Market-mediated effects: What are they? And why are they important for geospatial analysis of sustainability policies

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Abstract— *Market-mediated effects can mitigate or amplify the intended effects of sustainability policies. They can also have unintended consequences, including inducing new sustainability stresses or threatening food security. It is important to understand these effects when designing sustainability policies. This paper provides prominent examples of market-mediated effects of a variety of sustainability policies in the food, energy, land and water nexus. This paper reviews the empirical evidence on market-mediated impacts of economic policies generally and then provides a review of recent geospatial modeling aimed at capturing these impacts in the context of local and regional land and water sustainability policies. The paper also discusses the challenges of designing sustainability policies that are effective in the face of market-mediated effects*.

Keywords: conservation, natural resources, sustainability policies, market-mediated effects, spillover effects, leakage, unintended consequences.

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I. Introduction

Sustainability policies are increasingly being implemented in an effort to address environmental and societal challenges. Nowhere is this more evident than on the global commons where the future of water and land resources and associated ecosystem services is being determined. To be effective, such policies must be tailored to local hydrological, ecological and socioeconomic conditions. Yet such local interventions can alter the availability – and demand for—marketed goods and services. This, in turn, alters prices, and prices communicate across local, national – and even global – boundaries. We term these 'market-mediated' effects of sustainability policies. These changes can lead to unintended consequences, including new sustainability stresses. This paper reviews some of the empirical evidence on market-mediated impacts of sustainability policies generally, and then provides a review of recent geospatial modeling aimed at capturing these impacts on the context of local and regional land and water sustainability policies. We find that market-mediated effects can mitigate the intended effects of sustainability policies and amplify the unintended consequences. The paper also discusses the challenges of designing sustainability policies that are effective in the face of market-mediated effects.

II. Market-mediated effects: what is the evidence?

It is natural to start this discussion by asking the simple question: Can these market-mediated effects be observed? If so, what evidence do we have that they convey significant information across geographical boundaries? By definition, market-mediated effects work through prices, so to understand them we need to be able to explain commodity and factor price movements. This is a challenging task and one that many individuals spend a great deal of time trying to do – with only limited success. We focus here on the most prominent episode of commodity price movements over the past two decades – the food price crisis of 2007/8. During this period, prices doubled – and even tripled in some cases – before declining in 2009, and then rising again in 2010 [1].

In an effort to understanding the drivers behind the 2007/8 commodity price boom, three professors from Purdue University: Philip Abbott, Christopher Hurt and Wallace Tyner wrote a series of papers seeking to tease out the different forces at work [1]–[3]. The most notable development over the period leading up to this price spike was the implementation of a biofuels mandate in the United States [4] and many observers attributed the entirety of the commodity boom to the biofuels mandate. However, as Abbott, Hurt and Tyner explain, there were other factors at work as well, including low levels of commodity stocks – which make any perturbation to demand much more volatile – adverse weather in key supply regions, macro-economic drivers of exchange rates, and a closer tie to energy markets (especially oil) which were also booming at the time. In short, it is not straightforward to tease out exactly what led to the commodity price boom. However, one thing was abundantly clear – the world outside the US responded to these elevated commodity prices by converting more land and expanding agricultural production. This is a clear example of a market-mediated phenomenon subsequently dubbed 'Indirect Land Use Change' or ILUC. ILUC is now a widely appreciated side-effect of policy interventions in agriculture and forestry.

In an effort to better understand how supply and demand developments in the US market influence decision making overseas, Villoria and Hertel [5] undertook a statistical study relating developments in the US coarse grains market (largely maize) to changes in coarse grains area planted in the following year in other countries around the world. They find a strong relationship between changes in US prices and future land use change elsewhere. What is particularly interesting is the pattern of influence. It is by no means uniform, rather there is a distinct geography to this market-mediated impact of developments in the US. In particular, those countries that are closely linked to the US through existing trade flows (imports or exports), as well as those countries that compete with the US in third markets, are most strongly influenced. This is consistent with the so-called 'Armington model of trade' which is widely used in simulation models of world commodity trade [6]. After estimating this model, Villoria and Hertel [5] proceed to examine how a US market shock like the biofuels boom is transmitted to land use change elsewhere in the world. They find that previous studies, which had treated global markets as relatively uniform (the 'integrated markets hypothesis'), were seriously flawed because they ignored the underlying geography of international trade.

III. Groundwater Sustainability Policy and Regional Crop Markets

Market-mediated effects play a central role in groundwater sustainability debates. On one hand, groundwater is becoming increasingly important for irrigated crop production. This is due to a number of factors, including population growth, climate change, the increasing demand for water-intensive crops such as rice and wheat, and the reliability of groundwater resources compared to surface water. In response to these pressures, policies aimed at restricting groundwater use to sustainable levels have been proposed. However, these have raised concerns about food insecurity. These concerns are valid at the local level, as groundwater is a vital source of irrigation water for many farmers. However, it is less important at the regional level. The extent of the regional impact depends on multiple factors, such as the possibility to perform deficit irrigation or convert to rainfed, the availability of other water resources, the economic connection to the world, and socio-economic conditions of the location.

Several comprehensive quantitative analyses are conducted to evaluate the impact of these policies on food systems considering market-mediated impacts [7], [8] They argue that the economic and biophysical effects of groundwater sustainability policies can be complex. They show that within a multi-scale, multi-system framework that take into account the full range of these effects, market-mediated responses can mitigate the impact of groundwater sustainability policies. A sustainability restriction can increase local competition for the available water. This will cause an increase in production costs and irrigation expenditure. Depending on changes in relative prices (across space), there are various market-mediated responses that help to reduce the impact of the irrigation shortfall. These responses include surface water substitution, expansion of rainfed production, relocation, and virtual trade in blue water. Haqiqi et al. [8] demonstrate that, over the long run, local impacts are largely ameliorated at the global level due to local, regional and global adaptations through market connections.

Due to market mediated responses, a groundwater sustainability policy at one location can shift the spatial pattern of crop production, which could have environmental impacts in other parts of the world. Further, restrictions on irrigated agricultural production can lead to depressed wages in local agricultural labor markets. The success of sustainability policies critically depends on the degree of responsiveness of local labor markets given the prominence of labor as an input to the production system.

IV. Weather, Climate Extremes and Global Agricultural Trade

Food security can be threatened by extreme events that negatively affect agricultural production. These extreme events are spatially heterogeneous. Therefore, connections to regional markets and global markets can reduce the negative impact on food consumption and food security. If a region is affected by heat and water stress, thereby reducing agricultural production, consumers can import the necessary food items from other locations and international markets that did not experience this adverse weather event. Recent research has shown that local, regional, and global market-mediated responses to these compound stressors can allow more than 20 million people to stay above the minimum caloric requirement in case of a compound weather-pandemic stress [9]. Ignoring these market-mediated effects can lead to overestimation of the damages from climate and weather extremes.

V. Water quality and corn-soy markets

Excess nitrate leaching has created a large hypoxic zone in the Gulf of Mexico, with subsequent environmental and economic damages. A variety of mitigation policies have been suggested to reduce the size of hypoxia including taxes, in-field and edge-of-field nutrient management practices, wetland restoration, etc. However, different policy options will have different impacts on agricultural markets, each with differing consequences for food and environmental security. Implementation of each policy option alters the supply of agricultural products as well as the demand for farm inputs. The resulting changes in output and input prices will affect the competitiveness of corn and soy producers and may cause a spillover effect. Thus, while a policy may reduce the fertilizer application rates and cropland extent in the targeted location, it can increase fertilizer applications in non-targeted locations in response to elevated crop prices and lower fertilizer prices. Pairing local measures with national policies, such as a fertilizer tax, can suppress the unintended adverse impacts of spatially targeting interventions [10].

VI. Biomass co-firing and market for corn-residue

Corn-residue biomass cofiring has been recommended in the Midwest to reduce the greenhouse gas (GHG) emissions from coal power plants. Despite potential reductions in GHG emissions, this policy has been shown to generate unintended consequences at the local level. Specifically, there are trade-offs between carbon emissions reduction, land use change, and water quality degradation [11]. The main mechanism is through the emergence of markets for corn residue around the cofiring power plants. Simulations suggest that the increased demand for corn stover in the neighborhood of co-firing power plants results in an increase in profitability of corn production, and therefore an expansion of area. It also encourages intensification of production, since the biomass is now also in demand – not just the grain. This intensification boost nitrogen fertilizer applications and results in an increase nitrate leaching from the agricultural sector. Unfortunately, many of the co-firing plants are also in areas where nitrate pollution is already a big problem. This example shows that an integrated, fine-scale economic analysis is necessary to capture the market-mediated environmental interactions within the energy–land–water nexus.

VII. Productivity and cropland expansion

By producing more with less farm inputs, boosting agricultural productivity is critical to achieve global sustainability outcomes. Over the past two decades, global agricultural output grew by 58 percent while agricultural input use increased by only 18 percent [12]. The role of agricultural productivity in driving future trends in land use and environmental outcomes is well documented. Hertel et al. [15] explore the impact of regional crop productivity improvements on global farmland extent. Their historical analysis of the Green Revolution finds that this set of agricultural productivity improvements spared cropland globally, as increased production in Asia, Latin America and North Africa lowered global prices and lessened pressure to expand land in other regions. These authors also examine the potential impact of a future Green Revolution in improvements in Sub Saharan Africa (SSA). Here they highlight the interplay between global land use impacts and the extent to which the SSA region is integrated into global commodity markets. Under current conditions (limited market integration), they find that the African Green Revolution would spare land and GHG emissions globally. However, under full market integration, this finding is reversed, as relatively low yield, GHG emissions intensive production in the SSA region displaces production elsewhere. So the impact of productivity improvements on global land use and emissions depends critically on the strength of market-mediated effects.

VIII. Impacts of conservation policies mediated through labor markets

The magnitude of market-mediated effects also depends on the functioning of agricultural input markets. For example, restricting groundwater use to sustainable levels, in the Western US where much of agricultural production relies on irrigation, could reduce groundwater extraction by up to 90 percent in the Central Valley region of California [17]. However, the impacts of such conservation policies are mediated in part through local labor markets. Stylized theoretical modelling has shown that the ease with which farmworkers are able to adjust to policy shocks to the agricultural sector, plays an important role in determining the local level impacts of conservation policies, its leakages and distributional impacts on local communities [18]. The simulated impact of a conservation policy is significantly different depending on the stickiness of the labor market or the mobility of laborers. If farmers and laborers cannot find alternative employment, it will be more difficult to achieve local groundwater conservation goals, while farmworkers absorb wage cuts and scarcity of the natural resource bid us resource rents. The magnitude of increase in food prices also depends on the mobility of farmworkers.

Hill, Ornelas, and Taylor [16] review the evidence on agricultural labor mobility that can affect the magnitude of market-mediated effects and show that the era of agricultural labor abundance is over [20] and there is increasing intensity of agricultural labor shortages in the US [21]. This is a challenge across all regions of the world. As economies evolve, fewer workers remain in the agricultural sector and those who remain are more settled and unwilling to migrate long distances for work [22]. All these factors limit the ease with which producers can respond to policy shocks. Ray et al. [15] show that the local (grid) level impacts are overestimated when we ignore labor market rigidities. Restrictions on groundwater use, at sustainable levels in the Central Valley, lead to a reduction in employment by up to 25 percent which is overestimated to 50 percent if we ignore labor market rigidities. Further, the spillover effects of the policy, in relatively groundwater abundant regions, which absorbs some of the reduction in employment in the directly targeted regions, is also over-estimated when labor market rigidities are ignored. And finally, the groundwater conservation policy depresses farm wages by up to 25 percent, since the policy reduces the number of available jobs as it restricts the use of over-exploited resources. Ignoring these market mediated effects, leads to a mis-representation of the distributional impacts of conservation policies.

IX. Forestry conservation and crop and labor markets

Another important category of sustainability policy is the payments for ecosystem services (PES) program, which provides subsidies to prevent logging, cultivating and farming on ecologically sensitive regions, in order to both protect and restore natural ecosystems and also support the welfare and livelihoods of local residents [23]. Among PES programs implemented, one of the largest-scale programs is the Grain-to-Green Program (GTGP) in China. It aims to restore forestry and grasslands on hilly or steep landscapes to prevent ecosystem degradation and disasters (soil erosion, biodiversity loss, flood, etc.) [24], [25]. The GTGP has been implemented in 25 provinces in China and restored 29.1 million hectare of forestry during 1998-2017 [26]. Studies find that for regions in which GTGP has been implemented, this program has caused the increase of forestry cover [24], [25] and shifted residents' income structure towards non-agricultural sources [29]. However, GTGP also results in substantial market-mediated effects, through at least three channels. First, the program's major aim is to restore forestry on hilly or steep landscapes, which exhibit relatively lower agricultural productivity but are highly sensitive to ecological degradation. However, the subsidy from GTGP has created an incentive to over-restore forestry on flat landscape with limited risk of soil erosion or disaster, which causes a reduction of agricultural productivity [30]. Second, GTGP causes the shift of laborers from agricultural to non-agricultural sectors, which would influence the labor supply in local market, or in adjacent counties via migration [31]. Finally, GTGP causes the shrinkage of extensive margin (cropland) in provinces involved [32], which reshapes the national crop production pattern. These important but not well-researched impacts of GTGP emphasize the importance of taking market-mediated effects into the design and evaluation of PES programs.

X. Conclusion

Sustainability policies are designed to protect the environment and ensure that resources are used sustainably. However, they can also have unintended consequences which are often communicated via markets. Markets for agricultural commodities (local, regional, and global) play an important role in determining the final impact of policies or changes. Capturing these market responses requires multi-scale quantitative frameworks considering planetary boundaries, local biophysical and economic features, and connections to agricultural markets. These frameworks can help policymakers to understand how changes in one location can affect other locations. They can also help policymakers to identify the potential impacts of sustainability policies on other goals.

To account for these market-mediated effects, sustainability policies need to be carefully designed with regional, national and international cooperation. This means that policymakers need to consider the potential impacts of their policies on markets locally and around the world. They also need to work with other countries to ensure that sustainability policies are not violating planetary boundaries or causing new problems.

Also, more research is needed to understand the full range of market-mediated effects that can occur as a result of local sustainability policies and global changes, as well as to communicate these indirect effects to decision makers. This will help policymakers to design more effective sustainability policies that take into account the full range of potential impacts.

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