Agricultural Labor Supply and the Impacts of Environmental Sustainability Policies

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Abstract

Gridded Integrated Assessment Models (IAMs) is a useful approach to model agricultural production using spatially explicit information on input use and simulate the impact of environmental sustainability policies. Notwithstanding the importance of labor markets in the agricultural sector, there has been limited focus on explicitly modelling agricultural labor. In this paper we highlight the importance of modelling agricultural labor market decisions at a spatially explicit scale since the nature of labor demand is closely linked to the crop produced on the farm. While agricultural labor markets are complex and constitutes of different types of labor, such as migratory, foreign-born, family and hired labor, it is important to realistically model labor market mobility. There is increasing evidence on agricultural labor shortages in advanced agricultural sectors and we argue here that labor immobility can dampen the impact of environmental sustainability policies. We present a version of the Simplified International Model of agricultural Prices, Land use and the Environment – Gridded (SIMPLE-G) by incorporating Commuting Zones that delineates a cluster of counties with strong commuting ties between residence and work.

We use this model to re-examine the impact of environmental sustainability policies presented in Baldos et al. (2020) which subsumes labor under into a composite input (i.e. non-land) which is implicitly perfectly mobile at the grid level. Preliminary analytical results from a two-input model shows that impact of such policies will be reduced at the grid level due to immobility of labor. In order to better understand the gridded results and delve deeper into the underlying structure, we propose a novel 'mini-model' approach. The 'mini-model' is extracted by leveraging the gridded market clearing structure of SIMPLE-G and using an analytically tractable number of grids. We use the 'mini-model' approach to identify policy levers that can alleviate environmental stresses.

1. Introduction

Integrated Assessment Models (IAMs) simulate interactions between human and natural systems and are being used to address the sustainability challenges posed by growing populations and rising incomes as they impinge on the world's land and water resources (United Nations 2019). While environmental stresses can be localized (e.g., groundwater depletion, biodiversity losses), the drivers of these stresses are global and local responses can feedback to national and global outcomes. In an effort to capture these global-local-global linkages, a growing family of models extends IAMs to finer spatial resolution using a 'gridded' approach (Baldos et al. 2020; Valin et al. 2013; Lotze-Campen et al. 2008). The gridded approach incorporates spatial heterogeneity in land and water characteristics underling agricultural production systems and sustainability challenges. IAMs within the gridded framework also allows modelers to explicitly account for site specific institutions and resource constraints while simulating the local-global-local responses to environmental policy interventions.

Gridded IAMs use different approaches to model agricultural production at a fine-scale using spatially explicit information on land, water and other inputs. However, agricultural labor, which constitutes anywhere from 15% (USA) to nearly 60% (Sub Saharan Africa) of costs in this sector (Aguiar et al. 2019) is typically neglected. The Global Biosphere Management Model (GLOBIOM) does not model labor costs

(IIASA 2018) while the Model of Agricultural Production and its Impact on the Environment (MAgPIE) assumes labor supply is perfectly elastic. The Simplified International Model of agricultural Prices, Land use and the Environment – Gridded version (SIMPLE-G) subsumes labor in a broader, non-land input category which is inelastically supplied at the national level, but freely mobile across grid cells.

In this paper we highlight the importance of modelling agricultural labor market decisions at a spatially explicit scale for two reasons. First, there is increasing evidence about farm labor shortages in the US and Europe as well as variation in labor supply elasticities by location, season and time frame (Taylor 2010). A review of agricultural labor supply elasticities with respect to farm wages by Hill, Ornelas and Taylor (forthcoming) shows labor markets are relatively inelastic in the short run (0.13-0.65) and more elastic in the long run (0.71-1.5). All of these estimates of labor supply elasticity are much lower than the perfectly elastic labor supply assumption implicit in the IAMs reviewed here. The long-run elasticity of farm workers could further decrease with economic development in rural Mexico, the pre-dominant source of farm workers in the US (Charlton et al. 2019). Second, the nature of agricultural labor demand is closely linked to the crop produced on the farm. Given the significance of labor to the agricultural sector, and the differences in the structure of labor markets across commodities and regions, it is important to incorporate spatially explicit estimates of labor supply to agriculture if we wish to understand the geographic impacts of sustainability policies. If labor is locally immobile, the response to limiting groundwater withdrawals, for example, is likely to be far more muted than if labor is geographically mobile.

First, we use a stylized sustainability policy in a standard two-input model to explore the analytics linking factor supply to production, land use and input intensity. This can be generalized to contrast implications of sustainability polices when labor is assumed to be perfectly mobile to a more realistic case of inelastic labor supply. Second, we build on previously published work to draw out the implications of grid cell-specificity in labor supply for a groundwater sustainability policy in the Western US. We overlay the map of commuting zones (Fowler, Rhubart, and Jensen 2016; Tolbert and Sizer 1996) on the gridded structure of SIMPLE-G to restrict the mobility of labor across commuting zones. Third, we propose a novel 'mini-model' framework which provides a more complete understanding of large scale, gridded modeling applications.

The rest of the paper is divided into four sections. In the next section we briefly describe the SIMPLE-G model (Baldos et al. 2020) and role of commuting zones to incorporate grid specific labor mobility. In the third section we present the theoretical and practical implications of the perfectly elastic labor supply assumption. In case of the former, we use a standard 2 input model and a stylized groundwater sustainability policy. For the latter, we use a combination of results from the 'mini-model' approach and full model results. The 'mini-model' approach allows us to preview the implications of relaxing the perfectly mobile labor supply assumption useful to interpret the results from the full model. In the final section we discuss the findings in this paper in the context of sustainability policies.

2. Methodology

In this paper we build on the SIMPLE-G which is a fine-scale partial equilibrium, agricultural trade model (Baldos et al. 2020; Baldos and Hertel 2013) by introducing commuting zones (Fowler, Rhubart, and Jensen 2016; Tolbert and Sizer 1996) that delineate local labor markets.

The underlying production structure in SIMPLE-G includes gridded biophysical and economic relations and incorporates local heterogeneity in climate, soils, water and institutions while capturing global change drivers and feedbacks for local adaptations to national and international markets. SIMPLE-G uses a nested production structure to model land, water, fertilizer and other inputs use where gridded optimization determines crop production. Labor cost is included in non-land inputs with a national market which implies that at each labor supply is perfectly elastic. Review of agricultural labor supply have shown that labor markets in the short-run are fairly inelastic (0.13-0.65) and more elastic in the long-run (0.71-1.5) but far from being perfectly elastic (Hill, Ornelas and Taylor (forthcoming)).

Commuting zones have been used in the literature to model the impact of trade (Autor, Dorn, and Hanson 2016), immigration (Burstein et al. 2020) and public policy (Dupor and McCrory 2018) on heterogenous local labor markets. Commuting zones refer to geographic delineations of counties with strong commuting ties. Commuting zones were first developed based on the 1980 US Census and updated subsequently (Tolbert and Sizer 1996). A map of commuting zones shows the geographic extent of regional labor markets in terms of a cluster of counties where workers reside and regularly travel to work. Commuting Zones were introduced since other geographic units such as counties, metropolitan area or states are inadequate to represent the geographical extent of local labor markets (Fowler, Rhubart, and Jensen 2016).

In this paper, we use the latest map of commuting zones to identify grids that belong to each commuting zone. This allows us to model local labor markets within which labor is assumed to be elastically but imperfectly mobile, while restricting movement of labor across commuting zone borders. While this approach to modelling local labor markets have been widely used, in case of agricultural labor it subsumes the vast variation in the types of agricultural labor (Hill, Ornelas and Taylor forthcoming). Explicitly modelling the different types of agricultural labor is difficult given its complex nature, econometric challenges and data limitations. We use this approach to relax the unrealistic assumption of perfectly elastic labor supply in the nested production structure of the SIMPLE-G. Future model developments can include broad distinctions of agricultural labor such as family or hired labor.

3. Results

3.1 Analytical model and theoretical results

In this section we consider the case of a two input, grid-level production function for agricultural crops. We will name the two inputs 'augmented land' (A) and 'labor' (L) for convenience. Assuming constant returns to scale, and a constant elasticity of substitution production function, we derive the linearized crop supply response (q) in each grid (subscript omitted) in response to a backward shift in augmented land supply ($-\phi_A$) due to a conservation policy (e.g. limiting groundwater use). Equation 1 is a function of supply elasticity of A (v_A), elasticity of input substitution (σ), and share of A in total production cost (θ_A), under the assumption of perfectly elastic supply of L.

(1) $$q=\left[\frac{v_A+\sigma-\sigma\theta_A}{\theta_A}\right]p-\phi_A=\left[\frac{v_A+\sigma\theta_L}{\theta_A}\right]p-\phi_A$$

Equation 2 provides the supply response when L also has a gridded inelastic supply response (v_L). The second element in the denominator for both terms on the right-hand side approaches zero as $v_L \to \infty$ and reduces to Equation 1. The inelastic gridded L supply reduces the supply response to the exogenous policy shocks, as expected. Therefore, the shift of output across grid cells, as a result of a conservation policy, will be diminished in the presence of inelastic labor supply.

(2) $$q=\left[\frac{1}{\frac{\theta_A}{v_A+\sigma}+\frac{\theta_L}{v_L+\sigma}}-\sigma\right]p-\frac{\phi_A}{1+\frac{(v_A+\sigma)}{(v_L+\sigma)}\frac{\theta_L}{\theta_A}}$$

Equation 1 shows that crop supply response is higher when augmented land supply is more elastic, substitution between two inputs is more elastic and cost share of augmented land is lower. In case of Equation 2, when labor supply is inelastic the relative magnitudes of the parameters determine crop supply response.

Another implication of incorrectly assuming gridded labor supply to be perfectly elastic can be observed from the structure of Equation 1. The crop supply response in Equation 1 is a magnification of $[v_A+\sigma\theta_L]p$ by the inverse of augmented land cost share net of the shift in augmented land supply. This implies that in grids with labor intensive production structure, and therefore relatively small augmented land cost, for instance 50 percent, the crop supply response is $2*[v_A+\sigma\theta_L]p$. This is a rather restrictive structure which is relaxed in Equation 2 by explicitly modelling inelastic labor supply.

3.2 Mini-Model

Gridded IAMs, including the SIMPLE-G, is an excellent tool to evaluate policy alternatives with spatially explicit information on land, water and other inputs. It provides a richer understanding of the intended and unintended consequences of a policy. However, with improvements in data availability and computing power, finer-scale gridded analysis generates model results for tens of thousands of grids. For example, the SIMPLE-G (Baldos et al. 2020) uses 5 arc-min grids for the contiguous United States which implicitly refers to 75,651 individual grids for a single country. On-going research further increases the grid resolution leading to a corresponding increase in the number of grids of analysis. The spatially explicit results generated from gridded IAMs are often presented in global or regional maps. However, maps might be insufficient to delve deeper into the underlying characteristics leading to specific outcomes in a grid. Therefore, we introduce a novel 'mini-model' approach which can be used to present, evaluate and discuss specific results from a gridded IAM such as SIMPLE-G.

The flexibility of the 'mini-model' approach allows the user to explore the results of a gridded simulation based on their interest in an analytically tractable number of grids (such as 10). The mini-model exploits the gridded market clearing structure of the SIMPLE-G and extracts the selected grids based on the following principles:

1. Market of inputs that are strictly spatially tied (such as land and water) clear at the grid level,
2. Market of inputs that are not spatially tied (such as fertilizer) clear at the national level, and
3. Market of output clear at the national level.

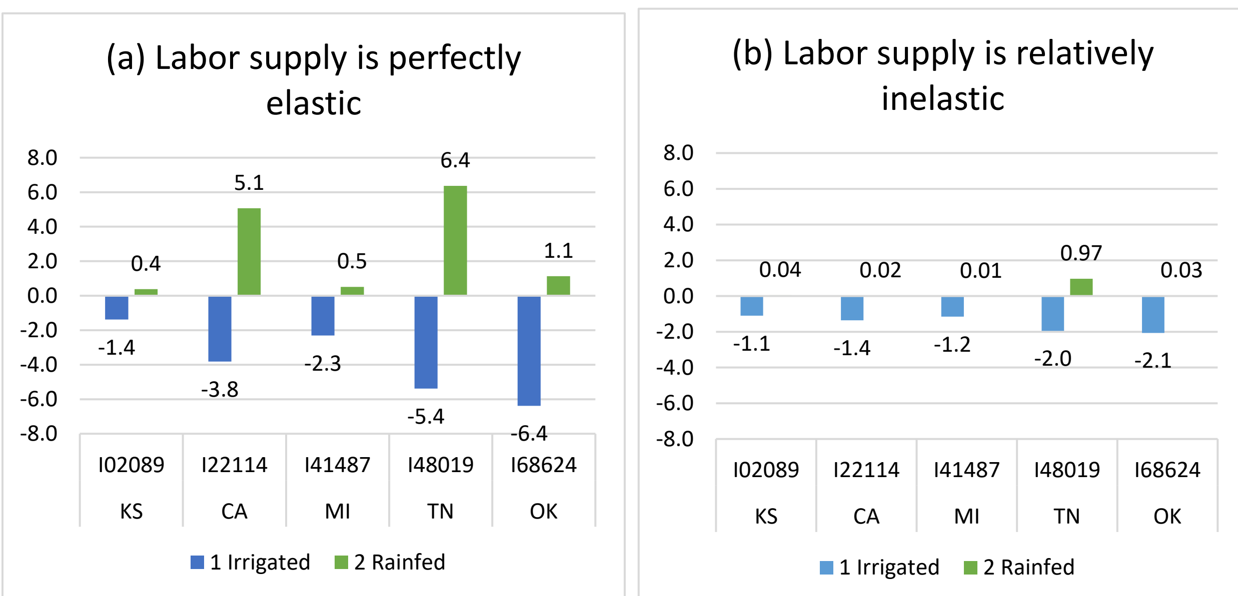
A 'mini-model' based on these principles replicate the gridded results of the SIMPLE-G for each selected grid with the exception of output price and prices of input markets clearing at the national level (fertilizer). Other gridded model parameters (such as labor and land supply elasticities) are also embedded in the 'mini-model' allowing the user to explore in detail the grid level bio-physical, agronomic, economic and institutional characteristics that explain the observed outcome.

Figure 1 shows the impact of a groundwater sustainability policy that restricts water withdrawal from a mini-model simulation for a single grid in five different states (Kansas, California, Michigan, Tennessee and Oklahoma). Panel (a) shows the crop supply response to the policy when labor, and other non-land inputs, are assumed to have perfectly elastic supply. Panel (b) shows the crop supply response to the policy when labor, and other non-land inputs have a relatively inelastic labor supply. Comparison between the two panels shows stark differences in the magnitude of response as a result of the perfectly elastic labor supply assumption.

Overall, irrigated cultivation falls due to limitation on groundwater extraction. However, in Panel (b) the changes are far muted compared to Panel (a). This follows the expectation from the analytical observations from Equations (1) and (2).

In some grids, the difference in response between Panels (a) and (b) is quite stark. For example, in California and Tennessee it appears cultivation shifts from irrigated to rainfed cultivation since the policy leads to a 5.1 and 6.4 percent increase in rainfed cultivation, respectively. However, when we relax the perfectly elastic labor (and non-land inputs) supply assumption, the impact on rainfed cultivation is negligible. This is because the free labor movement assumption is compounded by other institutional and bio-physical characteristics that unrealistically allows a relatively cost-less shift between irrigated and rainfed cultivation. This further highlights that the impact of the perfect labor mobility assumption can vary spatially and is difficult to predict without more explicit modelling.

Figure 1: Mini-model results: Impact of a policy that restricts groundwater restrictions on crop supply (%)



3.3 SIMPLE-G with local labor markets

In this section, we replicate the groundwater conservation policy analysis presented in Baldos et al. (2020) with updated data from 2017. Next, we compare the implication of the same conservation policy when labor markets are explicitly modeled. This is work in progress.

4. Discussion and Conclusion

Results of the first analytical exercise described above highlight the importance of modelling labor market supply on a spatially explicit scale. Analytical results from the 2 inputs crop production structure shows that the assumption of perfectly elastic labor supply leads to a larger crop supply response when, the cost-share of L is high, A is in relative abundant supply, inputs are good substitutes and true labor supply is inelastic. The 'mini-model' simulation which models the scomplex production structure further reiterate these findings.

We argue that, under the perfectly elastic gridded labor supply assumption, grid level output responses to environmental restrictions are over-estimated. Under the more realistic case of imperfect labor mobility, the responsiveness of production to the sustainability policy is more muted. This is further explored in the simulation exercises described in the previous section which highlights the spatial impact of conservation policies.

References

Aguiar, Angel, Maksym Chepeliev, Erwin L. Corong, Robert McDougall, and Dominique van der Mensbrugghe. 2019. “The GTAP Data Base: Version 10.” *Journal of Global Economic Analysis* 4 (1): 1–27. https://doi.org/10.21642/JGEA.040101AF.

Autor, David H., David Dorn, and Gordon H. Hanson. 2016. “The China Shock: Learning from Labor-Market Adjustment to Large Changes in Trade.” *Annual Review of Economics* 8 (1): 205–40. https://doi.org/10.1146/annurev-economics-080315-015041.

Baldos, Uris Lantz C., I. Haqiqi, T. W. Hertel, M. Horridge, and J. Liu. 2020. “SIMPLE-G: A Multiscale Framework for Integration of Economic and Biophysical Determinants of Sustainability.” *Environmental Modelling & Software* 133 (November): 104805. https://doi.org/10.1016/j.envsoft.2020.104805.

Baldos, Uris Lantz C., and Thomas W. Hertel. 2013. “Looking Back to Move Forward on Model Validation: Insights from a Global Model of Agricultural Land Use.” *Environmental Research Letters* 8 (3): 034024.

Burstein, Ariel, Gordon Hanson, Lin Tian, and Jonathan Vogel. 2020. “Tradability and the Labor-Market Impact of Immigration: Theory and Evidence From the United States.” *Econometrica* 88 (3): 1071–1112. https://doi.org/10.3982/ECTA16196.

Charlton, Diane, J Edward Taylor, Stavros Vougioukas, and Zachariah Rutledge. 2019. “Innovations for a Shrinking Agricultural Workforce,” 8.

Dupor, Bill, and Peter B. McCrory. 2018. “A Cup Runneth Over: Fiscal Policy Spillovers from the 2009 Recovery Act.” *The Economic Journal* 128 (611): 1476–1508. https://doi.org/10.1111/ecoj.12475.

Fowler, Christopher S., Danielle C. Rhubart, and Leif Jensen. 2016. “Reassessing and Revising Commuting Zones for 2010: History, Assessment, and Updates for U.S. ‘Labor-Sheds’ 1990–2010.” *Population Research and Policy Review* 35 (2): 263–86. https://doi.org/10.1007/s11113-016-9386-0.

IIASA. 2018. “GLOBIOM Documentation.” 2018. https://iiasa.github.io/GLOBIOM/#model-documentation.

Lotze-Campen, Hermann, Christoph Müller, Alberte Bondeau, Stefanie Rost, Alexander Popp, and Wolfgang Lucht. 2008. “Global Food Demand, Productivity Growth, and the Scarcity of Land and Water Resources: A Spatially Explicit Mathematical Programming Approach.” *Agricultural Economics* 39 (3): 325–38. https://doi.org/10.1111/j.1574-0862.2008.00336.x.

Taylor, J. Edward. 2010. “Agricultural Labor and Migration Policy.” *Annual Review of Resource Economics* 2 (1): 369–93. https://doi.org/10.1146/annurev-resource-040709-135048.

Tolbert, Charles M., and Molly Sizer. 1996. “US Commuting Zones and Labor Market Areas: A 1990 Update.”

United Nations. 2019. “Global Sustainable Development Report 2019: The Future Is Now – Science for Achieving Sustainable Development.” https://sdghub.com/project/global-sustainable-development-report-2019-the-future-is-now-science-for-achieving-sustainable-development/.

Valin, Hugo, Petr Havlík, Niklas Forsell, Stefan Frank, Aline Mosnier, Daan Peters, Carlo Hamelinck, and Matthias Spöttle. 2013. “Description of the GLOBIOM (IIASA) Model and Comparison with the MIRAGE-BioF (IFPRI) Model,” 39.