policy shock is equal to the extensive supply response net of the full magnitude of the gridded conservation policy shock. As the labor supply elasticity is reduced, both terms are deflated by the scaling factors: Γ_A and Γ_ϕ that represent the impact of endogenously determined wages on both terms in (6). These are both less than 1 and positively correlated with the labor supply elasticity parameter. For example, in case of the 'slippage effect', when labor becomes less than perfectly elastic, extensive margin responses by the producer also bid up wages (and at a higher rate as labor becomes more inelastic), thereby dampening the extensive margin (slippage) response by the producer compared to the perfectly elastic case. However, the overall direction of change in resource use, i.e., the sign of (6), depends on the relative magnitudes of the two terms and the impact of their corresponding scaling factors, which in turn depend on the labor supply elasticity parameter.

The aggregate change in output in the grid cell can be expressed as the cost-share weighted sum of the two input changes: q_A and q_L, arriving at (9), wherein the extensive supply response and conservation policy shock are scaled by Γ_A and the intensive supply response is scaled by Γ_σ. Since Γ_σ is a function of the difference in the two factor supply elasticities: $\nu_L - \nu_A$, the intensive margin response in crop production (second term in 9) accounts for competition between inputs to capture any increase in returns due to rise in output prices. The relative input supply elasticities determine the magnitude of the substitution effect. The scaling factor Γ_σ is also positively correlated with the supply elasticity of labor. This implies that as labor becomes more inelastic, the substitution effect of hiring more labor to substitute for the scarce natural resource inputs, also becomes smaller. The overall impact on production of the conservation policy on the grid depends on the magnitudes of each of the three terms in (9), which depend on the labor supply elasticity parameter.

Impacts on resource use and output supply in the indirectly affected grids are always positive due to the spillover effects of the conservation policy (6 and 9). Proposition 4b shows that the increase in employment opportunities is smaller when there is an inelastic labor supply. The same holds for total production and resource use.

Application of the two-input model at the grid level enables us to drill down to a fine spatial resolution to evaluate the success of a spatially targeted conservation policy as well as wage effects and returns to resources. This discussion reinforces the point that labor market rigidities are critical to the effectiveness of a conservation policy. An inelastic labor supply reduces the effectiveness of the conservation shock in a grid, while also reducing the amount of resources conserved due to the slippage effect in response to higher resource rents (8). Therefore, an accurate estimation of the potential impact of a conservation policy depends on accurate representation of local labor markets.

As argued in the national level case, accurate characterization of local labor market behavior is important to understand the distributional implications of conservation policies for key stakeholders including agricultural workers and resource owners, at the local level. Proposition 4a shows that a relatively inelastic labor supply elasticity can lead to divergent welfare effects on agricultural wages and resource rents, particularly when the negative policy shock is dominant. While stringent groundwater conservation policies may be necessary in regions such as the Central Valley of California, where unsustainable groundwater use supports high-value agricultural production, such policies could depress local agricultural wages while raising resource rents accruing to resource owners. We explore this further with our quantitative model.

3. Quantitative model, ‘bridging’ methodology and the policy shock

In this section we briefly describe the SIMPLE-G-CZ model (Ray et al. 2023) and introduce the ‘bridging’ methodology that helps us to use the theoretical framework to derive economic insights from the results of the SIMPLE-G-CZ model. This novel, bridging methodology allows us to tie the spatially explicit policy impacts back to economic theory to explain the results in terms of underlying local economic and bio-physical parameters. We also discuss the sustainable groundwater policy implemented in previous studies (Ray et al. 2023; Baldos et al. 2020) as an example of a spatially targeted conservation policy whose environmental and distributive impacts will be mis-represented if we ignore labor market rigidities.

3.1 SIMPLE-G-CZ

SIMPLE-G-CZ, our quantitative model, draws inspiration from the recent literature on quantitative trade modeling of climate and resource issues (Costinot, Donaldson, and Smith 2016; Gouel and Laborde 2021). As with those papers, production is modelled at the level of individual grid cells. The SIMPLE-G-CZ model builds on SIMPLE-G-US (Baldos et al. 2020) with two important distinctions (Figure 1). First, Augmented-labor is split into Labor and Non-Labor inputs. Second, local labor markets are introduced based on the Commuting Zones[5] literature, which is widely used in labor economics (Fowler and Jensen 2020; Fowler, Rhubart, and Jensen 2016; Tolbert and Sizer 1996). In the SIMPLE-G-CZ model, worker mobility across CZs is restricted, while workers can search for alternative job opportunities across all grid cells within a CZ. An upward sloping agricultural labor supply curve determines the supply of agricultural workers in a CZ and an Additive CET function determines the allocation of agricultural workers across all the grids in the CZ. SIMPLE-G-CZ assumes the mobility of workers within the agricultural sector is higher relative to that between the agricultural and non-agricultural sectors (Ray et al. 2023). The parameterization of agricultural labor supply mobility is based on the most recent estimates of agricultural labor supply elasticity on the extensive margin (Hill, Ornelas, and Taylor 2021).

SIMPLE-G-CZ builds on the SIMPLE framework, that has been designed around the principle that a model should be no more complex than is absolutely necessary to understand the basic forces governing the supply and demand for crops, natural resources and food prices. SIMPLE (Simplified International Model of agricultural Prices Land use and the Environment) is a higher dimensional generalization of the national analytical model developed in Section 2. 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 (Baldos and Hertel 2014; Hertel, Baldos, and Fuglie 2020; Hertel, Ramankutty, and Baldos 2014).

SIMPLE-G-US, documented in Baldos et al. (2020), replaces US national crop supply in SIMPLE with a market clearing condition that sums crop supplies across irrigated and rainfed production in each of the 75,000+ grid cells in the US. The gridded data come largely from USDA sources, with details provided in (Baldos et al. 2020). In the non-US regions, the rainfed and irrigated production functions follow the same nested CES structure as in Figure 1. At the bottom of this figure, groundwater and surface water are combined with irrigation capital to deliver water to

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[5] CZs are clusters of counties grouped together based on the propensity of their residents to travel within the county cluster for regular employment (Figure C3.4)

irrigated crops which also require nonland inputs and fertilizer. SIMPLE-G-CZ extends this by disaggregating labor from the nonland inputs and modelling spatially explicit labor markets as discussed above (ref: Ray et al. 2023 for more detail).

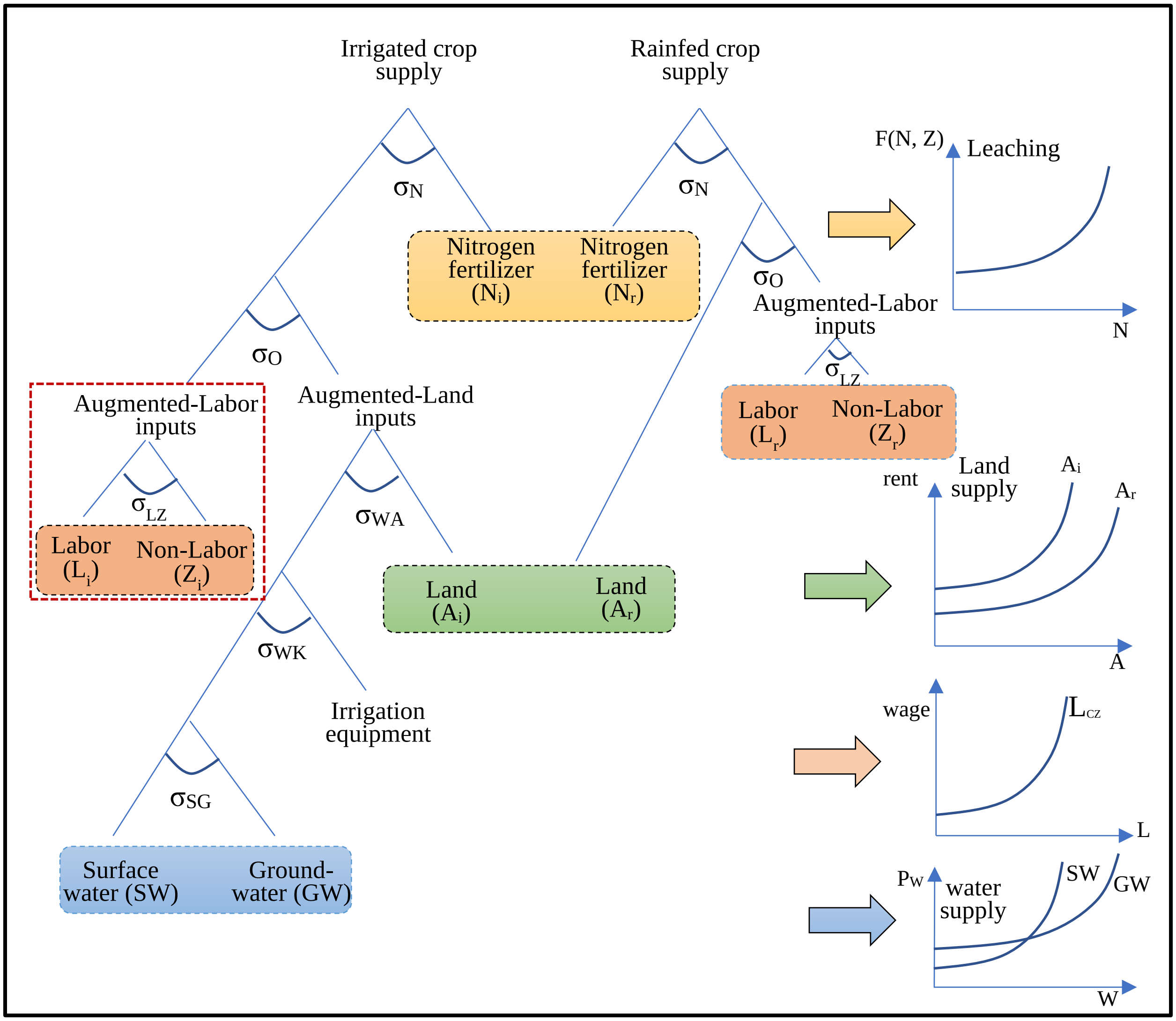

Figure 1: Structure of Crop Production in SIMPLE-G-CZ. This figure is developed based on SIMPLE-G-US (Baldos et al. 2020). The red dashed box shows the extension introduced in SIMPLE-G-CZ by splitting Augmented-Labor inputs into Labor and Non-Labor inputs and introducing spatially explicit labor markets. The **e**lasticity of substitution parameters are shown by σ indexed by the relevant inputs. The equilibrium quantity and price of land and water are determined at local level. Equilibrium wages are determined at local labor market sheds (commuting zones). Irrigated and rainfed practices compete for land. Land supply depends on total cropland supply and the elasticity of transformation between irrigated and rainfed.

We recognize that generalized CZs may not be the optimal representation for some types of agricultural labor. In particular, we do not distinguish between migrant and domestic workers in this paper since labor sheds specific to the different types of agricultural workers are not yet available. However, using our theoretical framework, we discuss the potential differences in the impact of the policy on domestic and migrant workers in the Section 4. In ongoing empirical work, we are seeking to differentiate labor market sheds for different types of agricultural labor.

3.2 'Bridging' Methodology: Using the Theoretical Framework to Understand Simulation Results from SIMPLE-G-CZ

In this section we describe our novel method of analysis to link the theoretical framework with the results from the policy simulation, which we refer as the 'bridging' methodology. This allows us to develop a deeper understanding of the economic consequences of conservation policies, at both the national and local levels. The groundwater conservation policy targets roughly 11 percent of the 75,000+ grid cells producing crops in the US. When combined with spatially heterogeneous model parameters such as irrigated-land supply elasticity, we expect locally varying policy impacts to emerge. While IAMs are equipped to capture this spatial heterogeneity in the evaluation of a conservation policy, the results have thus far not been carefully explored in light the underlying economic theory and model parameters.

The novel bridging methodology developed here simulates the parameters identified in Section 2 at both the national and grid levels. While our theoretical model is a stylized two input framework – simplifying several aspects of real-world agricultural production that are incorporated in the SIMPLE-G modelling framework – it nonetheless is capable of explaining the heterogeneous responses across grid-cells. Using this method of analysis, we can also decompose the numerical model results into the intensive and extensive margins of response to the conservation policy in each grid-cell. This allows us to use the theoretical propositions identified in Section 2 to explain the results of the numerical simulation at the same spatial resolution as the numerical model while being grounded in economic theory.

At the national level, we extract the equilibrium price elasticity of aggregate crop demand (i.e., η^C in Box 1), from the SIMPLE-G-CZ model. The national price elasticity of demand for crops is a function of three categories of demand: food processing, livestock and direct consumption within the US and across the 17 SIMPLE regions. We simulate η^C by perturbing the aggregate supply curve and find that the price elasticity of aggregate demand for US crops is –1.4. This seems reasonable in light of prior empirical work. Muhammad et al. (2011) estimated the domestic price elasticity of food at around -0.2 in the US. This must be combined with the much higher price elasticity of export demand which constitutes about 20 percent of US agricultural production on average (USDA 2018). Hertel et al. (2007) estimate export demand elasticities for agricultural products ranging from 2.6 to 10.1. In Section 2 we showed that the relative magnitude of σ^C and η^C interact with the supply elasticity of labor to determine the impact and distributional consequence of the conservation policy. Since σ^C refers to the substitution between aggregate inputs Augmented-Land and Augmented-Labor, the substitutability between aggregate inputs is likely to be inelastic. For example, the value used in the GTAP data base is 0.26 (Hertel and

Mensbrugghe 2019).) Therefore, we expect the numerical simulations results to follow the condition wherein $\sigma^C < \eta^C$.

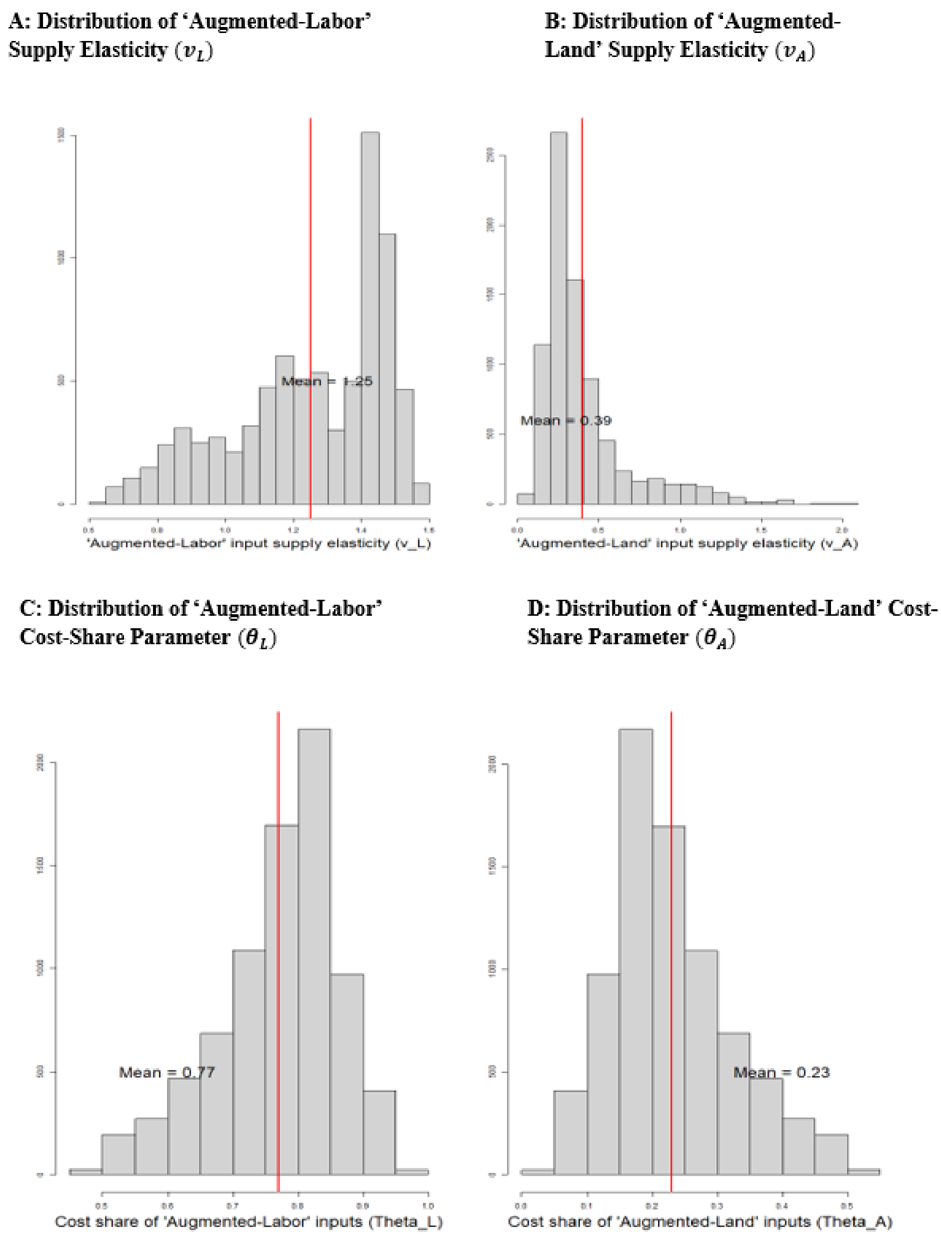

Figure2: Grid Level Share and Elasticity Parameters for 'Augmented-Labor' and 'Augmented-Land' Aggregate Inputs. These two sets of supply elasticities are elicited from the model by perturbing grid-level demands, and observing the price and quantity responses of augmented labor and irrigation-augmented land.

At the grid level, we collapse the multi-input production tree, underlying the SIMPLE-G-CZ model (Figure 1), into a two input CES function that underlie the theoretical framework developed in

Section 2.3. The first step in this methodology at the grid level, involves collapsing the SIMPLE-G-CZ model results into two composite inputs, namely 'Augmented-Labor' and 'Augmented-Land'. 'Augmented-Labor' refers to a composite input including labor and a residual category of other non-labor inputs including capital. 'Augmented-Land' refers to the aggregate input including land and different sources of irrigation water in case of irrigated agriculture. The change in Augmented-Land use and its price change estimated by the SIMPLE-G-CZ model refers to q_L and p_L respectively in the theoretical model. Similarly, change in Augmented-Land use and its price change estimated by the SIMPLE-G-CZ model refers to q_A and p_A respectively.

As shown in the theoretical model, the input supply elasticities for the two composite inputs are critical in determining the impact of a conservation policy. In the second step, we elicit these supply elasticities i.e., the supply elasticity of Augmented-Land and Augmented-Land. We do this by perturbing grid-level demand for the output and observing the price and quantity responses of Augmented-Land and Augmented-Land. These two elasticities can then be interpreted as the local values for ν_L and ν_A in our theoretical model. We also estimate the local values for the CES cost-share parameters θ_L and θ_A. Figure 4 shows the distributions of gridded input supply elasticities and share parameters. These distributions highlight the considerable heterogeneity in production across grids (ref Appendix C for details).

The third and critical step in the novel bridging exercise is the estimation of ϕ_A. In general, ϕ_A refers to the percentage shift in the natural resource supply schedule as a result of the sustainability policy. In case of the groundwater conservation policy, ϕ_A refers to the restriction on groundwater extraction, which is embedded within the Augmented-Land nest (Figure 1). The groundwater policy is imposed at the bottom level of the nested CES production function, and there are a variety of substitution possibilities available within the land-water composite (e.g., use of surface water, improvements in irrigation efficiency through capital investment and deficit irrigation). In our mapping from simulation results to analytics, we account for these by numerically simulating the impact of the shock to groundwater at the level of augmented land, using equation (6) to solve for the estimate of ϕ_A at the two-input level. This estimate of ϕ_A is shock to the composite input (Augmented-Land) as a result of the policy conservation shock on groundwater, after accounting for the substitution possibilities embedded in the production nest. For instance, Figure C3.3 shows that for grid "G003425", the policy shock is of the magnitude of 88% and the simulated estimate of ϕ_A is 60%. This implies that, after accounting for the potential substitutions between ground and surface water, as well as potential improvement in irrigation efficiency, the 88% shock to groundwater use implies a 60% shock to the aggregate input Augmented-Land at the top of the node. Figure C3.3 shows that magnitude of the shock at the aggregate input level is usually smaller than the magnitude of the policy shock due to the substitutions embedded in Augmented-Land.

With these three steps we have built the necessary 'bridge' between the theoretical model implemented at the grid level and the numerical results presented in the Section 4. Essentially, the bridging exercise derives the reduced form estimates of supply elasticities of the two (composite) inputs and policy shock underlying the theoretical framework. This ensures that our gridded analytical results map directly to the results from the SIMPLE-G-CZ model aggregated to two (composite) inputs.

3.3 Sustainable Groundwater Conservation Policy

Rosa et al. (2020) show that major irrigated regions in the US, including the High Plains region, Central Valley in California and the Snake River basin, currently rely on unsustainable groundwater use. With rising demand for agricultural goods due to increasing population and income, the severity of water scarcity is likely to be further aggravated. We implement a sustainable groundwater policy shock previously implemented in (Ray et al. 2023; Baldos et al. 2020).

The groundwater policy implemented here imposes a grid specific restriction on groundwater use in grids where annual groundwater abstraction is greater than the annual recharge rate in 2010. We choose year 2010 since the baseline data for SIMPLE-G-CZ also pertains to the same year. This is a simplification of a more complex policy that would limit groundwater use at a sustainable level for each aquifer in the US. Such a policy design would require well developed water markets that facilitate trading of groundwater rights within the aquifers across the US. In the absence of such mature water markets, this policy imposes grid level restrictions on unsustainable levels of groundwater use. Figure 3 shows the grids affected by the policy located in well-known groundwater hotspots in the Western US. Overall, the policy affects 66.7 percent of groundwater use in the continental US. The magnitude of the conservation policy shock depends on groundwater use and the annual recharge rate accounting for site-specific hydrological and bio-physical characteristics.

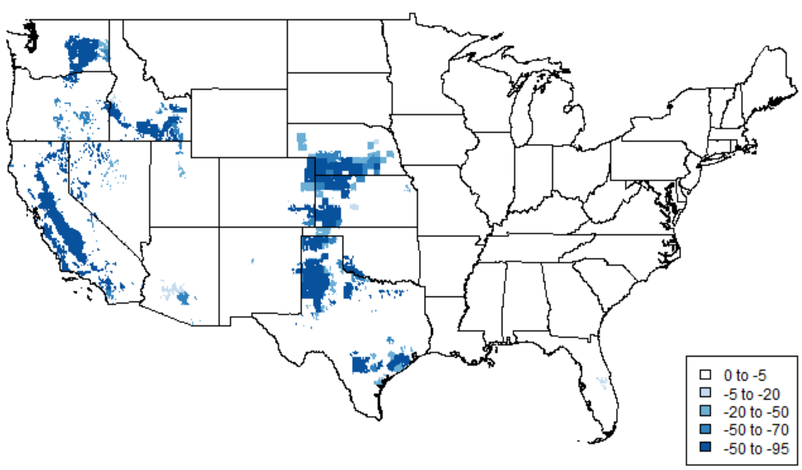

Figure 3: Grids affected by Sustainable Groundwater Conservation Policy Shock (% reduction in groundwater use). This policy limits the extraction of groundwater in excess of the groundwater recharge rates at each grid cell. The policy targets the Central Valley in California, Snake River Basin in the Pacific Northwest and the Ogallala Aquifer. Ref: Haqiqi 2023.

4. Results

We compare results from our labor market model (SIMPLE-G-CZ) with typical IAM style conservation policy analysis (using SIMPLE-G as an example), to highlight the importance of explicitly modelling agricultural labor markets and its increasing rigidities. First, we assess the national impact of the groundwater conservation policy and highlight the stark variation in the policy impact at the national level versus the local level where the policy is targeted. Since our numerical simulation of the aggregate parameters finds $\sigma^C < \eta^C$, we focus on the analytical results summarized in Column (4) of Table 1 to explain the national level impacts. Second, we use the bridging methodology to discuss the policy impact at a higher spatial scale and decompose the policy impacts in terms of producer behavior grounded in economic theory. In our discussion we also highlight the equity implications of the groundwater conservation policy in the presence of labor market rigidities which may be mis-represented or totally overlooked if we assume perfect labor mobility.

4.1 National and Local Impacts of the Conservation Policy: Under contrasting specification of the structure of agricultural labor market

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. While the national differences are modest, the change in crop production and crop price are smaller when we restrict labor mobility as predicted by Proposition 1. The impact of the conservation policy on the Augmented-Labor market outcomes vary starkly across the two labor market specifications. As expected from Proposition 2, given $\sigma^C < \eta^C$, there is a reduction in Augmented-Labor wages by 0.8 percent and a fall in Augmented-Labor employment by 0.3 percent which translates to a reduction in wages by 3.8 percent and employment by 0.9 percent. In contrast, if we ignore labor market rigidities the fall in wages in totally overlooked and fall in employment is over-estimated at 3.7 percent. The difference is further exaggerated in the irrigated sector where a 2.6 percent reduction in employment under the Labor Market Model is over-estimated to a 12.6 percent reduction under typical IAM style analysis. Further, the increase in employment in the rainfed sector, that absorbs the spillover effects of the conservation policy, is also overestimated if we ignore labor market rigidities. We observe a similar pattern in the policy impact on crop production since the pattern of change in input use is closely linked to the pattern of change in production. The reduction in irrigated production (by 10.8 percent) and increase in rainfed production (by 2.1 percent) are both overestimated under the perfect labor mobility assumption as predicted by Proposition 1.

The national level impact on employment accounts for the impacts on employment in irrigated production in the directly affected grids, as well as the spillover effects on irrigated production in the indirectly affected grids and the rainfed sector. It is interesting to note (and further explored with the novel bridging methodology later), that the impact of the policy on employment is not unidirectional in the targeted grids (Panel C). In some cases, employment rises. However, the policy impact on the directly targeted grids, in *both* directions, are over-estimated under typical IAM style analysis (Panels A and B).

Employment in the irrigated sector falls by up to 25 percent (orange grids in Panel C) which is overestimated at 50 percent under the perfect labor mobility assumption (dark-red grids in Panel E). The increase in employment in most targeted grids is restricted to 2 percent (light-green grids in Panel C) which over-estimated up to 10 percent (darker-green grids Panel E) in typical IAM style analysis. These grids also observe an increase in resource use and production (Appendix D1). This also highlights the difference in the local level impact of the conservation policy on employment, and subsequently production, across the two models, which are masked by the aggregate level impacts reported in Table 3.

Table 3: National impact of the US Sustainable Groundwater Conservation Policy (%) on Irrigated and Rainfed Agriculture

Policy Analysis	Labor Market Model (SIMPLE-G-CZ)			Typical IAM Style (SIMPLE-G)		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall
Crop Production	**-10.8**	**2.1**	**-2.7**	**-12.8**	**3**	**-2.9**
Augmented-Land	**-24**	**0.3**	**-13.9**	**-24.1**	**0.4**	**-13.7**
Cropland under production	-0.6	0.4	0.2	-0.7	0.5	0.3
Groundwater withdrawal			-53.6			-54.3
Augmented-Labor	**-5.9**	**2.3**	**-0.3**	**-9**	**3.3**	**-0.7**
Employment	-2.6	1.2	-0.9	-12.6	4.7	-3.7
Commodity Price	**--**	**--**	**2.1**			**2.2**
Augmented-Land Rent	**32.2**	**5.8**	**19.6**	**25.8**	**7.3**	**17**
Land Rent	--	--	-0.4			0.6
Irrigation Cost			60.1			50.8
Augmented-Labor Wages	**-6.1**	**1.8**	**-0.8**	**-3.8**	**1.7**	**-0.04**
Wages			-3.8			0

Note: Bold rows refer to changes in quantity and price of output and composite inputs. Other rows refer to changes in quantity and price of inputs. Columns (4) and (7) reports the impact of the conservation policy on the agricultural sector under SIMPLE-G-CZ and SIMPLE-G respectively. A comparison of columns (4) and (7) show the change in the policy impact when we explicitly model labor market rigidities i.e., 'smaller' v_L^C in Table 1 relative to the perfect labor mobility assumption i.e., $v_L^C \to \infty$.

As a result of the conservation policy, that removes irrigated land from agriculture, some production shifts to neighboring grids, within the same CZ (Panels C and D) and also to the rainfed sector (Appendix D1). This spillover effect, increases employment (dark green grids in Panel D), by up to 30 percent in the Labor Market Model. This is under-estimated in typical IAM style policy analysis (lighter green grids within the red boxes in Panel F relative to Panel D) where agricultural workers who lose their job locally are unrestricted to can move across the nation costlessly. This also leads to the over-estimation of the spillover effects of the policy across the rest of the country (darker-greens in Panel F relative to Panel D, outside the red box).

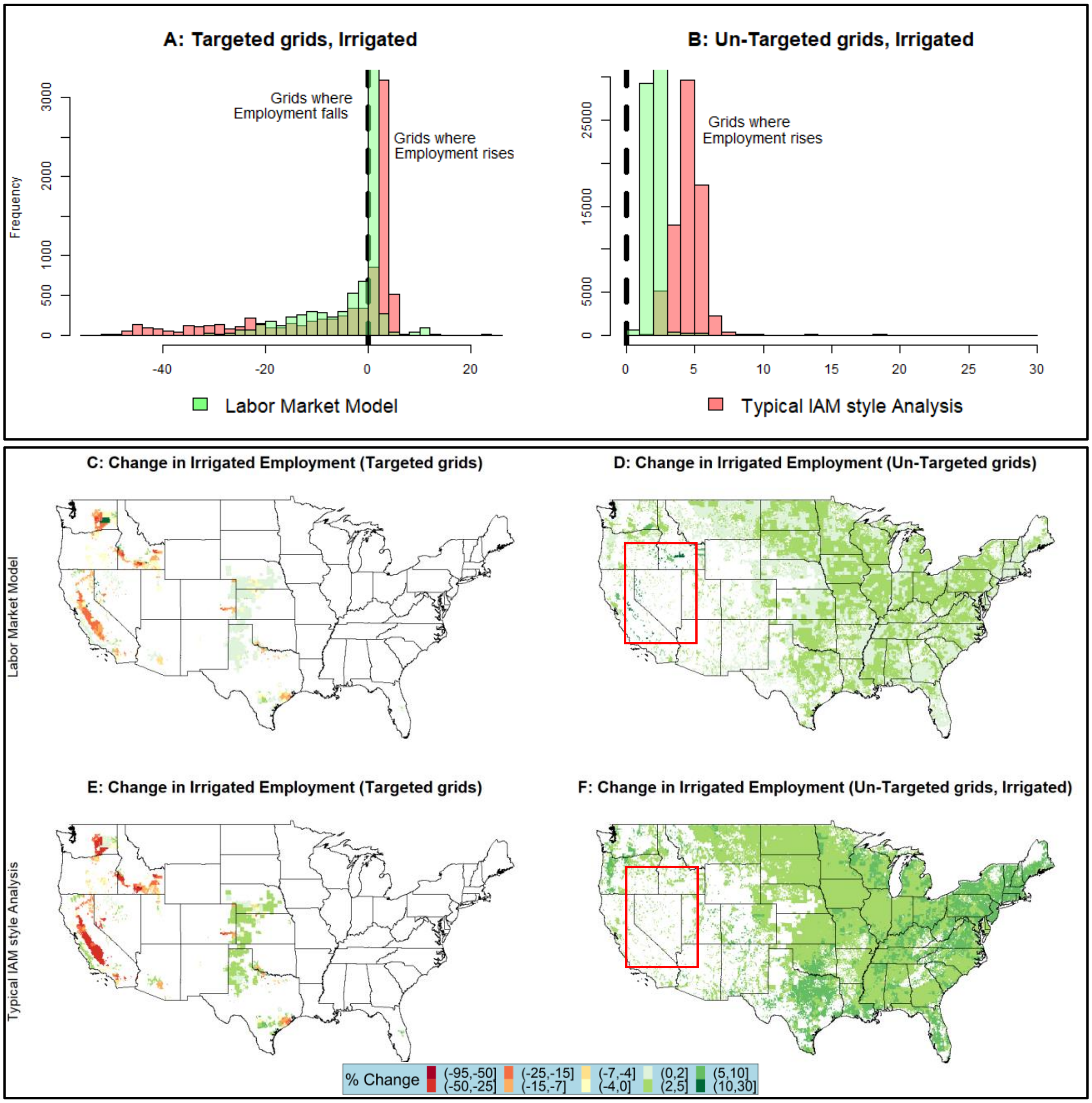

Figure 4: Changes in employment due to the groundwater conservation policy shock. This figure shows the numerical (Panels A to B) and spatial (Panels C to F) distribution of grid level changes in employment in the irrigated sector as a result of the groundwater conservation policy under two models: Labor Market Model (SIMPLE-G-CZ) which incorporates labor market rigidities (light green bars) and Typical IAM style Analysis (SIMPLE-G) assumes perfectly elastic labor supply (red bars). Darker green bars denote overlap. Distributions in Panels A refers to the targeted grids where the policy may lead to an increase or decrease in employment, in both the models, which are shown in Panels C and E. Panel B refers to the un-targeted grids where the spillover effects of the policy, also observed in the rainfed sector (Appendix D1), leads to an increase in employment, in both the models, which are shown in Panels D and F. In Panels A and B, the distribution consisting of red bars model has a wider dispersion relative to the light green bars, showing overestimation of negative as well as positive changes in employment in typical IAM style policy analysis. This is reflected in lighter red and green grids in Panels C and E. The red boxes in Panels D and F highlight the untargeted grids neighboring the targeted grid in the irrigated sector. It shows that the local level spillover effects on employment in neighboring grids is underestimated in the typical IAM style policy analysis since worker mobility is costless by assumption.

We can expect some spillover effects with increased production from across the country, due to the higher crop prices. Considering the empirical evidence on labor market rigidities, it is unrealistic to expect spillover effects, leading to up to 30 percent increase in employment, in other parts of the US.[6] With explicit modelling of agricultural labor markets, these spillover effects are restricted to the neighboring grids with limited impact (less than 5%) on rest of the country.

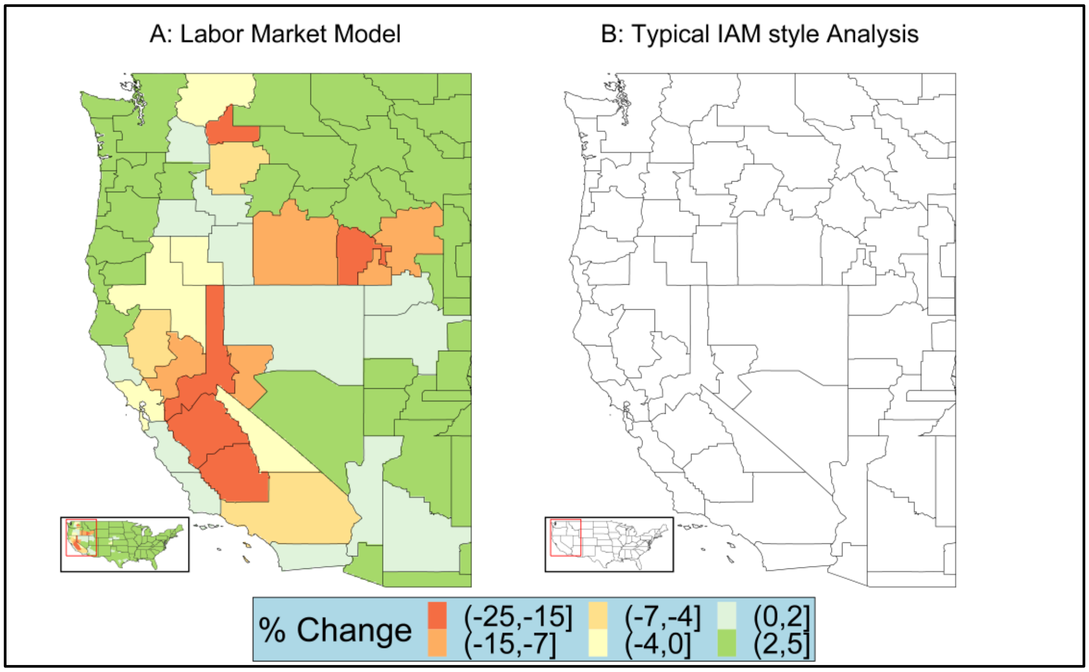

Figure 5: Impact of the conservation policy on agricultural wages across CZs in Western US. The CZs with directly targeted grids show a reduction in wages (orange-red) while other CZs show increase in wages (yellow-green) when we restrict labor mobility (Panel A). This is in stark contrast with the SIMPLE-G (Panel B) model where perfect labor mobility overlooks any impact of a conservation policy on agricultural wages.

The groundwater conservation policy has significant local level impacts on agricultural wages (Figure 5) in the Western US. While the national average agricultural wage is estimated to fall by 3.8 percent, Panel A shows that wages fall by up to 25 percent in the labor sheds that are directly targeted by the conservation policy under the Labor Market Model. Under the perfect labor mobility assumption, there is a stark contrast where wages are considered to be non-responsive to the conservation policy (Panel B).

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 Irrigation-Augmented-Land' use by 24 percent and a 54 percent reduction in groundwater use under both models. We explore this further in the next section using the bridging methodology to highlight underlying economic

[6] Since labor is assumed to be perfectly mobile across the country in Figures 6E and 6F, the spillover effects are driven by the propensity to divert land and water resources into agriculture along the margins of the Corn Belt, as well as Southern and Northeastern US (ref Figure C2.1 for simulated agricultural land supply elasticity).

processes contributing to this observation. The change in groundwater use, under both models, is smaller than the magnitude of the shock at 66.7 percent.[7] The difference is due to the 'slippage' effect ranging between 12 – 13 percent (Appendix D1).

Resource rents increase as a result of the groundwater conservation policy as expected in (18) since the policy leads to a relative scarcity of irrigated land. Ignoring labor market rigidities leads to an underestimation of the increase in resource rents at 19.6 percent (SIMPLE-G-CZ) relative to 17 percent (SIMPLE-G) in the irrigated sector. This is driven by the larger increase in irrigation cost in the Labor Market Model at a 60.1 percent increase relative to 50.8 percent.

In our analytical framework the impact of the conservation policy on the market returns to resource owners depends on the relative magnitudes of the increase in resource rents and the fall in resource use. Under both scenarios for the structure of agricultural labor markets, we find that the increase in resource rents, offsets the reduction in resource use, leading to an increase in market returns, inferred from Equation 21, to the resource owners. However, the increase in market returns is higher (5.7 vs 3.3 percent) in the Labor Market Model.

The conservation policy's impacts on consumers, in terms of higher crop prices, do not vary much between the two models. The zero-profit condition (Equation 3) determines the distribution of gains from the higher output prices, between the two inputs. Under the perfect labor mobility case, we assume wages remain unchanged and therefore the entire benefit of crop price increases accrues to resource owners in terms of higher rents. However, when we incorporate labor market rigidities, and given $\sigma^C < \eta^C$, there is a fall in agricultural wages. This implies a greater share of the crop price increase accrues to resource owners while farmworkers absorb a wage cut. Therefore, the distributional effects of a conservation policy, between farmworkers and resource owners will be misrepresented if we do not account for labor market rigidities.

4.2 Grid-level policy impacts using the novel 'bridging' methodology: Central Valley of California

In this section we leverage the novel 'bridging' methodology to investigate the local level impacts of the conservation policy at the grid level. After we verify that the analytical model accurately estimates the results of the numerical simulation, using the bridging methodology, at the 2-input level (Appendix D2), we decompose the policy impacts into the extensive and intensive margins of producer response net of the 'effective' shock in the irrigated sector. The gridded decomposition exercise, under the perfect and restricted labor mobility assumptions, helps us to better understand the direction of change in employment (production and resource-use), as a result of the conservation policy. While the we emphasize the policy impacts in the targeted grids, we also discuss the spillover effects of the policy in the indirectly affected grids (by setting $\phi_A = 0$)

[7] Proposition 3 identifies the analytical condition where the conservation policy is dominant in (20).

in the irrigated sector. We focus on the Central Valley of California because the policy shock is most severe in this region.[8]

Before presenting the results, we revisit Equation C1, the condition that underlies the quantitative impacts of a conservation policy and the impact of labor supply elasticity on the same (Section 2.3). Using the bridging methodology, we plot whether the policy shock or the total supply response is dominant in C1 (Figure 6).

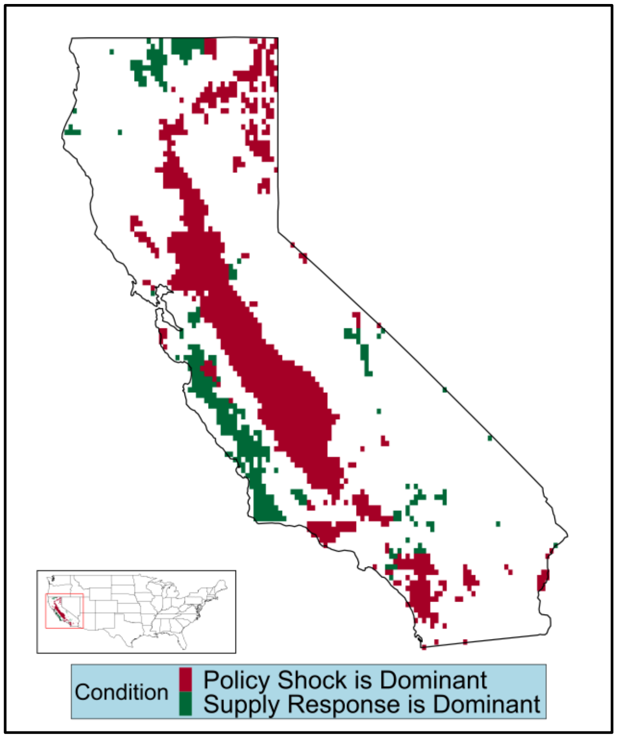

Figure 6: Sign of Condition C1 underlying Proposition 4**.** This figure plots the sign of Condition C1 in directly targeted grids. Red refers to grids where the shock is dominant and the sign of C1 is negative. Green refers to grids where the total supply response is dominant and the sign of C1 is positive. In the following sections we draw heavily on the spatial pattern of the sign of Condition C1.

4.2.1 Decomposition of the Policy Impact on Employment in the Central Valley, CA

The change in Augmented-Labor employment, as a result of the groundwater conservation policy, is not unidirectional (Figure 4). Figure 7 shows the case for the Central Valley, highlighting the grids that experience increased employment in green amidst a majority of grids experiencing a decrease in employment (red grid). From our analytical model, we know that the direction of change in Augmented-Land employment in the targeted grids, varies depending on the sign of C1. The directly targeted grids where the C1 is negative (red grids in Figure 6), experience a decrease in Augmented-Land employment (red grids in Panels A and E in Figure 7). The reverse is true when C1 is positive where Augmented-Land employment increases in the targeted grids. Spillover effects of the policy leads to increase in employment in non-targeted grids.

Restricted labor mobility dampens the impact of the conservation policy (Proposition 4). In Figure 7, we observe that the employment reduction (red cells) and increases (green cells) are smaller in

[8] Similar exercises for other regions impacted by this policy can be readily produced

the Labor Market Model (Panel A relative to E). When C1 is negative, leading to a reduction in Augmented-Land employment, restrictions in labor mobility dampens the *fall* in employment relative to the case of perfect labor mobility (Proposition 4). Targeted grids where C1 is negative, we observe a reduction in employment ranging between 4 – 50 percent in the Labor Market Model (Panel 7A). These reductions are over-estimated in Typical IAM style analysis where a majority of grids observed a reduction in employment by 25 – 50 (Panel 7E). On the other hand, when C1 is positive, leading to an increase in Augmented-Land employment, restricted labor mobility dampens the *increase* in employment (Proposition 4). The increase in employment in the targeted grids where C1 is positive, is limited to less than 2 percent in the Labor Market Model (Panel 7A), and is exaggerated to range between 2 – 5 percent under Typical IAM style analysis (Panel 7E). The spillover effects in the un-targeted grids in the irrigated sector, follows the same pattern, as observed in Table 2.

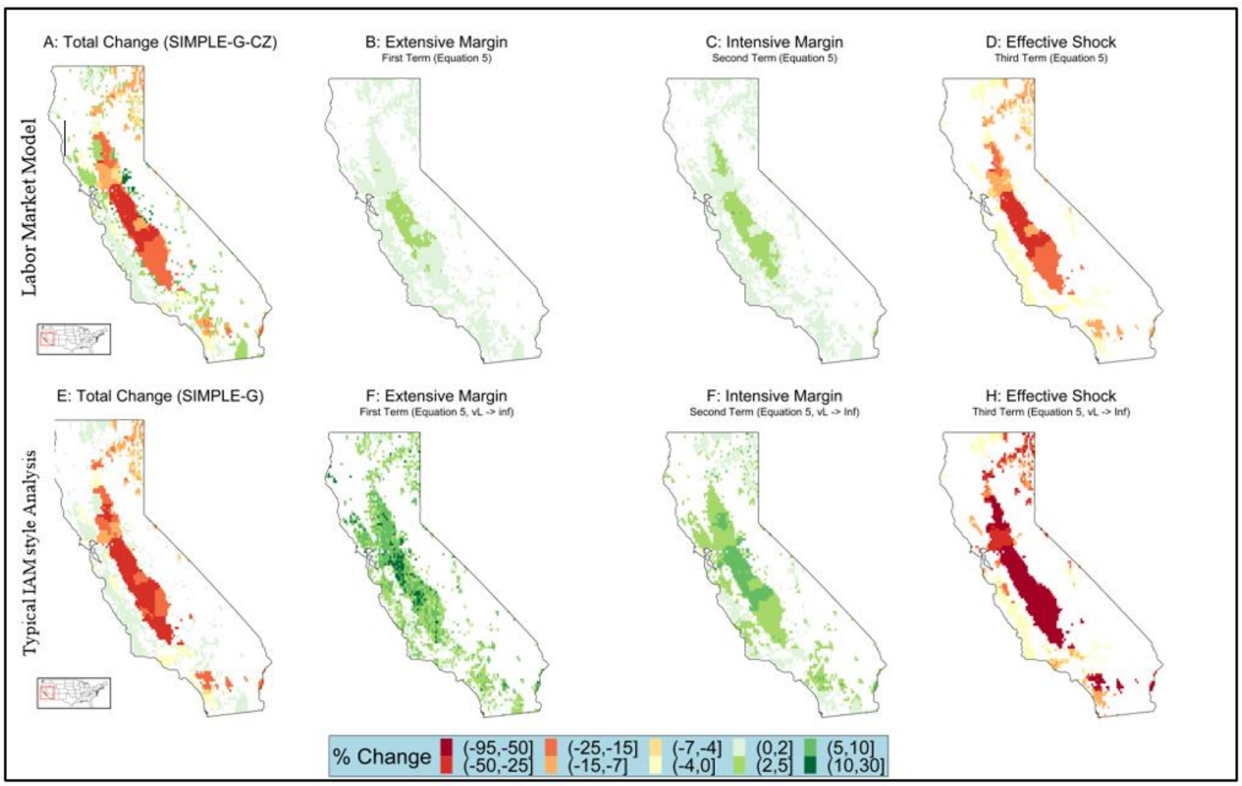

Figure 7: Grided Decomposition of Policy Impact on Augmented-Labor Employment in Irrigated Sector. (i) The polygons (black border) within the map of California shows the grids targeted by the groundwater conservation policy. The 'effective' shock shown in Panels D and H are fully contained within the polygons. The colored grids outside the polygons refer to the indirectly affected grids in the irrigated sector which absorbs the spillover effects of the policy similar to the rainfed sector (shown in Appendix D3). (ii) The figure shows the overall policy impact (Panels A and E), extensive (Panels B and F) and intensive (Panels C and G) margin supply response and the effective shock (Panels D and H) under SIMPLE-G-CZ and SIMPLE-G models respectively.

While, Proposition 4 allows us to hypothesize the directional change in employment as a result of the conservation policy, using Equation C1, the bridging methodology, allows us to decompose the total change in 'Augmented-Labor' employment into three components with useful underlying economic intuition (Equation 5). The negative effect of the conservation policy is moderated by the extensive (Panels 7B and 7F) and intensive (Panels 7C and 7G) margin responses to the crop price increase. Both the extensive and intensive margin responses are over-estimated in Typical IAM style analysis. In the Labor Market Model, the extensive margin response to the policy shock is limited to 2 percent (Panel 7B) in a majority of the targeted grids, which is exaggerated to 5 – 30 percent under Typical IAM style analysis (Panel 7F). Across both models, the intensive margin response is larger than the extensive margin response. This is not surprising due to the limited availability of alternative land and water resources that can be diverted into agriculture in the Central Valley. In the Labor Market Model, intensification increases by upto 5 percent which is magnified to 10 – 30 percent, under the perfect labor mobility assumption in Typical IAM style analysis. Given a relatively small increase in commodity price (x%), an intensification response of greater than 10 percent seems unrealistic given the evidence of increasing rigidities in agricultural labor markets, especially in the Central Valley region.

The 'effective' magnitude of the policy shock (Panels 7D and 7H) also varies across the two models. Under restricted labor mobility, the 'shock multiplier' decreases, and therefore the 'effective' shock is smaller than the magnitude of the policy shock. This is reflected in the wide variation in 'effective' shock magnitude in Panel H relative to Panel D since Γ_L is a function of the underlying economic parameters introduced in Box 1. Under perfect labor mobility, the 'effective' policy shock is equivalent to the magnitude of the shock since the shock multiplier $\left(\Gamma_L\right)$ in (5) converges to 1.

The total impact on Augmented-Land employment is the sum of the extensive and intensive margin response to the crop price increase due to the policy shock net of the impact of the 'effective' shock itself. Decomposition of the total impact into its component terms, using the 'novel' bridging methodology, helps us to answer the question, at a high spatial resolution, *what is driving the local impact of this conservation policy?* For instance, since the extensive and intensive margin responses are quite small in magnitude, in the SIMPLE-G-CZ model, the spatial pattern of change in Augmented-Land employment (Panel E), reflects the spatial pattern of the 'effective' policy shock (Panel H). The 'effective' policy shock, captures the impact of endogenously determined wages in the Labor Market Model, which is overlooked in Typical IAM style analysis.

4.2.2 Decomposition of the policy impact on Augmented-Land use:

The 'success' of the conservation policy, measured in terms of the irrigated land, along with conservation of the underlying groundwater, is insensitive to the structure of agricultural labor markets (Panels A and D in Figure 8). However, implementing the bridging methodology, to decompose the changes in Augmented-Land, shows that its sub-components are both sensitive to the structure of agricultural labor markets. The first component, i.e., the extensive margin response is referred to as the 'slippage' effect of the policy in the targeted grids which could lead to further exaggerate of the groundwater scarcity problem.

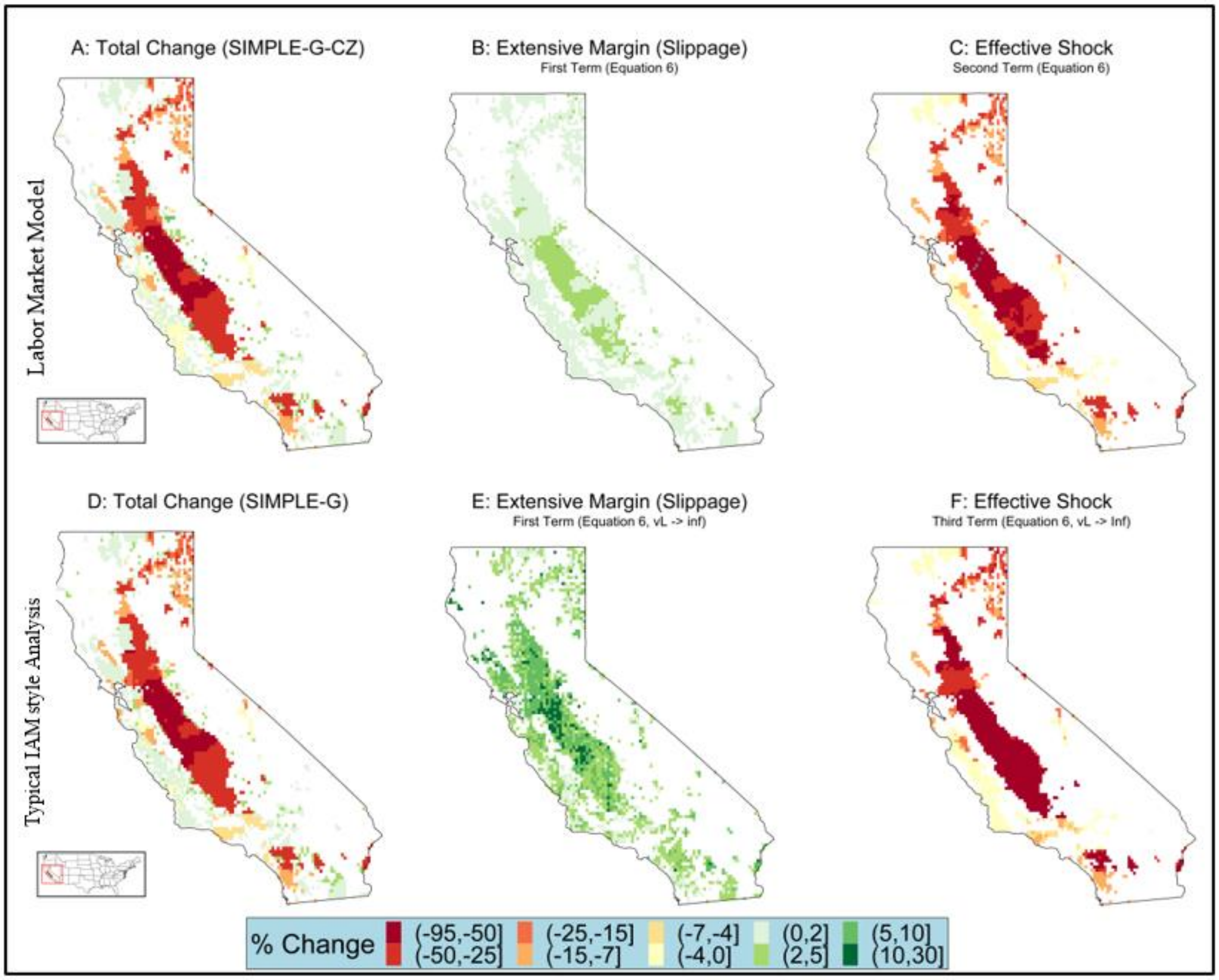

Figure 8: Grided Decomposition of Policy Impact on Augmented-Land use in the Irrigated Sector. (i) The polygons within the map of California shows the grids targeted by the groundwater conservation policy. The 'effective' shock shows in Panels C and F are fully contained within the polygons. The colored grids outside the polygons refer to the indirectly affected grids in the irrigated sector which absorbs the spillover effects of the policy similar to the rainfed sector (shown in Appendix D3). (ii) The figure shows the overall policy impact (Panels A and D), extensive (Panels B and F) supply, which is the 'slippage' effect, and the 'effective shock' (Panels C and F) under SIMPLE-G-CZ and SIMPLE-G respectively.

The 'slippage' effect of the conservation policy in the Central Valley region leads to an increase in irrigated land use by up to 5 percent (Panel 8B) in the Labor Market Model. This is significantly over-estimated to be greater than 5 percent in almost all grids and could also exceed 30 percent in Typical IAM style analysis. Similar to the change in Augmented-Labor employment, the 'effective' shock in case of Augmented-land use change is equal to the magnitude of the shock itself if we ignore labor market rigidities (Panel 8F). Explicitly modeling agricultural labor market, the magnitude of the 'effective' shock is smaller due to adjustments in the labor market to endogenously changing wages. While the net change in resource use across grids is similar between the two model, the decomposition unveils that Typical IAM style analysis is likely to over-estimate the positive 'slippage' effect of the policy and the negative 'effective' shock magnitude.

The overall 'success' of the conservation policy in most grids is driven by the 'effective' shock magnitude which refers to the magnitude of the shock pre-multiplied by Γ_{ϕ}. Under perfect labor mobility, $\Gamma_{\phi} \to 1$, leading to a larger magnitude of 'effective' shock (darker-red grids in Panel 8F relative to Panel 8C) which offsets the larger extensive margin response. This, in turn, leads to similar total impact of the policy at the grid-level as well as at more aggregate scales.

4.2.2 Divergence in the Policy Impact on Wages and Land Rents in Central Valley, CA

The conservation policy impact on national resource rents is always positive since it creates a relative scarcity of the resource inputs. This holds true at the grid level under both the models (Panels A and C in Figure 9). The impacts on wages however, in the directly targeted grids, are not unidirectional (Panel 9B), in the Labor Market Model. While the conservation policy leads to a reduction in wages in most (red-orange) grids, some (green) grids experience an increase in wages. Under Typical IAM style analysis, wages do not change, by assumption (Panel 9D).

Proposition 4 and Table 2 show that the intensity of change in wages and rent depend on the interaction between labor supply elasticity and sign of C1 (Figure 6). In the Labor Market model, grids where total supply is dominant (C1 is positive), experience an increase in wages (light green grids in Panel 9B) as well as rent. In these grids producers are able to divert resources (both human and capital) outside of agriculture into production to more than offset the shock impact. If labor is erroneously assumed to be perfectly mobile, producers can hire more workers costlessly, therefore further driving up increase in resource rents.

In the opposite case, when C1 is negative, there is a fall in wages (red-orange grids in Panel 9B) and the increase in resource rents is higher (darker green grids in Panel 9A) in the Labor Market Model. In this case, the policy shock is dominant leading to higher relative scarcity of the natural resource input. If we assume perfect labor mobility, we overlook the reduction in wages. When labor markets are explicitly modeled, workers who continue to be employed absorb a wage reduction of up to 50 percent while the returns to the relatively scarce and inelastically supplied natural resource input increases by up to 20 percent. In fact, the grids where the wage cuts are most acute (red grids in Panel 9B) also correspond to grids where the resource rent increases are the highest (dark green in Panel 9A). The perfect labor mobility assumption glosses over this important distributional impact of the conservation policy between farm workers and resource owners.

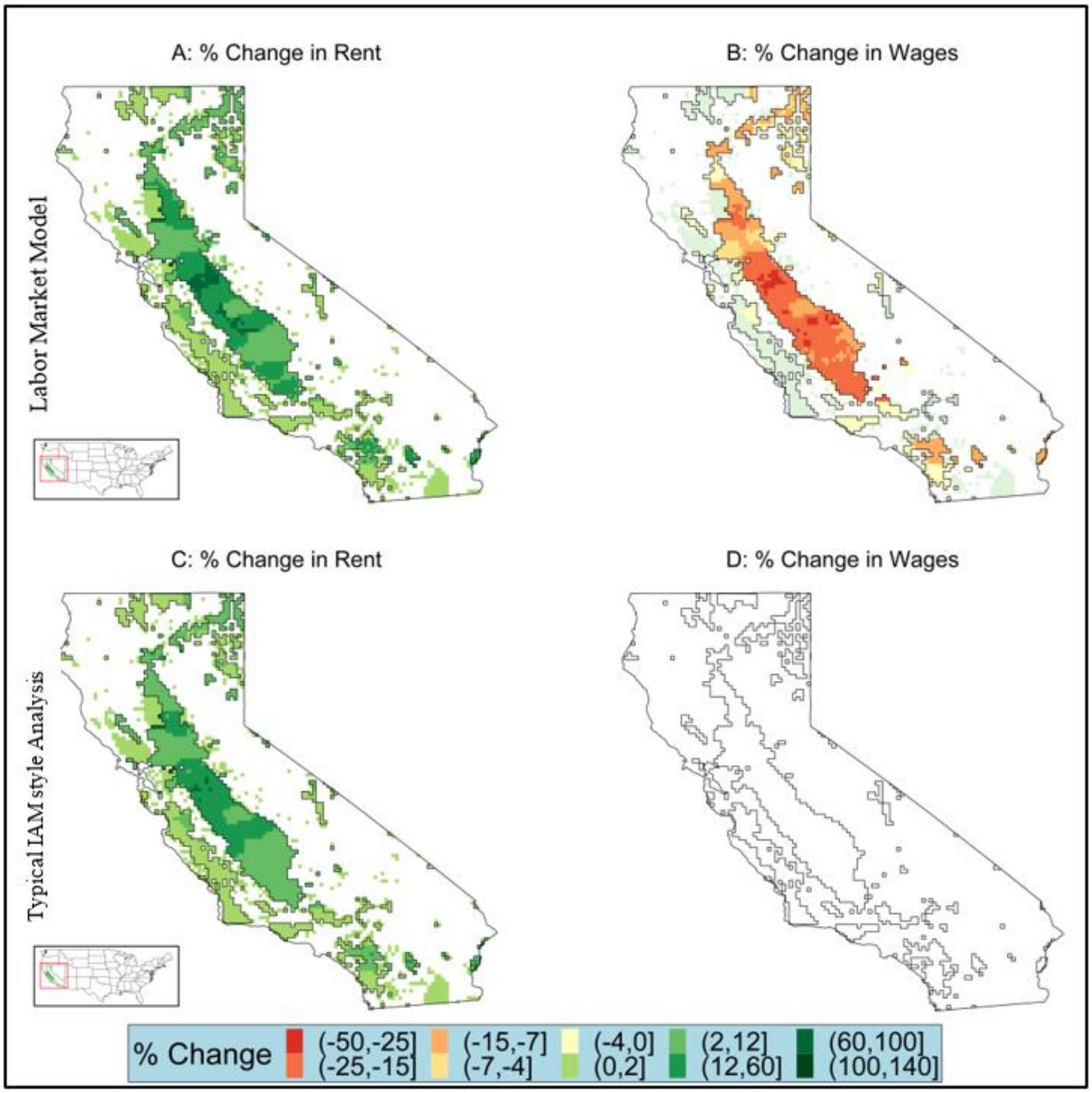

Figure 9: Change in Augmented-Labor Wages and Augmented-Land Rent due to the Conservation Policy. The polygons within the map of California shows the grids targeted by the groundwater conservation policy and the grids outside the black polygons are the spillover effects. Panels A and B shows the change in Augmented-Land rents and Augmented-Labor wages under the SIMPLE-G-CZ model. Panels C and D show the same under the SIMPLE-G model which assumes perfect labor mobility and therefore no change in wages as a result of the conservation policy. When we restrict labor market mobility, accounting for empirical evidence on tightening agricultural labor markets, we observe that a conservation policy leads to an increase or decrease in agricultural wages depending on the sign of C1.

Panels A and B in Figure 9 also show the spatial distribution of the higher returns to crop production between the two aggregate inputs as a result of the conservation policy. While the perfect labor supply elasticity assumption completely overlooks the change in wages by assumption, it also abstracts from the spatial pattern in the increase in resource rents. Equation (5) shows that changes in Augmented-Land rent is fully determined by its supply elasticity and cost share under perfect labor mobility (Panel C). When we explicitly model labor markets, we see that changes in Augmented-Land is determined by a richer interaction of all the model parameters (Panel A).

4.2.3 Policy Impacts on Migrant and Domestic Farmworkers

In this paper we model agricultural labor as an aggregate category which glosses over important distinctions amongst farmworkers (ref: Figure 1 in Hill, Ornelas, and Taylor (2021)). One primary characteristic that distinguishes between types of farmworkers is whether or not they are migrant workers.[9] This is an important distinction amongst farmworkers and is associated with the nature their work. In the US, migrant workers constitute a greater share of the workers employed in labor intensive crops such as fruits, nuts and vegetables particularly for planting and harvesting. Local workers, including family labor, are typically engaged in supervisory roles. While the overall mobility of farmworkers across categories is declining, the mobility of migrant workers is likely to be remain relatively higher than for local workers.

Our analysis shows that in case of greater farmworker mobility, the job losses are higher in targeted regions with higher spillover effects in untargeted regions and. This implies that in response to a conservation policy that restricts production, migrant workers are more likely to lose their jobs and move to more resource abundant regions where higher production offsets some of the policy shock. This could lead to higher rents in the untargeted regions. As an aggregate group however, the percentage of job loss for migrant workers is likely to be greater.

The impacts on local farmworkers are expected to be different since their mobility is relatively more restricted. Local farmworkers, which includes farm owners and family laborers, are less likely to leave farming in this location. The direction of impact on the wages of those remaining in the grid/sector depends on whether they can bring additional irrigated land untargeted by the policy into production to offset the policy shock. Where production can continue, farm owners will also benefit from higher rental returns.

While we can use a combination of our analytical and numerical results to investigate the potential differences in the impact of a conservation policy on the different types of farm workers, further research is necessary to explicitly model these distinctions. The degree of mobility of migrant workers can also vary due to the seasonality of demand for farmworker. At the peak of harvest season, mobility of migrant workers can be restricted by their contractual managers. The mobility of 'follow the crop' skilled migrant workers (Hill, Ornelas, and Taylor 2021) is likely to be different from other migrant workers.

[9] These are still broad classifications of farmworkers. For the purpose of discussion, we refer to migrant workers as those who have greater mobility relative to other workers who have stronger preference to be local workers. Migrant workers in this case can be domestic migrant workers as well as immigrants from other countries.

5. Discussion and Conclusion

The interface between agriculture and the environment is critical to future efforts to preserve biodiversity, improve water quality, mitigate greenhouse gas emissions and implement sustainable groundwater usage. Most of the associated policies entail withdrawing natural resources – in particular land and water – from farming. Yet the analytical frameworks currently being used to assess these policies ignore a key element of the economic response at the local level – namely the functioning of labor markets. This is key, given the considerable evidence on increasing agricultural labor market rigidities (Hill, Ornelas, and Taylor 2021; Taylor, Charlton, and Yúnez-Naude 2012; Charlton, Rutledge, and Taylor 2021). By assuming (either explicitly or implicitly) that labor adjusts to these policies in a seamless fashion, IAMs tend to overstate the effectiveness of these policies, as well as likely changes in agricultural production and employment. Perhaps most importantly, they risk grossly misstating the distributional impacts of these conservation policies. By developing a theoretical framework which incorporates labor immobility, are able to show how this feature of rural labor markets impacts key outcomes of policy interest. We then illustrate these points numerically using a recently developed, gridded IAM which models US labor markets, at the level of commuting zones, across 75,000+ 5-arcmins grids involved in agricultural production in the US. We focus on a conservation policy in which US groundwater withdrawals are restricted to recharge rates, thereby sharply reducing irrigation in many localities across the Western US.

We develop a novel methodology, which allows us to build a bridge between the theory and the grid cell outcomes in the SIMPLE-G-CZ model (Ray et al. 2023), demonstrating where and how the unrealistic assumption of perfect labor mobility has led previous analyses astray. We find that the perfect labor mobility assumption over-estimates the reduction in employment, crop production and subsequently the success of a groundwater sustainability policy at a local level. It also over-estimates the spillover effects of the policy on indirectly affected areas. Most importantly, the assumption completely overlooks the wage effects and therefore the distributional effects of the conservation policy. In the directly affected grids, we observe 5 to 20 percent reduction in agricultural wages while resource rents increase by a similar amount when we explicitly model the labor market rigidities. In some of the targeted grids, we also observe modest increase in wages. In summary, the distributional and spatial impacts of a conservation policy are critically linked to a better understanding of agricultural labor markets.

While we expect to see some important differences in policy impact across broad categories of agricultural workers, we gloss over these important distinctions in our modelling framework. In the absence of labor-shed delineations of the different types of agricultural workers, we model it as an aggregate group as a first step in this area of research. Future research must focus on explicitly breaking out different types of labor and their labor market extent. This can be accommodated in the SIMPLE-G-CZ framework by disaggregating the labor input into sub-categories and modifying the CZ approach to be more suited to the different types of agricultural workers to delineate different labor type specific labor sheds.

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