

ASSESSING THE IMPACT OF CONSERVATION POLICIES ON RURAL COMMUNITIES: THE ROLE OF LABOR MARKETS

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Abstract

Labor is a critical, but often overlooked, input in agriculture. In this paper we develop a theoretical model to demonstrate how agricultural labor market functioning plays a significant role in determining the impact and distributional consequences of conservation policies. We next propose a novel approach to use the theoretical model to explain the impacts of a groundwater conservation policy from a spatially explicit quantitative model comprising 75,000+ grids within the US. Building on existing literature of gridded agricultural production (Baldos et al. 2020) and local labor markets using Commuting Zones (Fowler, Rhubart, and Jensen 2016b) we develop the SIMPLE-G-CZ model of agricultural production and labor markets. We find that labor market rigidities dampen the effectiveness of conservation policies. Limited labor mobility also results in the conservation policy's incidence being borne in greater proportion by farm workers, with these impacts varying widely across local labor markets.

1. Introduction

Labor is a critical input in agriculture, and an important determinant of rural household and community outcomes in the wake of policies directed at the farm sector. With rising demand for agricultural products due to projected increases in population and income (O'Neill et al. 2014), there is an increasing role for conservation policies to ensure sustainable management of natural resources such as groundwater conservation and protecting ecologically vulnerable land. Christiaensen, Rutledge, and Taylor (2021) argue that agricultural labor market functioning is one of the most important factors underlying the potential impact of conservation policies. Recent literature on the impact of economy-wide environmental policies such as a carbon tax in Canada and the United States (US) highlight the potential employment and wage effects (Hafstead, Williams, and Chen 2022; Carbone et al. 2020; Yip 2018). However, to date, Integrated Assessment Models (IAMs), such as GLOBIOM (Global Biosphere Management Model), MAgPIE (Model of Agricultural Production and its Impact on the Environment) and SIMPLE-G (Simplified International Model of agricultural Prices, Land use and the Environment – Gridded version), designed to evaluate the impacts of land-based conservation policies, have focused little attention on labor markets (Baldos et al. 2020; Valin et al. 2013; Lotze-Campen et al. 2008). In this paper we develop a theoretical model that highlights the role of agricultural labor market rigidities in governing the success of conservation policies, as well as the distributional impact on local communities. We also propose the SIMPLE-G-CZ model as an advance in explicitly modeling agricultural labor markets in the context of conservation policies.

In 2017, labor accounted for more than 30 percent of production costs in the agricultural sector globally and close to 60 percent in Sub-Saharan Africa (Hertel and de Lima 2020). In the United States (US), average labor costs as a share of gross farm income (2017-2019) range between 25 – 35 percent in the production of fruits, nuts, vegetables and other specialty crops (USDA 2021). Countries across the various stages of the agricultural transformation, face shortages in agricultural labor with fewer workers willing to enter the (migrant) agricultural workforce (Charlton, Rutledge, and Taylor 2021). Evidence pertaining to the US suggests that the era of farm labor abundance is close to its end and reflected in relatively rapid increases in farm wages and expanding guest workers program to source farmworkers from a shrinking pool rural Mexicans willing to work in agriculture (Charlton, Rutledge, and Taylor 2021; Hamilton et al. 2021; Zahniser et al. 2018; Hertz and Zahniser 2013; Taylor, Charlton, and Yúnez-Naude 2012). Farmers face a combination of factors, such as costly search-matching processes amongst a limited pool of farmworkers, competing for ‘follow the crop’ farmworkers during narrow harvest windows and potential sunk costs in specialized assets, all of which imply that farmers face an inelastic labor supply curve (Hamilton et al. 2021; Hill, Ornelas, and Taylor 2021). In this paper, we show that assuming agricultural labor supply is perfectly elastic completely overlooks potential adverse wage impacts on agricultural workers as a result of conservation policies.

Policies that target conservation of natural resources, such as sustainable management of groundwater resources, protecting ecologically sensitive land and establishing wetlands to limit nutrient leaching in the Mississippi River Basin, are likely to specifically target regions where

land-water resources are under threat and the site-specific bio-physical characteristics are suitable to the intervention. For example, agriculture in the Western US is heavily reliant on groundwater use. Rosa et al. (2020) show that the High Plains and the California's Central Valley already use unsustainable levels of groundwater for several months during their cropping season. This is likely to be further exaggerated, threatening access to freshwater sources in these regions as well as the Colorado River Basin and the Snake River Basin (USGS 2021; Faunt 2009), when combined with unpredictable periods of drought in the context of climate change. Site-specific characteristics of an aquifer such as recharge rate and hydraulic conductivity are important determinants of the magnitude of the policy shock (Edwards 2016). Therefore, conservation policies restricting groundwater usage for sustainable management of watersheds is likely to directly impact communities relying on agricultural production in the Western US. In this paper, we evaluate a sustainable groundwater management policy in the Western US. While the national impact of the policy on irrigated production, employment and wages are small, regions in California's Central Valley show a fall in irrigated production by up to 65 percent, fall in employment by 40 percent and reduction in wages by up to 35 percent.

The trade and labor literature offers an important motivation for paying greater attention to labor markets in assessing the impacts of locally targeted conservation policies. Recent examinations of the local impacts of trade policy changes – most notably China's entry into the WTO – have shown that labor in the US is far less mobile than previously assumed (Acemoglu et al. 2016). As a result, the adverse effects of concentrated local economic shocks have resulted in unemployment and depressed wages, specifically in the manufacturing sector amongst local labor markets that were directly exposed to the trade shocks (Autor, Dorn, and Hanson 2016; Caliendo, Dvorkin, and Parro 2019). The persistence of these adverse effects for more than a decade is attributed to geographic rigidities in labor mobility and low absorption of manufacturing workers in other sectors (Autor, Dorn, and Hanson 2021). Taken in the context of the aforementioned rigidities in agricultural labor markets, this suggests the need to better understand the role that labor markets play in determining the equity implications of locally targeted conservation policies that seek to take resources out of production. In this paper, we find that a relatively inelastic labor supply may lead to a divergence in welfare effects, such that the positive welfare effects of a conservation policy on resource owners are magnified at the cost of wages of agricultural workers.

This paper extends the emerging literature on the interactions between the labor market and policies designed for sustainable management of natural systems. Carbone et al. (2020) show that a carbon tax leads to the largest decline in employment in carbon-intensive sectors while employment increases in the least carbon-intensive sectors. However, they assume perfect mobility of labor between sectors in a region. Hafstead, Williams, and Chen (2022) provide a generic critique of this assumption. The impact of the 'China Shocks' and evidence from agricultural labor markets, show that the perfectly elastic labor supply assumption is overly simplistic when evaluating conservation policies. Most conservation policy analyses lacks a deep understanding of location-specific economic behavior in the context of local policy design. Many IAMs incorporate bio-physical interactions at a granular level, which is critical for assessing conservation policies, yet they tend to over-simplify economic behavior. Econometric approaches are limited in incorporating site specificity as well as the potential market-mediated feedback from local

conservation policies to regional and national markets. The method of analysis adopted in this paper provides important insights into the impact of a conservation policy in the context of policy design that is based on site specific bio-physical characteristics, firmly grounded in economic theory and a more thorough treatment of labor markets.

We begin by developing a stylized 2-input theoretical framework which enriches our understanding of the interactions between the agricultural labor supply elasticity and the effectiveness of conservation policies. We focus specifically on the distributional consequences for the three key interest groups in rural communities, namely: consumers, farmworkers and resource owners. Using this framework, we provide insights into the impact of a conservation policy seeking to remove over-exploited natural resources from agricultural production. We consider the impacts, at the national level as well as at a spatially disaggregated scale such as a county, or ‘grid cell’. The latter refers to a geo-referenced parcel of land commonly used in IAMs. This framework provides the theoretical foundation to investigate the results from our quantitative model (SIMPLE-G-CZ) and highlights the tradeoffs between different stakeholders in a rural community as a result of a natural resource conservation policy.

Our quantitative framework builds on the existing literature by extending the SIMPLE-G model (Baldos et al. 2020) to incorporate spatially explicit labor markets. Specifically, we employ the Commuting Zones (CZs) (Fowler, Rhubart, and Jensen 2016) widely used in labor economics (Autor, Dorn, and Hanson 2021; Burstein et al. 2020; Asquith et al. 2019). As the name suggests, SIMPLE-G is a gridded, partial-equilibrium model of agricultural production with explicit spatial detail on land use, ground and surface withdrawals, and nutrient leaching (Baldos et al. 2020). Variants of SIMPLE and SIMPLE-G have been used 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) and adaptation to climate change (Baldos and Hertel 2015; Lobell, Baldos, and Hertel 2013). In this paper, we use the concept of CZs, to delineate clusters of counties with strong commuting ties between residences and work to introduce labor market rigidities.

This paper makes three important contributions. First, 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. These propositions provide policy-relevant insights into the ‘winners’ and ‘losers’ from a natural resource conservation policy under different market conditions. Second, this framework provides a foundation, grounded in economic theory, to understand subsequent quantitative model results. Third, we extend the existing, gridded quantitative modeling of agriculture to incorporate spatially explicit CZs. We use this newly developed model, along with the attendant theoretical propositions, to examine in detail the consequences and distributional impacts of a spatially targeted groundwater sustainability policy in the Western US at the level of 75,000+ individual grid cells.

This paper is divided into seven sections. The next section introduces the theoretical model and develops propositions. The third section introduces the SIMPLE-G-CZ model. The fourth section describes the method of analysis and the groundwater conservation policy to be examined. This is followed by a discussion of model results using the insights developed in the theoretical model

and a section on sensitivity analysis of model results to the labor supply elasticity parameter. The final section concludes with discussion of 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 design 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 generate eco-system services. We implement this framework at two spatial scales i.e. aggregated at the country level and disaggregated at the ‘grid’ level with the latter modeling taking output prices as exogenous. This provides important insights into the distributional consequences of such policies and how they hinge critically on the functioning of agricultural labor markets.

While there are different ways to conceptualize a conservation policy within the theoretical framework, we implement it as a backward shift in the supply of natural resources embedded in A i.e. $\phi_A > 0$. This approach captures the voluntary nature of most conservation policies in the US and the implicit restriction on employing a combination of land and water resources into agriculture. Importantly, this leaves the equilibrium employment of irrigation-augmented land (A) 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 later) and 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 impacts of a conservation policy which implies that any increase in revenue, due to a positive (negative) change in p (e.g. due to an exogenous demand shock), 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 a function of the two input supply elasticities, the elasticity of input substitution and the cost shares. The first term in (4) 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*, a country with 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.

For example, as labor supply elasticity increases, so does the aggregate supply response, since with more elastically supplied inputs adjustments to output price changes are easier.

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: $q_j^D = q - \sigma(p_j - p)$ 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)

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

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

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

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

$\phi_L = 0, \phi_A > 0$

The second term in (4) captures the backward shift in the aggregate supply function in response to a natural resource supply shock. It shows that the magnitude of shift in q^S is adjusted by a scaling factor Γ_A , which accounts for the adjustments in both factor markets to the aggregate conservation shock discussed in Section 2.2. If the magnitude of Γ_A is smaller than 1, the backward shift in q^S is smaller than the relative magnitude of the conservation shock. As labor supply elasticity increases, the magnitude of the scaling factor increases ($\partial\Gamma_A/\partial v_L > 0$) and approaching 1 in the limit ($v_L \rightarrow \infty$). 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.

2.1 National Market Model with Endogenous Output Price

In this section, we implement the theoretical model at an aggregate level i.e., country level, and index the parameters with a ‘C’. We also introduce the country level agricultural demand curve (10) which interacts with the country level agricultural supply curve to determine the impact of a conservation policy on output prices. In Section 2.2 we use these country level outcomes to discuss the distributional effects of a conservation policy in rural communities.

Equation 10 shows the change in demand for national agricultural output (q^D) as a function of output price changes, absolute value of the price elasticity of demand (η^C) and exogenous demand shifters (z) such as population and income growth (Appendix A2). The equilibrium changes in aggregate commodity production (q^*) and price (p^*) due to the groundwater conservation policy is determined by the intersection of (4) and (10) (Appendix A3). Throughout this discussion, we will assume that the augmented-land supply elasticity is smaller than the labor supply elasticity, 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 has been estimated to be between 0.01 and 0.06 (Barr et al. 2011) while based on the most recent estimates (1990s to 2010s) of agricultural labor supply elasticity for the US, v_L^C ranges between 0.25 and 0.27 (Hill, Ornelas, and Taylor 2021). Equations 11 and 12 show that a conservation policy unambiguously leads to an increase in national level output price and aggregate agricultural production. As expected, a more restrictive conservation policy ($\phi_A^C > 0$) leads to a larger increase in output price (11) and consequently a greater fall in production (12).¹

¹ Appendix A3 shows
$$\begin{cases} \Gamma_\phi^C > 0 \Rightarrow p^* > 0 \& q^* < 0 \text{ if } v_L^C - v_A^C > 0 \\ \Gamma_\phi^C > 0 \Rightarrow p^* > 0 \& q^* < 0 \text{ if } v_A^C - v_L^C < \bar{v} \end{cases}$$

The national level model introduced here and discussed next are distinguished from a more disaggregated model with spatial specificity in Section 2.3. One important factor that distinguishes the two is that at the aggregate country level we allow output price to be endogenously determined. Later we assume output prices changes are exogenous when we implement at model at a disaggregated (grid cell) scale.

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

$$(11) \quad p^* = \phi_A^C \Gamma_\phi^C \quad \text{where} \quad \Gamma_\phi^C = \frac{1}{\frac{v_A^C}{\theta_A^C} + \eta^C \left[\frac{\theta_L^C (v_A^C + \sigma^C)}{\theta_A^C (v_L^C + \sigma^C)} + 1 \right] + \sigma^C \left[\frac{\theta_L^C (v_L^C - v_A^C)}{\theta_A^C (v_L^C + \sigma^C)} \right]} > 0 \text{ when } v_L^C > v_A^C$$

$$(12) \quad q^* = -\eta^C \phi_A^C \Gamma_\phi^C$$

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 immediate impact of a policy aimed at restricting land and/or water use in production is to raise the rental price of these natural resources. This, in turn, affects producers through two different channels.

First is the extensive margin, which is determined by the supply elasticity of natural resources (v_A^C). By raising the rental rate of A, there is an incentive to draw more of this resource into production for example by converting non-agricultural land into cropland or increase the depth of a well not targeted under the policy. A higher v_A^C will generate a greater extensive margin response. The second is 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 irrigation-augmented land. A higher v_L^C and 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 food prices. In addition to the exogenous policy shock, the magnitude of the output price increase is determined by a Γ_ϕ^C which depends on production side parameters including the country level

labor supply elasticity and price elasticity of demand (a consumption side parameter). If Γ_{ϕ}^C is relatively large, the positive change in output price will be larger and the magnitude of reduction in aggregate output is also larger. The incidence of the conservation policy on consumers varies with the aggregate labor supply elasticity and interacts with production and consumption side 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. 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. 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.*

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

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 (6). $\sigma^C > \eta^C$ ($\sigma^C < \eta^C$) implies that substitutability between aggregate inputs is more (less) elastic relative to the price elasticity of demand.

To gain greater insight, let us consider each of these cases in turn. Start with the situation in which input substitution is relatively larger ($\sigma^C > \eta^C$). 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 lower 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 a relatively higher labor supply elasticity, wherein wages rise more modestly.

Now consider the opposite case, wherein the substitutability between aggregate inputs is smaller than demand elasticity ($\sigma^C < \eta^C$). Now the presence of 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 more limited. Rather, producers respond on the extensive margin, further bidding-up the price of irrigation-augmented land. This leads to a higher output price increase compared to the case where labor supply is a relatively less elastic.

2.2.2 Agricultural Workers

As we have seen in equation (11), the immediate effect of a conservation policy is to raise the price of agricultural output, with the subsequent contraction in production depending on the price elasticity of demand. This leads directly to a loss of employment due to the reduction in irrigated area. *Ceteris paribus*, this leads to diminished labor demand in agriculture and lower wages. However, the more expensive irrigation-augmented land input also provides an incentive to substitute labor in an effort to better manage the irrigated land remaining in production. The strength of this effect is governed by the elasticity of substitution. Therefore, the relative size of these two parameters (σ^C and η^C), determine the impact of the conservation policy on wages (14) and employment (11).² This gives rise to Proposition 2.

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

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

$$(15) \quad q_L^* = \frac{v_L^C (\sigma^C - \eta^C)}{v_L^C + \sigma^C} p^* \quad (\text{Appendix A4})$$

If the elasticity of substitution is greater than price elasticity of demand, intensification of production by hiring more labor leads to higher wages (14) and employment (15). The extent of increase in wages and employment also depends on labor supply elasticity. When labor supply is relatively less elastic, there is a greater increase in wages (16) and employment (17). In the opposite case, when elasticity of substitution is smaller than price elasticity of demand, 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 (16) and employment (17). In this case, a less elastic labor supply leads to a smaller reduction in employment (17), 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).

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

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

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

2.2.3 Resource conservation and resource owners

Economic intuition dictates that returns to the irrigated land resource (p_A^*) must rise in response to a conservation policy which shifts its supply curve backwards and this is indeed the case in (18) (Appendix A4). Equation (19) shows that the impact of the conservation policy on irrigated land (q_A^*) is more complex. It depends first on how aggressive the policy is, as characterized by the backward shift in augmented land supply, $-\phi_A^C$. 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 by the first term on the right-hand side of (19).

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

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

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: $v_A^C \left[1 - \frac{\theta_L^C (\sigma^C - \eta^C)}{v_L^C + \sigma^C} \right] \frac{p^*}{\theta_A^C}$ 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 term, the sign of which once again hinges critically on the relative size of the input substitution elasticity and the elasticity of output demand. If the elasticity of substitution is relatively large ($\sigma^C > \eta^C$), then the 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 ($\sigma^C < \eta^C$), then the slippage effect becomes larger in the presence of less than perfectly elastic labor supply. But 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 and slippage effect (19). The slippage effect, in turn, depends critically on the labor supply elasticity.*

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

If the policy shock is dominant, there will be a fall in natural resource use (20). 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 in a sub-region untapped resources diverted to production is large enough to offset the conservation policy shock, leading to a boost in aggregate resource use.³

Table 1: Summary of the interactions between labor supply elasticity, input substitutability and demand elasticity underlying the implications of a natural resource conservation policy			
		$\sigma^C > \eta^C$	$\sigma^C < \eta^C$
(1)	(2)	(3)	(4)
A.	Food price (p^*)	Increase	Increase
	Smaller v_L^C	Magnifies	Dampens
B.	Agricultural Wages (p_L^*)	Increase	Decrease
	Smaller v_L^C	Magnifies	ambiguous
C.	Employment (q_L^*)	Increase	Decrease
	Smaller v_L^C	Dampens	Dampens
D.	‘Slippage’ effect $\left(v_A^C \left[1 - \frac{\theta_L^C (\sigma^C - \eta^C)}{v_L^C + \sigma^C} \right] \frac{p^*}{\theta_A^C} \right)$	Decrease	Increase
	Smaller v_L^C	ambiguous	ambiguous

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 resource 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, we focus on the percentage change in market returns to resource owners ($r_A^* = p_A^* + q_A^*$).

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

The necessary condition for a negative change in market returns to resource owners is a reduction in resource use. When change in resource use is positive (where the slippage effect is dominant),

³ We discuss spatial heterogeneity in the impact of a conservation policy in a subsequent section.

the change in returns to resource owners is positive. The sufficient condition for a fall in market returns requires that the absolute value of the reduction in resource use is greater than the rent increase (21). This holds when the ‘slippage’ augmented extensive supply response of A is smaller than the conservation policy shock (20). 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.

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

The impact of a conservation policy on rural communities depend on the interaction between the labor supply elasticity and the difference between input substitution elasticity and demand elasticity (Table 1). 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.

Two important insights from this discussion highlight the need for further research on these parameters to understand the distributional implications of a conservation policy. First, the zero-profit equation (3) determines the distribution of gains from higher output prices between the two inputs in inverse proportion of the input supply elasticity for the relevant input. This implies, for example, that under-estimating supply elasticity of natural resources may lead to an over-estimation of the increase in resource rents. Proposition 1 further shows that the incidence of food price increase depends on the interaction among labor supply elasticity, input substitutability and demand elasticity. If substitutability between inputs is more elastic than the price-responsiveness of food demand, consumers bear a greater burden of the policy consequences. Labor market rigidities accentuate this burden. However, the higher output price paid by consumers incorporates an increase in wages, which diminishes the increase in resource rents (Proposition 2). If the demand elasticity is greater than input substitutability and labor market rigidities are mitigated by higher labor supply elasticity, consumers bear a smaller increase in food prices. In this case, the increase in resource rents is larger than the output price increase since agriculture workers absorb a reduction in wages.

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. The size and distributional impact of the ‘slippage’ effect crucially depends on labor supply elasticity.

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 to regions with deteriorating natural resources and site-specific factors determine the magnitude of the policy shock. For example, only a sub-set of agricultural lands in the Mississippi River basin are suitable for wetlands and their efficiency in filtering

nutrients depends on a combination of bio-physical factors (Horvath et al. 2017). 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 abundant 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.

In the next section, we implement the same theoretical framework (Box 1) introduced in this section at the ‘grid’ level. This can leverage similar analytics in order to gain insight into the heterogenous local impacts of a conservation policy – taking commodity prices as exogenously determined, i.e., outside the grid.

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 country 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’ level (‘g’ notation omitted). A ‘grid’ in this paper is a geo-referenced 6-8 square kilometer parcel of land (or 5 arc-minutes often used in IAMs). 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. Though constant across grids, the common change in output price induces varied grid specific responses in input use (5 and 6), input price (7 and 8) and production (9).

By implementing the theoretical model at the disaggregated level we can distinguish between the ‘direct’ impact of a conservation policy in grids that are targeted ($\phi_A > 0$) and the ‘indirect’ impact on grids where the producers solely respond to the market-mediated output price change ($\phi_A = 0$).

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 outcome variables depends on the magnitude of the different terms in each equation. However, the indirect impacts are positive and referred to as ‘spillover’ effects. Grids indirectly affected by the conservation policy absorb some of the potentially adverse, direct economic impact of the policy. 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 $\left[p^* \frac{v_A}{\theta_A} + p^* \frac{\sigma}{\theta_A} - \phi_A \right]$. We find that the interaction between the labor supply

elasticity and the impacts of a conservation policy at the grid level depends heavily on this expression and therefore requires further attention. The first and second terms refer to the extensive and intensive margins of supply response to the output price change, and the third term refers to the direct impact of the conservation shock itself.⁴ When the grid level labor supply elasticity is less than perfectly elastic, each of these terms in (5) are scaled by $0 < \Gamma_L < 1$. The direction of change in employment (5) and wages (7) depends on total (extensive + intensive) supply response to output price change net of the conservation policy shock. If the conservation policy shock is

⁴ Under the perfectly elastic grid labor supply assumption the extensive margin response of L equals the same for A

where (23) collapses to $\left[p^* \frac{v_A}{\theta_A} - \phi_A \right]$.

dominant $\left[p^* \frac{v_A}{\theta_A} + p^* \frac{\sigma}{\theta_A} < \phi_A \right]$, the job losses due to the conservation policy shock lead to a fall in wages and employment in the grid. In the opposite case, if the total supply response is dominant $\left[p^* \frac{v_A}{\theta_A} + p^* \frac{\sigma}{\theta_A} > \phi_A \right]$, there is an increase in wages and employment in the grid (Appendix B2).

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 (5 and 7).

Proposition 4a summarizes the impact of labor market rigidities on wages, employment and resource rents in grids that are directly shocked. If the sum of total supply response (both intensive and extensive margins) is dominant, 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).

On the other hand, if the conservation policy shock is dominant, leading to a reduction in wages and employment, agricultural workers who continue to be employed in grids with lower labor supply elasticity absorb a greater reduction in wages, while the increase in resource rents is larger. In this case, greater labor market rigidities limit producers' ability to adjust to the shock, leading to a smaller reduction in employment (24).

Proposition 4a: *In directly affected grids, when 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 (23). If 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 (24) (Appendix B2).*

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

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

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).*

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

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).

The final impact of a conservation policy on natural resource use at the grid level (6), similar to the country level, depends on the relative magnitude of the ‘slippage’ effect (first term) and the ‘effective’ incidence of the shock (second term). Again, it is insightful to consider the case where

labor supply elasticity is perfectly elastic where (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 non-negative scaling factors: Γ_A and Γ_ϕ . These are both less than 1 and positively correlated with the labor supply elasticity parameter. The extensive supply response is scaled by Γ_A and the impact of the shock is scaled Γ_ϕ . Since these scaling factors are introduced as we deviate from the perfectly elastic labor supply assumption, the scaling factors represent the impact of endogenously determined wages on both terms in (6). For example, in case of the first term, 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), reducing the extensive margin 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 q_A and q_L as in (9), where 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 $v_L - v_A$, it accounts for competition between inputs to capture any increase in returns due to rise in output prices. Relative input supply elasticity determines 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. However, as in the case of (6), 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.

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^C	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

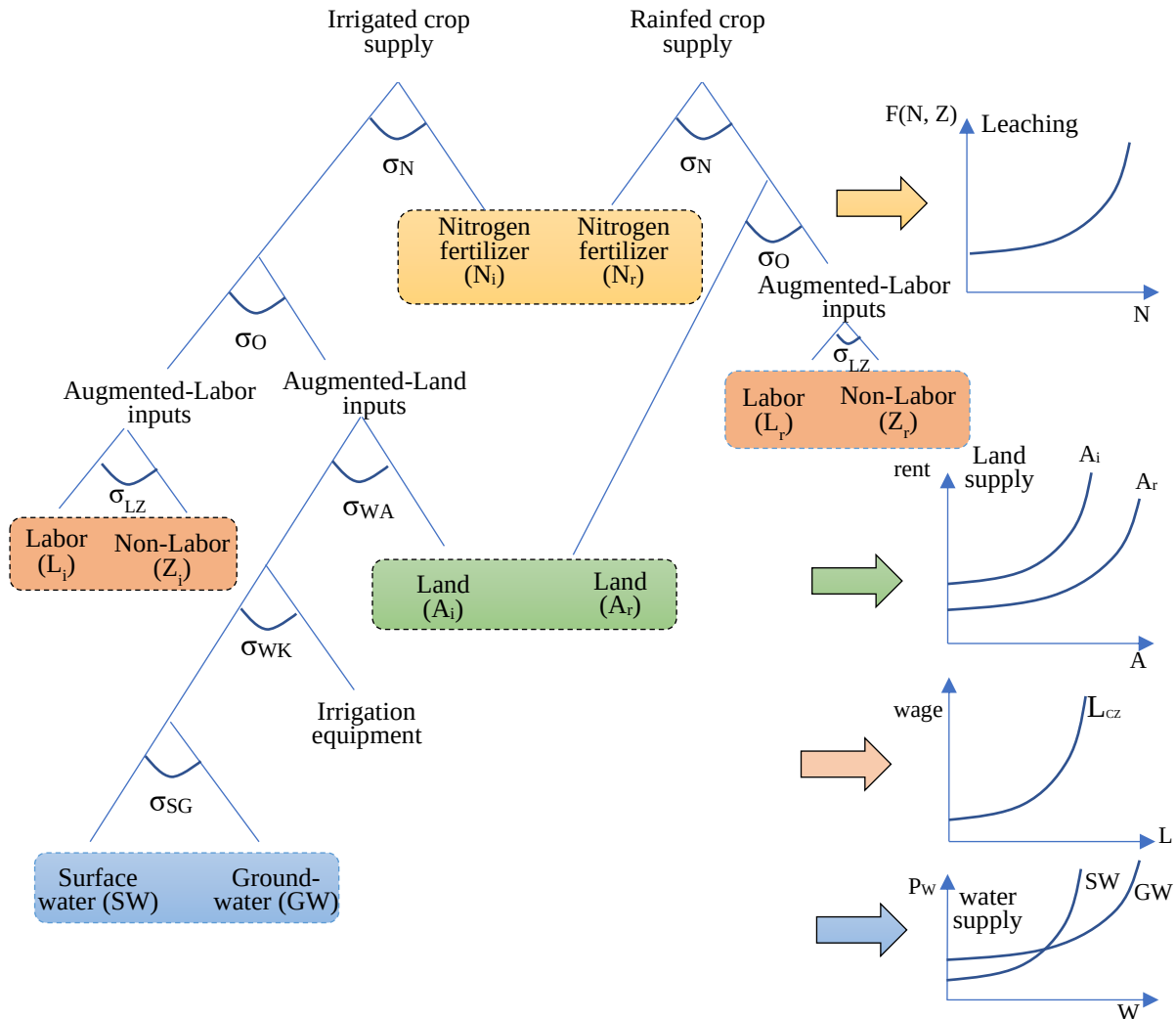
Application of the two-input model at the grid level enables us to drill down to a fine spatial resolution to evaluate the success of a spatially targeted conservation policy as well as welfare effects on agricultural workers and returns to resources. This discussion reinforces the point that labor market rigidities are critical to the effectiveness of a conservation policy. A less elastic 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.

Accurate characterization of local labor market behavior is also important to understand the distributional implications of conservation policies for rural communities and key stakeholders including consumers, agricultural workers and resource owners. 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.

3. Quantitative Model

With these analytical insights firmly in mind, we now move on to the quantitative model which 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, we model production at the level of individual grid cells. For this work, we take as a starting point the SIMPLE-G-US model documented in Baldos et al. (2020). This is a partial equilibrium model of agriculture, resource use and trade, which disaggregates US crop production into 75,000+ grid cells, each of which distinguishes between rainfed and irrigated agriculture.

Figure 1: Structure of Crop Production in each Grid in the SIMPLE-G-CZ model.

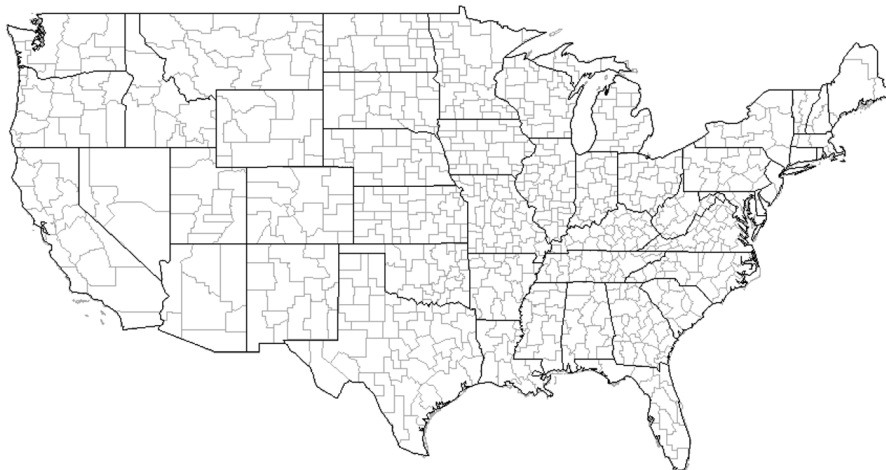


Note: Elasticity of substitution is shown by σ . The equilibrium quantity and price of land and water are determined at local level. Equilibrium wages are determined at local labor market sheds (commuting zones). Irrigated and rainfed practices compete for land. Land supply depends on total cropland supply and the elasticity of transformation between irrigated and rainfed.

Nested CES production functions (Figure 1) combine groundwater and surface water with irrigation capital to deliver water to irrigated crops which require nonland inputs and fertilizer to be produced. For this study, we disaggregate labor from the nonland inputs.

The crop composite is traded internationally, with production and consumption occurring in 17 world regions. The non-gridded version of this model provides the global context for this exercise. Dubbed SIMPLE (Simplified International Model of agricultural Prices Land use and the Environment) the global model has been validated against historical data (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).

Figure 3: Map of Commuting Zones in the Continental US (Fowler, Rhubart, and Jensen 2016)



Note: Light grey lines demark the boundaries of commuting zones which may cut across state borders drawn in black

As its name suggests, SIMPLE 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, cropland and food prices. SIMPLE is just a higher dimensional generalization of the national analytical model developed in Section 2. SIMPLE-G replaces US national crop supply with an equation summing crop supplies across irrigated and rainfed production in each of the 75,000+ grid cells in the US. In the non-US regions, the rainfed and irrigated production functions follow the same nested CES structure as in Figure 1. However, output of these two activities comprises total regional output (i.e., there is no gridded representation in the non-US regions).

A detailed discussion of model parameterization is provided in Baldos et al. (2020). For purposes of this paper, we focus on those parameters underpinning the equations shown in Table 2 and conduct sensitivity analysis to these specific parameters in Section 7. Land supply elasticities have

been estimated using grid level data across a wide range of agroecological zones (Villoria and Liu 2018), gridded groundwater supply response has been estimated by Haqiqi (2019), the local elasticity of transformation between rainfed and irrigated land within a grid cell is based on Jame and Bowling (2020) and depends on local water law. Finally, the gridded substitution elasticity between fertilizer and land is based on simulations of the Agro-IBIS agro-ecological model of production (Liu et al. 2018). The national price elasticity of demand for crops is a function of three categories of demand: food processing, livestock and direct consumption – both in the US and in the other 16 SIMPLE regions. The labor supply elasticity in this version of SIMPLE-G is simulated within the model after using the underlying structure of CZs. The gridded data come largely from USDA sources, with details provided in (Baldos et al. 2020).

Importantly for this paper, we have created local labor markets based on the commuting zones literature, which is widely used in labor economics (Fowler and Jensen 2020; Fowler, Rhubart, and Jensen 2016; Tolbert and Sizer 1996). CZs are clusters of counties grouped together based on the propensity of their residents to travel within the county cluster for regular employment (Figure 2). We recognize that generalized CZs may not be an accurate representation for some types of agricultural labor such as migrant labor; we adopt this approach as a logical starting point and highlight the importance of further research in this area. In the SIMPLE-G-CZ model, worker mobility across CZs is restricted, whereas workers are free to search for alternative job opportunities within a grid. The most recent agricultural labor supply elasticity (1990s to 2010s) is estimated to be in the range of 0.25 – 0.27 (Li and Reimer 2021; Hill 2020). A broader review of agricultural labor supply elasticity shows that these recent estimates are smaller than estimates from studies focusing on the middle of the 20th century (Hill, Ornelas, and Taylor 2021). We conduct sensitivity analysis on this parameter to account for uncertainties about the labor supply elasticity parameter due to types of agricultural labor and different methods of estimation.

4. Conservation Policy and Method of Analysis

The theoretical framework developed in this paper is suitable to model conservation policies that imply a restriction of natural resource use such as land or water in the agricultural sector. For the rest of this paper, we focus on a policy designed for sustainable management of groundwater systems in the Western US. We abstract from the complexities in the different approaches that can be used to manage common property resources such as groundwater (Madani and Dinar 2013) and focus on the consequences for rural communities of limiting groundwater extraction. 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 by 2050 (Baldos et al. 2020). We implement a policy shock targeting grids where annual groundwater abstraction is greater than the annual recharge rate, after accounting for the additional stressors of projected increase in population and income by mid-century. This policy limits groundwater withdrawal in each grid to its annual

recharge rate by the year 2050. Overall, the policy affects 68 percent of groundwater use in the continental US.

Figure 3: Grids affected by Sustainable Groundwater Conservation Policy Shock (% reduction in groundwater use)

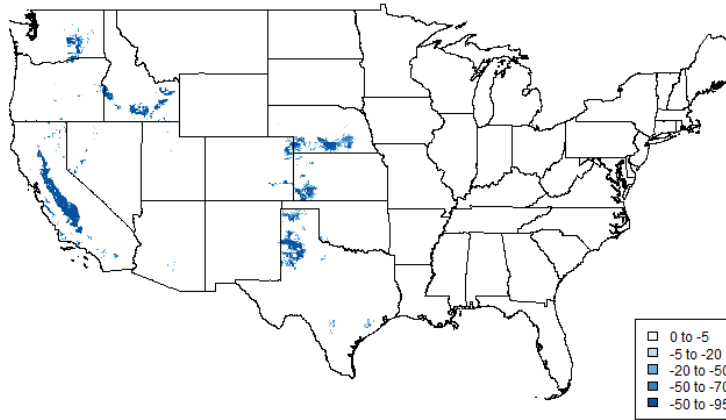


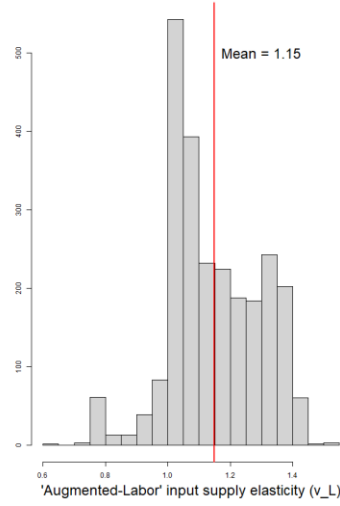
Figure 3 shows the grids affected by the policy located in well-known groundwater hotspots in the Western US. The magnitude of the conservation policy shock depends on projected levels of groundwater use and the annual recharge rate accounting for site-specific hydrological and biophysical characteristics. Under ‘business as usual’, half of the affected grid cells face groundwater supply shocks between 41 and 83 percent of the projected groundwater use in 2050, while a quarter are shocked by more than 83 percent. These severe supply-side shocks, highly localized to specific regions, are likely to have significant consequences on local communities.

In order to develop a deeper understanding of the consequences of conservation policies, grounded in economic theory, we use the theoretical model developed in this paper to decompose the numerical model results presented in the next section. 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 (Figure 1) – it nonetheless is capable of explaining the heterogeneous responses across grid cells.

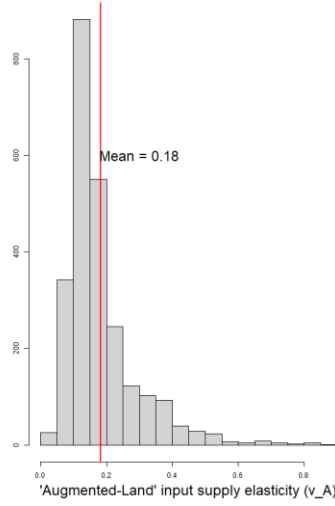
In order to leverage the insights from our theoretical model, we have developed a ‘bridging’ methodology which permits the analytical equations and propositions derived from the theoretical model to shed light on the numerical model results. This involves collapsing the SIMPLE-G-CZ model results into 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 not explicitly modelled in the SIMPLE-G framework. ‘Augmented-Land’ refers to the aggregate input including land and different sources of irrigation water in case of irrigated agriculture.

Figure 4: 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.

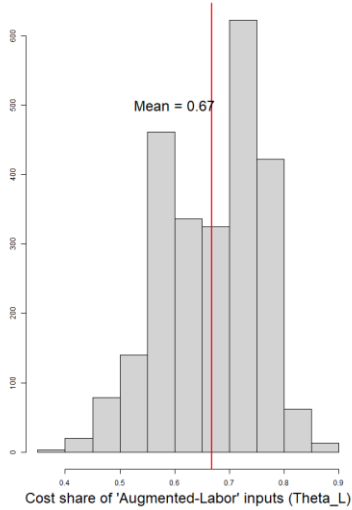
A: Distribution of ‘Augmented-Labor’ Supply Elasticity (v_L)



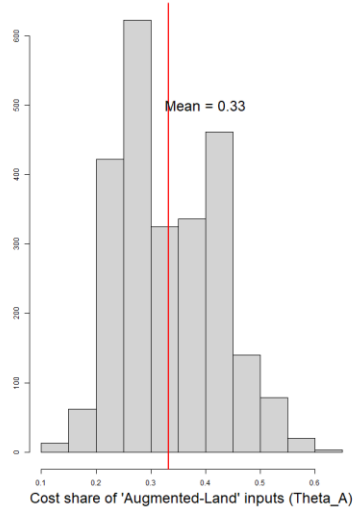
B: Distribution of ‘Augmented-Land’ Supply Elasticity (v_A)



C: Distribution of ‘Augmented-Labor’ Cost-Share Parameter (θ_L)



D: Distribution of ‘Augmented-Land’ Cost-Share Parameter (θ_A)



The change in ‘Augmented-Labor’ input 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’ input 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 these two composite inputs are critical to determining the impact of a groundwater conservation policy. We elicit them from the quantitative model by perturbing grid-level demands and observing the price and quantity responses of augmented labor and irrigation-augmented land. These two elasticities can then be interpreted as ν_L and ν_A in our theoretical model. This ensures that our gridded analytical results map directly to the aggregated results coming from the SIMPLE-G 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 structured across grids (Appendix C1).

Another critical step in the bridging exercise is the estimation of ϕ_A . The groundwater conservation policy is designed to restrict groundwater extraction, which is embedded within ‘Augmented-Land’ nest (Figure 1). The groundwater policy is imposed at the bottom level of the production function, and there is 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 shock to the land-water composite implied by a given value of ϕ_A in each grid cell (Appendix C2). With this, we have built the necessary ‘bridge’ between the theoretical model implemented at the grid level and the numerical results presented in the next section. In so doing, we can explain differences in outcomes across grid cells in terms of differences in economic and biophysical parameters pertaining to those grid cells.

5. Results

We present results from the SIMPLE-G-CZ model assessing the impact of the sustainable groundwater conservation policy targeting specific regions where the annual groundwater withdrawal rates are greater than the annual groundwater recharge rates (Haqiqi et al. forthcoming). We recognize that governance of groundwater use in agriculture is a complex collective action problem, plagued by high transaction costs (Ayres, Edwards, and Libecap 2018). However, in this paper, instead of focusing on the challenging question of how excessive groundwater might be limited, we focus instead on the consequences of such limitations for local economies. Our counterfactual experiment thus shifts the groundwater supply curve to limit withdrawals to groundwater recharge rates in targeted regions, then examine the impact on both national and local variables of interest.

At the national level, we assess the impact of the groundwater conservation policy in terms of changes in groundwater withdrawals for irrigation as well as changes in total crop production, area under production and output price. At the grid level, we use the analytics developed in this paper to decompose the model results to understand producer behavior and the competing forces at work at a spatially explicit scale in the face of a groundwater conservation policy shock. We also highlight the role of labor supply elasticities in determining the equity implications of the

conservation policy in rural communities. The analytical insights discussed above can be used to understand the impact of the conservation policy on irrigated agriculture specifically at the grid level, while the national level results include buffering responses, both by rainfed agriculture and by overseas producers.

5.1 National Results

The groundwater conservation policy leads to a 10.2 percent reduction in irrigated crop production corresponding to a 1.8 percent reduction in irrigated cropland (the targeted areas are also the most productive) and 3.1 percent reduction in employment in the irrigated sector (Table 3). Rainfed crop production in the US expands in the wake of this groundwater restriction, as observed in Haqiqi et al. (forthcoming), but with a smaller magnitude due to the explicit modeling of labor markets⁵. This verifies Equation (10) that predicts a reduction in irrigated production overall, with the ‘slippage’ effect (17) dominant at the national level. While overall cropland area cultivated decreases by 0.04 percent, the reduction in total crop production is disproportionately large at 2.6 percent, because the policy directly targets production in high yielding areas such as the Central Valley of California.

Table 3: National impact of the US Sustainable Groundwater Conservation Policy (%) on Irrigated and Rainfed Agriculture			
	Irrigated	Rainfed	Total
Crop Production	-10.2	1.6	-2.6
Cropland Area	-1.8	0.34	-0.04
Groundwater Withdrawal	-17	--	-17
Employment	-3.1	0.9	-0.8
Commodity Price	--	--	1.7
Wages	--	--	-0.2
Rent	--	--	0.01

The sustainability policy achieves a 75 percent reduction in groundwater extraction in the grids targeted by the conservation policy and a 17 percent reduction in total groundwater extraction nation-wide. As expected, this is a relatively modest reduction in groundwater withdrawals when compared with the 50 percent reduction estimated by Haqiqi et al. (forthcoming) from similar conservation policy but assuming perfect labor mobility. This difference highlights the importance of considering labor supply response when assessing conservation policies.

Figure 5 shows the spatial distribution of changes in groundwater use. Regions directly targeted by the conservation policy (Figure 3) show significant reduction in groundwater extraction (green grids). However, we also observe modest increases in groundwater extraction by up to 10 percent

⁵ Haqiqi et al. (forthcoming) also discuss the international spillovers of conservation policies implemented in the US.

in grids neighboring those that were directly shocked (orange grids). This implies that, in some grids within the same labor market, irrigated production increased moderately. This begs the question whether these grid cells might be drawing on the same groundwater aquifer – a point that requires further examination.

Figure 5: % Change in Groundwater Withdrawals

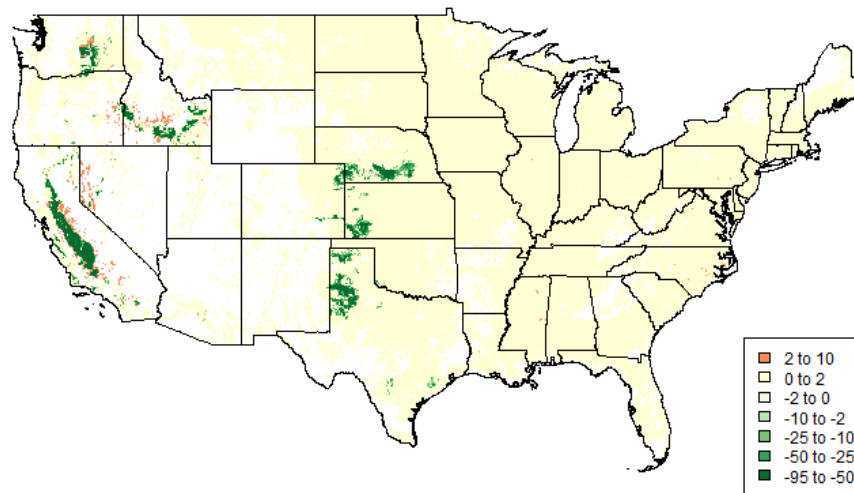


Table 3 shows that national level wages and employment fall by less than 1 percent and land rents increase by less than 1 percent. This confirms our hypothesis based on Proposition 2, that a conservation policy may have divergent impacts on agricultural workers (fall in wages and fewer employment opportunities) and resource owners (higher rents). However, the impact of the conservation policy on aggregate (national) wages and rents glosses over far larger local impacts in the communities targeted directly by the conservation policy. We next turn to a discussion of these impacts.

The largest reductions in irrigated production (darker reds in Figure 6A) are concentrated in California's Central Valley, and they are associated with the largest reductions in employment (Figure 6B). In some Central Valley grids irrigated production falls by up to 65 percent while employment falls by 40 percent. Figure 6 shows that some of the production shifts to neighboring grids (lighter green) and generates employment, though with a smaller magnitude of up to 5 percent. However, wages in the labor-sheds directly targeted by the policy fall by 10 - 35 percent in the Central Valley (Figure 7), much more than the national level reduction of 0.2 percent (Table 1). The change in wages depends on the degree of labor mobility (Section 2.2.2); assuming the labor supply is perfectly elastic completely overlooks these potential adverse impacts on agricultural workers.

Figure 6: Impact of the Conservation Policy on Irrigated Production and Employment (%) across all grids in the US

A: % Change in Irrigated Crop Production

B: % Change in Employment in Irrigated Production

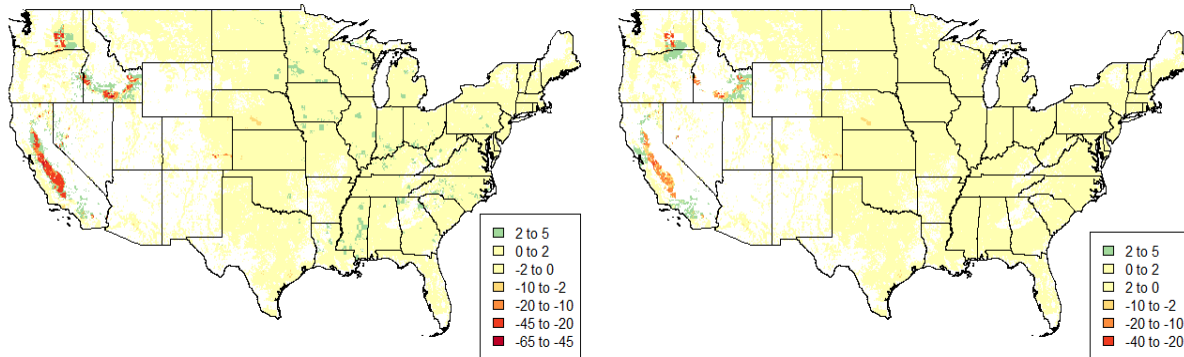
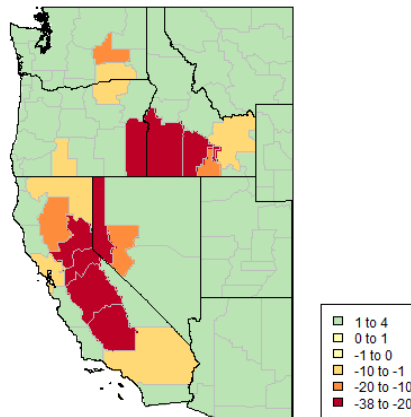


Figure 7: % Change in Wages in Commuting Zones in the Western US



Note: Grey lines in the map delineate commuting zone boundaries and black borders show state boundaries

5.2 Grid Level Results in the Central Valley of California (CA)

We focus on the Central Valley of California to discuss detailed grid level impacts of the groundwater conservation policy, because the policy shock is most severe in this region.⁶ In this section we use the insights from Section 2.3, the theoretical model applied at the grid level, to delve deeper into the site-specific impacts of the conservation policy and understand them in terms of site-specific parameters. In order to do so, we leverage the ‘bridging’ methodology described

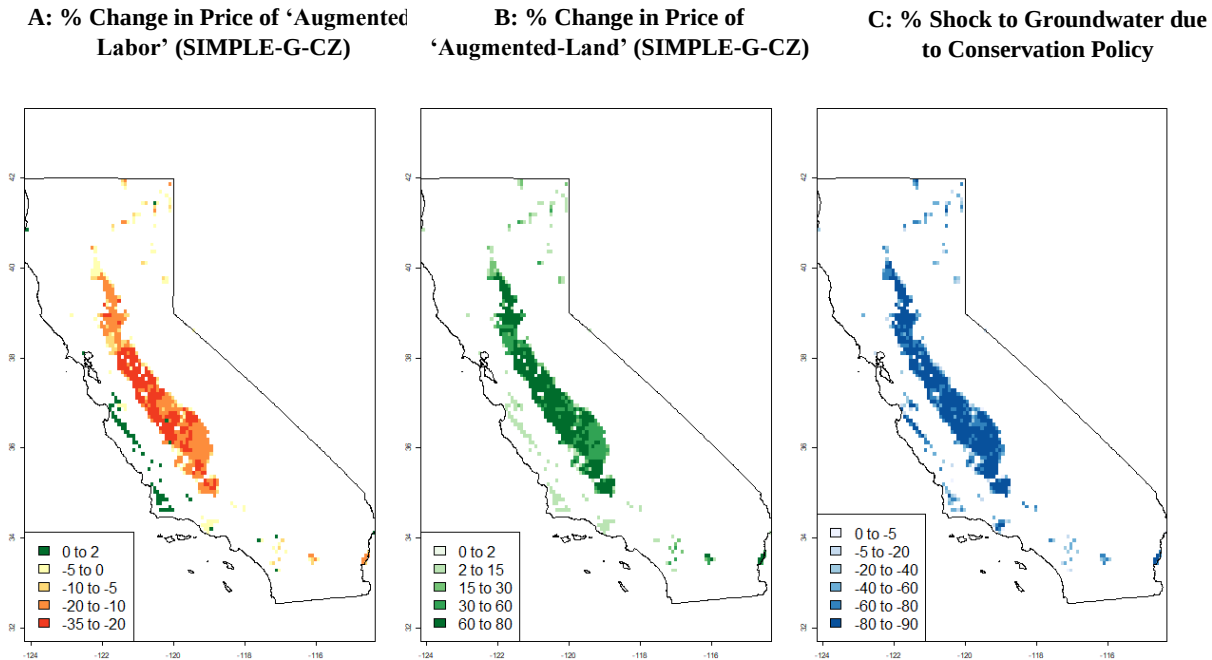
⁶ Similar exercises for other regions impacted by this policy can be readily produced

in Section 4. We discuss the gridded policy impact in terms of two composite inputs within the nested structure of the SIMPLE-G-CZ (Figure 1) model. First, ‘Augmented-Labor’ inputs, which proxies for the impact on labor, indexed with L in the theoretical framework. Second, ‘Augmented-Land’ input which refers to the impact of irrigated land use (and therefore groundwater) indexed with A in the theoretical framework. Then we use the analytical equations from the theoretical framework to disaggregate the observed results with well understood producer behavior grounded in economic theory.

5.2.1 Change in Wages and Resource Rent amongst Directly Affected Grids in Central Valley

Figure 8 shows the divergence in wages (8A) and resource rents (8B) in the directly affected grids (8C) of the Central Valley. Grids affected by a larger shock (darker blue in 8C) show a larger fall in wages (darker reds in 8A) and a higher increase in resource rents (darker greens in 8B). Resource rental rates increase up to 80 percent in some grids, and agricultural wages fall by 35 percent in the same grids.

Figure 8: Impact of a sustainable groundwater conservation policy on wages and resource rents in Central Valley, CA

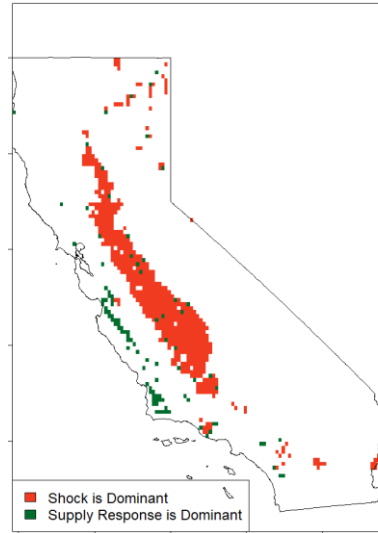


As expected from (8), the direction of change in resource rental rates is positive across the affected grids. In contrast, some agricultural workers’ wages increase by up to 2 percent. Proposition 4a shows that both resource rental rates and wages increase when the total supply response is

dominant i.e. $p^* \left[\frac{v_A + \sigma}{\theta_A} \right] > \phi_A$. Figure 9 shows that the grids experiencing higher wages in Figure 8 exhibit a dominant total supply response. However, in a majority of the grids affected by the conservation policy resource rents and wages diverge (Figure 8), due to the underlying condition that the conservation shock is dominant $p^* \left[\frac{v_A + \sigma}{\theta_A} \right] < \phi_A$ (Figure 9). Labor market rigidities widen the divergence in returns to different inputs, inasmuch as a relative inelasticity of labor supply magnifies the increase in rents and further dampens already distressed wages (Proposition 4a). Studies that do not explicitly model labor markets overlook potential equity implications spatially as well as between resource owners and agricultural workers. Under the perfect labor mobility assumption, we would erroneously assume that agricultural wages for all agricultural workers remain constant. However, Figures 8 and 9 show that, even in grids directly affected by the conservation policy, some agricultural workers may earn higher wages and there can be important labor market spillover effects across grids.

Figure 9: Map compares the relative sizes of the terms $p^* \left[\frac{v_A + \sigma}{\theta_A} \right]$ and ϕ_A , where

$p^* \left[\frac{v_A + \sigma}{\theta_A} \right] < \phi_A$ is indicated by red, green otherwise



5.2.2 Decomposition of Employment and Irrigated Land-Use Changes in Directly Affected Grids in the Central Valley

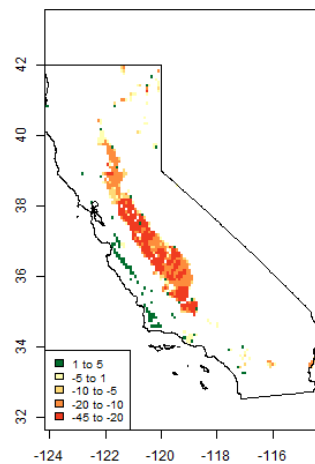
Figure 10A presents the change in ‘Augmented-Labor’ use in the grid cells directly affected by the groundwater conservation policy. Comparing Figure 10A and Figure 9 reveals that the change in agricultural employment is positive when the total supply response is dominant, and it

decreases when the policy shock is dominant (Proposition 4a). Employment increases up to 5 percent in a relatively small number of grids, whereas reductions in employment are as high as 45 percent.

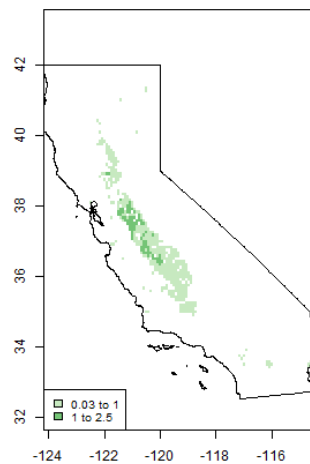
Using the ‘bridging’ methodology described in Section 4, we can delve deeper into the underlying factors driving change in employment shown in Figure 10A, based on equation 21. Appendix D verifies that Equation 21 closely approximates the numerical solution from the SIMPLE-G-CZ model.

Figure 10: Decomposition of the total impact on employment as a result of a conservation policy shock in Central Valley, CA

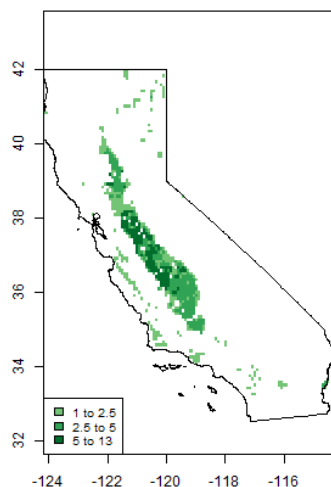
A: Analytical Estimation of Change in ‘Augmented-Labor’ aggregate Input use in the Central Valley with q_L (Equation 21)



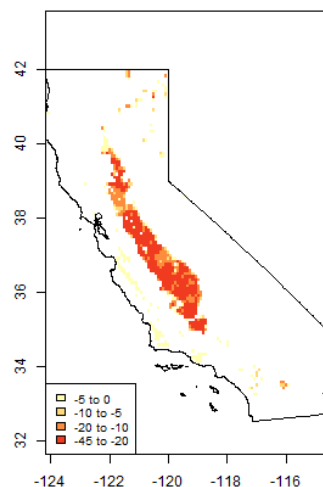
B: Extensive Margin (%) (Equation 21 – First Term)



C: Intensive Margin (%) (Equation 21 – Second Term)

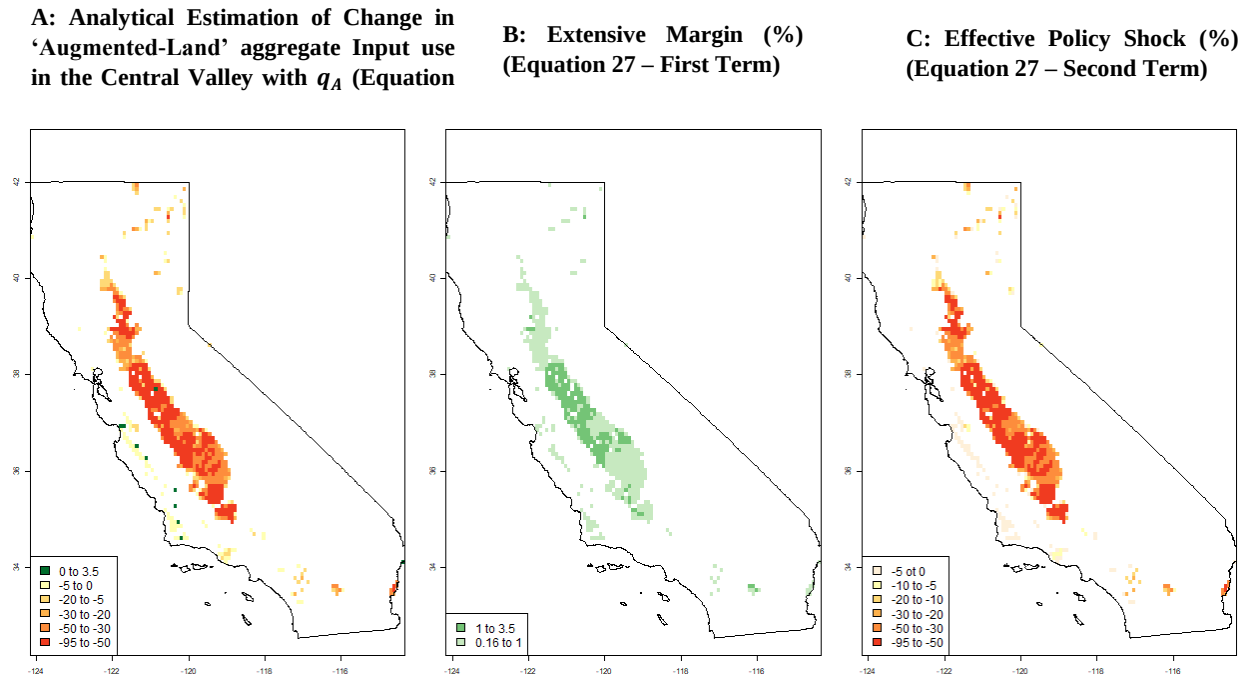


D: Effective Policy Shock (%) (Equation 21 – Third Term)



Panels B, C and D of Figure 10 decompose Panel A of Figure 10 into three terms with important underlying economic intuition, using Equation 6. The total change in employment (10A) is the sum of the extensive margin response (10B), the intensive margin response (10C) and the effective policy shock (10D). Comparison of panels A and D in Figure 10 shows that the negative effect of the policy shock is moderated by the extensive and intensive margin changes. In most grids, the intensive margin response has a greater impact on employment, ranging from 1 to 13 percent, while the impact of the extensive margin response is less than 2.5 percent across the affected region. This is not surprising due to the limited availability of alternative water resources that can be diverted into agriculture in the Central Valley. The intensive margin response to the conservation policy shock can mitigate some of the job losses in the directly affected grids. The labor supply elasticity is a crucial parameter underlying the intensive margin response in a grid. Proposition 4a highlights the complexity in the interaction between the labor supply elasticity parameter and intensity of the shock relative to the total supply response.

Figure 11: Decomposition of the total impact on ‘Augmented-Land’ input use as a result of a conservation policy shock in Central Valley, CA



A similar decomposition of the conservation policy’s impact on irrigated land use is shown in Figure 11. The total change in ‘Augmented-Land’ aggregate input (11A) is the sum of the extensive margin response (11B) and the effective incidence of the shock (11C). The reduction in irrigated agriculture is up to 95 percent, while the increase in irrigated agriculture is up to 3.5 percent. We see fewer grids with a positive change in resource use compared to the number of grids where employment increases (Figure 10A). The total impact on resource use (11A) closely

reflects the magnitude of the effective shock (11C), indicating a very small slippage effect. The extensive margin response, which underlies the slippage effect, is rather weak in Panel B, as also observed in Figure 10B.

The impact of labor market rigidities on the success of the conservation policy is ambiguous and difficult to trace out within the theoretical model. However, it is clear from (6) that Γ_A and Γ_ϕ are positively correlated with ν_L . A lower elasticity of labor supply deflates the extensive margin response (Figure 11B), further limiting the slippage effect, and it deflates the effective shock (Figure 11C). The relative magnitudes of these two effects determine the implications of a lower labor supply elasticity for the success of the conservation policy.

The primal form of the zero-profit condition (3) implies that the total change in production is the sum of change in employment (Figure 10A) and change resource use (Figure 11A) weighted by the respective cost-shares (Figure D2). The labor supply elasticity underlies the changes in use of both inputs. Therefore, it is also an important parameter explaining changes in total crop production as a result of a conservation policy shock.

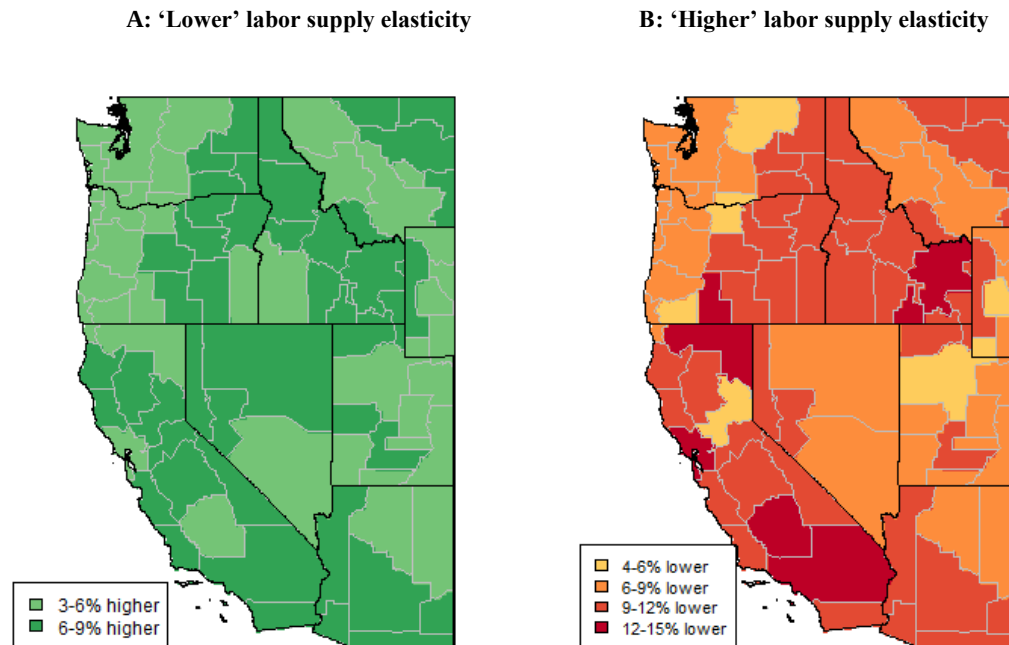
6. Sensitivity Analysis

The discussion above highlights the importance of modelling labor markets explicitly. Labor market rigidities can have significant implications for the success of conservation policies as well as shaping distributional effects of the policy in local labor sheds. Results from the SIMPLE-G-CZ model presented in this paper are based on three recent studies that estimate agricultural labor supply elasticities ranging between 0.25 and 0.27 (Li and Reimer 2021; A. Hill 2020; Richards 2020). However, these estimates are uncertain and can vary with types of agricultural labor, different estimation methodologies and temporal periods. In this section, we show the sensitivity of our numerical model results to the labor supply elasticity parameter based on the expansive review of agricultural labor supply elasticities in the US presented in Hill, Ornelas and Taylor (2021). In Table 4, we see that simulated impacts of a groundwater conservation policy at the national level are quite robust to the labor supply elasticity parameter.

Table 4: Sensitivity of National impact of the US Sustainable Groundwater Conservation Policy (%) to Labor Supply Elasticity						
	‘Lower’ Labor Supply Elasticity			‘Higher’ Labor Supply Elasticity		
	Irrigated	Rainfed	Total	Irrigated	Rainfed	Total
Crop Production	-10.3	1.6	-2.7	-10.3	1.7	-2.6
Cropland Area	-1.8	0.32	-0.06	-2.29	0.35	-0.71
Groundwater Withdrawal	-17.1	--	-17.1	-17	--	-17
Employment	-2.6	0.78	-0.72	-3.9	1.1	-1.04
Commodity Price	--	--	1.7	--	--	1.7
Wages	--	--	-0.19	--	--	-0.17
Rent	--	--	0.08	--	--	0.09
Note: ‘Lower’ and ‘Higher’ labor Supply elasticity refers to a lower (0.2) and upper (0.4) bound on the parameter based on review by Hill, Ornelas and Taylor (2021). The model simulations assume labor supply elasticity of 0.26.						

However, local level impacts of the policy are more sensitive. Figure 13 shows the deviation in wage changes resulting from the groundwater conservation policy when we consider ‘lower’ (Panel A) and ‘higher’ (Panel B) labor supply elasticities. Overall, rigidities in the labor market (reflected in a ‘lower’ labor supply elasticity) amplify wage changes (Panel A) shown in Figure 7, and vice-versa. Specifically, the labor-sheds highlighted in orange-red colors in Figure 7 are likely to face further reduction in wages by up to 9 percent if we under-estimate agricultural labor supply elasticity. Conversely, labor-sheds which observed increase in wages in Figure 7, may observe higher increase in wages. This underscores the importance of further research in this area to understand agricultural labor mobility, specifically for the different types of agricultural labor such as migrant vs domestic labor, an important distinction from which we have abstracted in this paper.

Figure 13: Sensitivity of Changes in Wages to Labor Supply Elasticity across CZs in Western US



Note: These results are relative to the wage changes presented in Figure 8. A 'lower' labor supply elasticity leads to greater increases in agricultural wages (green colors), while a 'higher' labor supply elasticity leads lesser increases in agricultural wages (orange-red colors).

7. Conclusion and Discussion

In this paper we develop a suite of conceptual and quantitative frameworks for studying the interplay between labor markets and conservation policies, thereby contributing to an emerging literature highlighting the importance of labor markets in the context of environmental policies more broadly (Hafstead, Williams, and Chen 2022; Carbone et al. 2020; Yip 2018). Furthermore, we use a novel approach in which the theoretical framework provides a roadmap for understanding the quantitative results from gridded SIMPLEG-CZ model. This 'bridging' methodology between the theoretical and numerical results, is employed by collapsing the SIMPLEG-CZ model to mirror the two-input theoretical framework and simulating the gridded parameters underpinning both the SIMPLEG-CZ model and theoretical framework. This allows for meaningful economic discourse, about the impacts of conservation policies on labor market outcomes, at a high spatial resolution. In the context of tightening agricultural labor markets (Charlton, Rutledge, and Taylor 2021), this is an important piece of conservation policy analyses that is largely missing in the current generation of Integrated Assessment Models.

At the national level, we show that the labor supply elasticity interacts with the relative size of the price elasticity of demand vs. the substitution elasticity between two the labor and non-labor inputs to determine the distributional impacts of a conservation policy. However, the national level

framework glosses over the heterogeneous local level impacts which characterize most conservation policies. At the grid level, we show that the impact on agricultural workers depends on the magnitude of the policy shock relative to the total supply response to elevated output prices. As expected, the returns to resources always increase, as a result of a conservation policy shock which induces resource scarcity. However, in the presence of labor market rigidities in those locations heavily targeted by the conservation policy, the decrease in wages (and employment) and the increase in resource rents are both magnified. On the other hand, in those locations where the commodity market spillover effect is dominant, labor market rigidities magnify the increase in wages (and employment) and dampen the increase in resource rents.

By explicitly modeling agricultural labor markets, we capture important heterogeneity in policy impacts. The sources of this diversity in outcomes can be systematically decomposed in terms of site-specific parameters, based on the economic theory laid out in this paper. In response to a policy shock, producers are likely to respond on the intensive margin by substituting the scarce resource with (the relatively cheaper input) labor, to mitigate some of the effect of the shock on output. The labor supply elasticity is an important parameter underlying the intensive margin response and therefore the overall impact of the policy.

Our focus on the key role of gridded economic parameters brings increased attention to the importance of accurately estimating these parameters at a fine spatial scale. Such fine-scale estimates can be obtained from observational data, as in Villoria and Liu (2018) and Chakravarty, Villoria, and Delgado (2020). However, it is also possible to obtain these parameters from simulation of appropriately validated biophysical models, as is the case for labor supply elasticities obtained by household models (Hill, Ornelas, and Taylor 2021) and elasticities of input substitution obtained from the Agro-IBIS model by Liu et al. 2018. Further improving the quality of these location-specific parameters will greatly enhance the accuracy and credibility of conservation policy assessments.

Finally, in this paper, we have abstracted from critical distinctions in the agricultural labor market, most importantly the distinction between types of agricultural labor such as migrant vs domestic farm workers and hired vs. family labor. Future research will disaggregate agricultural labor along these lines, recognizing that the functioning and extent of labor markets will likely vary by type of labor. Bringing labor into such multi-scale analyses of environmental policies will allow for improved targeting of such policies, while also bringing into the discussion the all-important equity dimensions of these policies.

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