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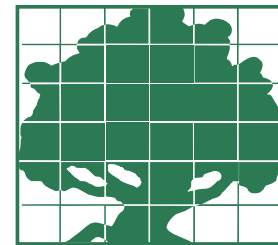
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Shale Gas Boom: Implications for California Agriculture

Colin A. Carter and Kevin Novan

Recent technological advances have unlocked vast supplies of domestic shale gas. As a result, the price of natural gas in the U.S. has plummeted. Cheap natural gas has the potential to provide cost savings for California's agricultural sector.

Over 31% of the fossil fuel energy consumed in the United States comes from natural gas—even more important than coal, which accounts for 25% of the total fossil energy consumed. Unlike coal and petroleum, which can easily be shipped around the world by vessel, natural gas is almost exclusively transported by pipeline. As a result, the vast majority (over 95%) of the natural gas consumed in the United States is produced domestically.

In the past, our natural gas largely came from conventional underground

reservoirs located in soft rock formations. While these reservoirs provided easily accessible sources of energy, vast amounts of natural gas remained locked deeper in the earth's crust in hard, shale rock formations.

Over the last decade, however, there has been a revolution in the way natural gas is extracted from the earth. Hydraulic fracturing (fracking) has made it possible to unlock the vast shale gas resources that previously had been uneconomical to extract. Fracking involves injecting a pressurized mixture of water, sand, and chemicals into deep wells, typically drilled horizontally into shale formations. The pressurized mixture creates fissures in the rock layer, releasing oil and natural gas, which flows back up the well.

Many energy industry participants have described fracking as a “game changer.” The technology is making cheap energy resources available to domestic consumers. It is clear that

energy-intensive industries in the United States will benefit from fracking. However, it is less clear what the impacts will be on the agricultural sector and, specifically, farmers in California. Does fracking represent a “game changing” technology for the state's agricultural sector?

Growth in Shale Gas Production

In 2000, shale gas production accounted for only 1.7% of U.S. natural gas production (see Figure 1). Twelve years later, shale gas accounted for 35% of total U.S. production. By 2040, the U.S. Energy Information Administration (EIA) forecasts that over half of the domestic natural gas production will come from shale formations.

However, there is substantial uncertainty surrounding the forecasted shale gas volumes. In regions with large shale formations, very little exploration has been carried out to determine the potential amount of natural gas locked in the layers of shale. In addition, from

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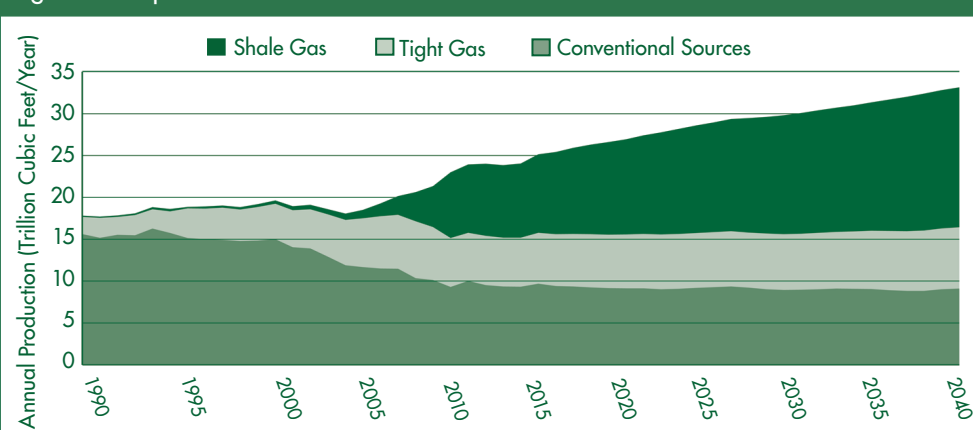
Distortions to Global Agricultural and Food Markets

Gordon Rausser.....4

Animal Waste Regulation and Transboundary Water Quality

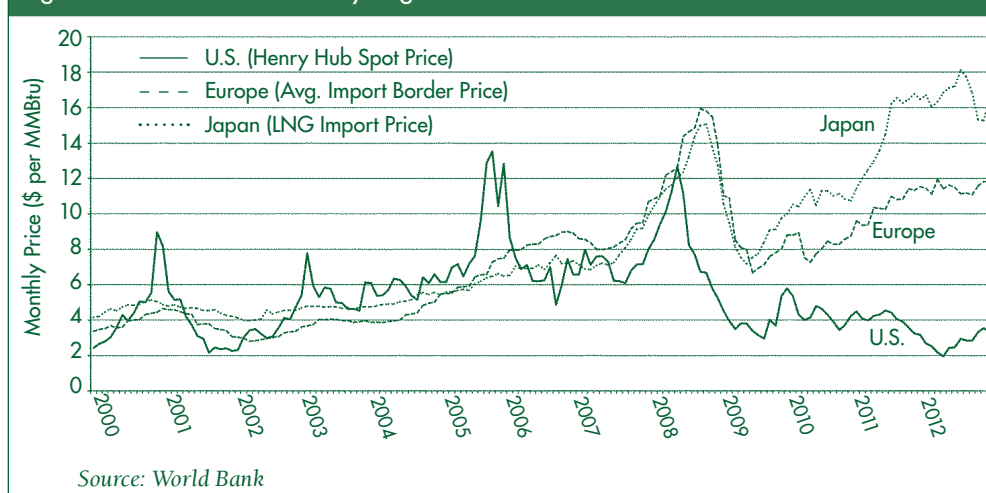
Antti Iho, Doug Parker, and David Zilberman.....8

Figure 1. Projected U.S. Natural Gas Production



Source: U.S. Energy Information Administration (EIA) Annual Energy Outlook, 2013

Figure 2. Natural Gas Prices by Region



the sites where horizontal drilling and fracking is underway, very few years of production data are available.

There are very contentious debates surrounding the costs and benefits of fracking. In regions with rich shale gas deposits, substantial growth in employment and tax revenues are already being seen. For example, during 2011, Texas brought in \$2.7 billion in severance tax revenue. A large portion of this came from the 7.5% severance tax levied on natural gas production. In states experiencing large budget shortfalls, fracking presents a very appealing revenue source.

While there are obvious economic benefits associated with shale gas, opponents of fracking are quick to point out that the technology could pose very serious risks to the environment. To extract gas from shale, millions of gallons of water, mixed with a variety of possibly hazardous chemicals, are pumped underground. The majority of the water remains in the well. However, up to 20% can be re-used for fracking in other wells or submerged into disposal wells. If not properly disposed, this mixture can contaminate surface waterways as well as groundwater.

On top of the threat of water contamination, there are also concerns arising from the impact shale gas will have on greenhouse gas (GHG) emissions. Compared to coal, the chief substitute

for natural gas in the electricity sector, burning natural gas emits just over half as much CO₂ per unit of energy created. Therefore, at first glance, it appears that expansions in natural gas production have the potential to deliver substantial reductions in GHG emissions and other air pollutants. However, recent reports from the Center for Atmospheric Research (NCAR) reveal that nontrivial amounts of methane—which compared to CO₂, is a much more potent GHG—are leaked into the atmosphere during the process of fracking. As a result, the net GHG impacts of fracking remain a serious question.

Decrease in Natural Gas Prices

Despite the uncertainty surrounding many of the costs and benefits of fracking, there is one effect that is certain—the recent boom in U.S. shale gas production has significantly reduced the price of natural gas for the foreseeable future. In the past few years, the price of natural gas in the United States has fallen so much as a result of the fracking boom that increased U.S. gas flaring (due to the low gas price) in the Midwest is now visible from space at night.

Due to the fact that natural gas must be converted into liquefied natural gas (LNG) before it can be exported overseas, natural gas is not well arbitrated with world markets. Therefore, the U.S. price is now well below the European

and Asian prices (see Figure 2). In June 2008, natural gas prices in the U.S. hit a high of \$12.68 per thousand cubic feet and recently traded around \$3.30. Current prices in Europe are close to \$12 per thousand cubic feet.

In the long-run, two factors may reduce the spread between the international prices. First, while fracking was developed in the United States, the technology is now spreading to other countries in Europe, Asia, and elsewhere. If fracking can result in similar increases in natural gas supply overseas, regional prices outside of North America will likely experience similar declines. Second, with expansions in LNG production capacity, the price differential may be arbitrated in the future as international trade grows. However, for the foreseeable future, the gap in prices will likely remain.

Given the importance of natural gas in the economy, the shale gas boom is being viewed by many industry participants as a “game changer.” The significant cost advantage that energy-intensive industries in the U.S. are now experiencing will certainly provide a competitive edge that will persist as long as the gap in international gas prices remains. But what does it mean for the agricultural sector and, in particular, the competitiveness of California’s agricultural sector?

Impact on Agriculture

Low natural gas prices will have direct and indirect economic effects on California agriculture. The direct impact of lower natural gas prices on California’s agricultural sector is likely small. According to the California Energy Commission, only 0.8% of total California natural gas consumption occurs in the agricultural sector. This is due to the fact that the majority of farm equipment runs on petroleum as opposed to natural gas.

Looking forward, if the relative price of natural gas remains below gasoline

and diesel, there could be a switch in the composition of technologies used on farms. For example, tractors running on diesel may be replaced by tractors powered by compressed natural gas. Additionally, with increased use of natural gas in the transport sector, the cost of moving products to markets may decrease. However, these long-run changes would not advantage California agriculture versus the rest of the nation.

Aside from the direct impact that low natural gas prices will have on the agricultural sector, there will also be two major indirect impacts. The first stems from the impact natural gas prices have on fertilizer prices. Natural gas is the main input in the production of ammonia, which in turn is the key input in the production of all nitrogen fertilizers. During 2010, 20.84 million tons of chemical fertilizers were used in the United States, of which nitrogen fertilizers accounted for 59%.

Recall from Figure 2, U.S. natural gas prices trended upwards from 2000 through 2006. These price increases had a direct effect on ammonia prices. From 2000-2006, the correlation between monthly U.S. natural gas and ammonia prices was 0.81. While natural gas prices increased from under \$3/MMBtu to over \$12/MMBtu, the ammonia prices paid by farmers increased by 130%—from \$227/ton to \$521/ton.

The low and stable natural gas prices being driven by the boom in shale gas production will put downward pressure on the price of ammonia. As a result, nitrogen fertilizers, as well as phosphate and potash fertilizers that serve as substitutes for nitrogen, will likely all experience price declines. These lower costs are a definite benefit for the agricultural sector as a whole.

However, given that fertilizers are arbitrated internationally, low ammonia prices will not directly provide a competitive advantage to certain regions. While regions with more fertilizer-intensive crops—corn,

for example—will potentially benefit to a greater degree, a corn farmer in California and a corn farmer in Iowa will be affected very similarly.

Agricultural Electricity Use

The second major indirect impact low natural gas prices will have on the agricultural sector stems from the role gas plays in setting electricity prices. In the United States, coal and natural gas account for almost 70% of the total electricity produced. While coal is the dominant energy source—in 2011, 44% of electricity came from coal-fired units and 25% came from natural gas units—natural gas generators are primarily the marginal sources of electricity.

As a result, natural gas prices play a key role in setting the price for electricity in most regions. This is especially true in California where over half of the electricity generated comes from natural gas units. Lower natural gas prices directly lead to lower wholesale electricity prices. According to a recent report by IHS Global Insight, Inc, the decrease in natural gas prices resulting from shale gas production will result in an average reduction of 10% in electricity costs nationwide over the next 25 years.

Why are lower electricity prices significant for California farmers? The answer to this question lies in California's heavy reliance on irrigation for agriculture. According to the latest USDA (NASS) data, California irrigates almost 50% of the farmed acres in the state. The water application rate is roughly double the national average. This means that relative to other states, California is by far the largest user of water for agricultural purposes, measured by total acre-feet applied.

One of the largest determinants of the cost of water is electricity. In California, over 7% of the total electricity produced is used for pumping water and the agricultural sector. During an average year, California agriculture irrigates 9.6 million acres.

This requires using roughly 34 million acre-feet of water of the 43 million acre-feet diverted from surface waters or pumped from groundwater. It takes more than 10,000 GWh of electrical power to pump and move this water.

Traditionally, California electricity prices are near the highest in the nation. Currently, only eight states have higher average retail rates. Due to California's heavy dependence on electricity for irrigation, farmers in the state could benefit greatly from lower electricity prices.

While lower natural gas prices have certainly reduced electricity generation costs in the state, this has not translated into lower retail electricity prices at this point. However, with natural gas prices remaining low into the foreseeable future, California farmers might soon begin to realize these benefits from lower electricity prices.

Conclusion

By lowering the price of natural gas, the recent boom in U.S. shale gas production has significantly changed the dynamics of the domestic energy market. These low gas prices are playing a key role in boosting the competitiveness of energy-intensive industries in the United States. Plentiful gas also has the potential to reduce the costs of key inputs in the agricultural sector. While fracking is not likely to provide a “game changing” competitive advantage to California farmers, the state's agricultural sector will certainly benefit if the lower natural gas prices translate into lower water and fertilizer costs.

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Distortions to Global Agricultural and Food Markets

Gordon Rausser

Based on a rich global data set covering a half-century of evidence on commodities, countries, and policy instruments, this article outlines hypotheses that have been explored on the extent of global agricultural and food market distortions and the conditions under which welfare-increasing reforms may be feasible.

Market distortions in global trade occur when a government creates policies that increase or lower prices of imported and/or exported goods. When prices are distorted, consumers pay either less or more than they would have if the price-altering policies were not in place. In agricultural and food markets, governments tend to create price-altering trade policies especially when global agricultural and food prices rise dramatically. The latter happens most often when the supply of the crop or food product is disrupted, whether by governmental “food-security” measures, weather, or new policies, such as incentives that motivate farmers (and downstream operators) to allocate crops for biofuels rather than for food.

When politicians seek to shield consumers from the effects of price increases by increasing export taxes, global price volatility often worsens. Other countries may respond with similar measures, so that market distortions in individual countries combine to generate sudden global price spikes that alter patterns of food production and consumption and create political turmoil. In particular, rapid increases in the prices of staple commodities (such as wheat, corn, and

rice) have a disproportionately severe effect on the world’s poorest people.

The “disarray in world agriculture” that market distortions create has manifested itself in overproduction of agricultural products in high-income countries and underproduction in low-income countries. This also means that there has been less international trade in such products than would occur under the counterfactual scenario of free trade. In 2004, country-specific agricultural policies accounted for an estimated 70% of the global welfare cost of all merchandise trade distortions, even though the upstream farm production contributed only 6% of global trade and 3% of global GDP.

Although many countries have recently begun to adjust their agricultural and trade policies in order to minimize their adverse global impact, these reforms have not kept up with the pace of globalization in the non-agricultural sectors of the world economy. Economic development is typically associated with some sectors within a country growing and some declining faster than others.

Historically, such changes have often led governments to intervene via a broad array of policy instruments: distortions to input markets (largely subsidies, plus controls on land use), production quotas, marketing quotas, target prices, price subsidies or taxes in output markets, and border measures that directly tax, subsidize, or quantitatively restrict international trade. Such measures, along with multiple exchange rates, account for at least three-fifths of governmental agricultural assistance globally. Because trade measures also tax consumers (and welfare costs are proportional to the square of a trade tax), these measures are responsible for an even larger

share of global welfare cost and agricultural welfare-reduction indexes.

New Data from the World Bank

A new global five-decade database of evidence compiled by the World Bank dramatically expands our understanding of the distortions to market incentives across the globe. Economists have recently been exploring hypotheses concerning the extent of price distortions and the potential for adopting sustainable unilateral and multilateral policy reforms. They have also examined the extent to which more recent agricultural-policy reforms have succeeded in reversing the prior era’s policy distortions.

These new analyses make it possible to test hypotheses about market and trade patterns across countries, commodities, and policy instruments. Understanding the historical forces that drive agricultural-policy choices can contribute to structuring policy options that address food-security, energy-security, and climate-change concerns.

Measures of Price Distortion

The Nominal Rate of Assistance (NRA) measures distortions imposed by governments that create a gap between current domestic prices and the prices that would exist under free markets. In the World Bank database, such rates have been computed for each commodity product as the percentage by which government policies have raised gross returns to farmers above what they would have been had the government not intervened (or the percentage by which government policies have lowered gross returns, if $NRA < 0$). NRAs are computed for 75 different farm products, with an average of almost eleven per country. Of the

world's 30 most valuable agricultural products, the World Bank's NRA estimates cover 77% of global output and 85% of global agricultural exports.

It is also now possible to compute a production-weighted average NRA for non-agricultural tradables and compare it to the NRA for agricultural tradables via a computed Relative Rates of Assistance (RRA). The RRA for each country is the percentage by which the government assists agricultural versus non-agricultural sectors. If a country's government assists both of these sectors equally, the RRA is zero. The RRA recognizes that farmers are affected not just by prices of their own products but also by the incentives faced by non-agricultural producers who are bidding for the same mobile resources. Calculating the RRA for each country provides an internationally comparable indication of which country's policy regimes have anti- (or pro-) agricultural biases.

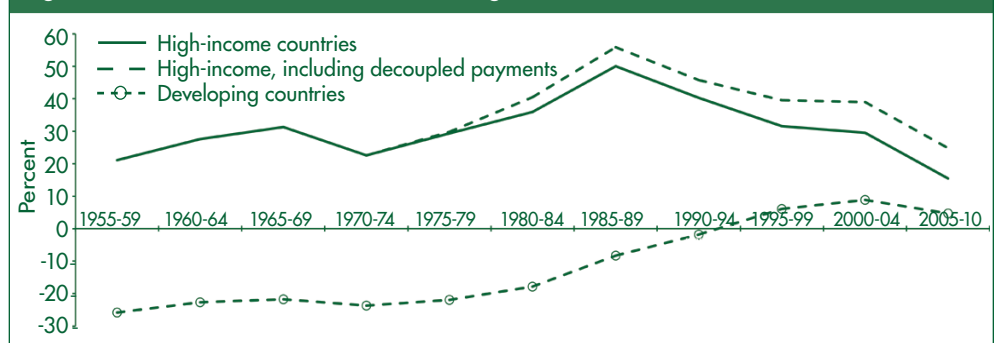
The database also allows us to compute a Welfare Reduction Index (WRI) and a Trade Reduction Index (TRI). The WRI recognizes that price distortions imposed by a government create an overall welfare cost, regardless of whether the government's policies favor or hurt producers in a particular sector. The TRI measures the extent to which import protection or export taxation reduces the volume of trade.

Analysis of Market Distortion

Historically, the higher a country's per capita income, the higher have tended to be its nominal—and especially relative—rates of assistance to agriculture (NRAs and RRAs). More generally, policy regimes in high-income countries have typically exhibited a pro-agricultural bias, while regimes in developing countries have typically exhibited an anti-agricultural bias. But since the 1980s, both biases have generally diminished (Figure 1).

In the case of developing countries, the rise in average RRA is due

Figure 1. Nominal Rate of Assistance to Agriculture, 1955–2010



as much to a decline in assistance to nonfarm sectors (especially cuts to manufacturing protection) as it is to declines in agricultural disincentives (especially cuts to export taxes). However, the extent and speed of convergence vary across regions.

As Figure 2a shows, among developing countries, RRAs to agricultural vs. non-agricultural tradable goods have been greatest for Asia and least for Africa. Among high-income countries (Figure 2b), until about 1985, RRAs to agriculture were greatest for the European Union, Japan, and South Korea. However, since 1985, the RRA

for EU countries has declined steadily. Meanwhile, the RRA for most non-EU Western European countries has risen sharply and then fallen. In contrast, Japan and South Korea have continued to increase RRAs. The only period during which RRA's for most countries fell rather than increased occurred in 2005–10, when international food prices rose steeply. The welfare- and trade-reduction indexes of the two main country groups have thus generally traced an inverted-U shape, rising until the mid-1980s and subsequently falling by half (Figures 3a and 3b).

Figure 2a. Developing Countries' Relative Rates of Assistance to Agriculture, 1965–2009

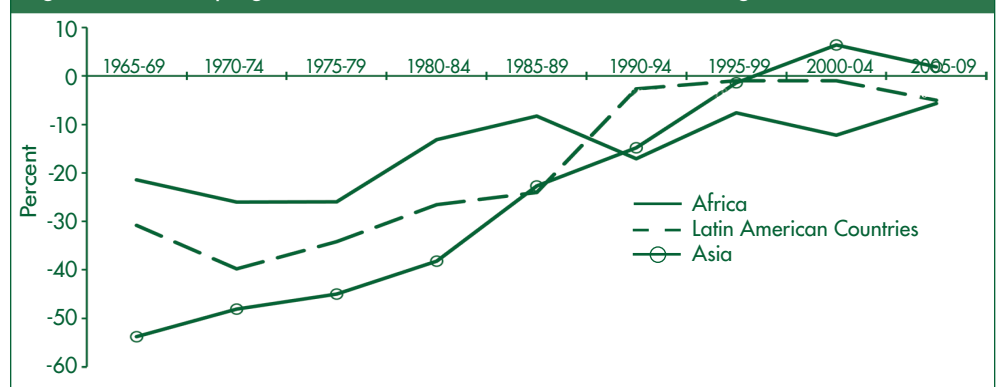


Figure 2b. High-Income Countries' Relative Rates of Assistance to Agriculture, 1955–2010

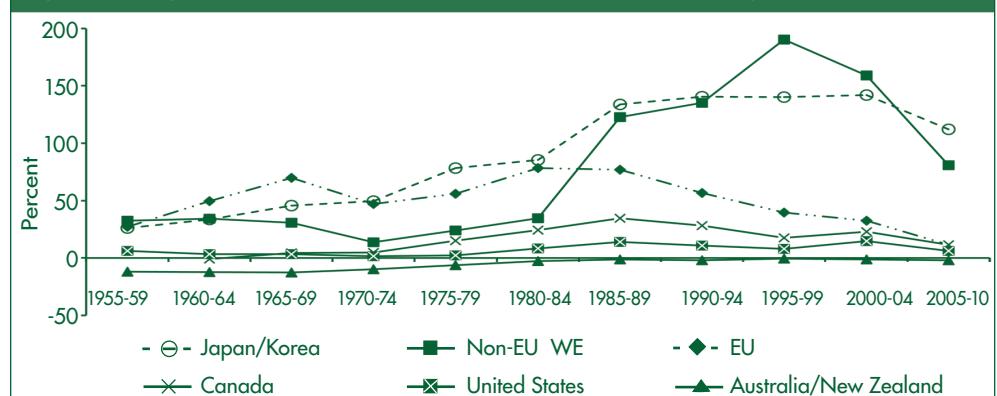


Figure 3a. Welfare-Reduction Index for Tradable Farm Products, 1960–2010

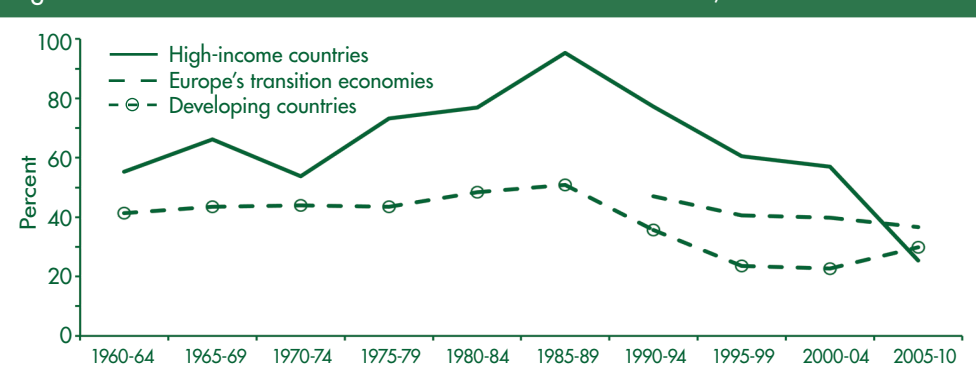
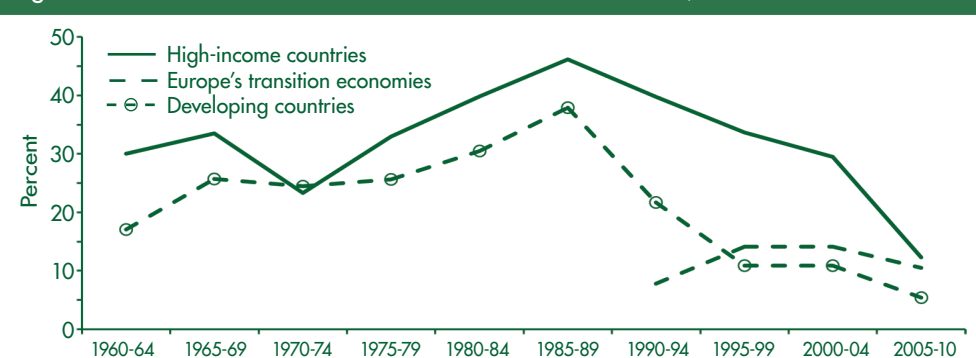


Figure 3b. Trade-Reduction Index for Tradable Farm Products, 1960–2010



As noted earlier, governments often seek to prevent domestic prices from being affected by spikes in international prices. In both agricultural-exporting and agricultural-importing countries, and in high-income as well as developing countries, large changes in nominal assistance occur during periods of international price spikes (whether up, as in 1973–74 and 2008, or down, as in 1986).

Variations in Market Distortions

The averages reported in Figures 1–3 do not reveal the substantial variability across countries in the level and rate of change in distortion indicators. National RRA estimates for 2005–09 varied from around -40% for several African countries to around 100% for a few high-income countries. Clearly, much could be gained worldwide from international relocation of production and consumption to remove these cross-country differences. Of particular note is that the average RRA for some developing countries, which converged toward zero from the 1980s,

did not stop at zero but “overshot” after the early 1990s (Figure 2a).

Within any single country’s agricultural sector, product-NRAs also vary widely. Some commodity-product NRAs are positive and high in almost all countries (sugar, rice, and milk). Others are positive and high in developed economies but highly negative in developing countries (most noticeably, cotton). Still other product NRAs are relatively low in all countries (feed grains and soybeans as inputs into intensive livestock, especially pork and poultry industrial activities).

Another crucial component of the variation in NRAs is that anti-agricultural trade bias has declined within the developing-country group. But for the high-income group, this bias is sourced with agricultural export subsidies and import protection. These factors explain the continued higher levels of TRI for high-income versus developing countries (Figure 3b).

The relative importance of policy instruments has changed greatly over time. Note that the contribution of

export taxes and import subsidies to the overall TRI rises and falls with international prices. While the opposite is true of import taxes and export subsidies, most developing countries have sharply slashed their export taxes. In sharp contrast, as these countries have bolstered their assistance to agricultural subsectors facing import competition, the relative importance of import taxes has increased dramatically (Figure 4).

Input subsidies are a relatively minor component of most countries’ assistance to farmers. But they lingered on in Australia and New Zealand when most other forms of assistance were being phased out, and such subsidies have also remained about one-fifth of the total NRA in the United States. With two notable exceptions (India and Indonesia), input subsidies are even less common in developing countries, where funds for such direct subsidies are scarcer.

Another form of market intervention, altering foreign exchange rates, was quite common for developing-country governments until the 1980s (and in some cases, the early 1990s). Such interventions added to the anti-trade biases that were targeted at tradable sectors, including agriculture. However, these interventions largely disappeared by the mid-1990s, as initiatives to reform overall macroeconomic policy took hold.

Summary of Market Distortions

Major differences in public-policy distortions in food and agricultural markets clearly exist among countries, among agricultural subsectors within countries, among policy-instrument choices, and over time within a particular country. Typically, developing countries are phasing out anti-agricultural policies; some are increasingly protecting farmers who face import competition.

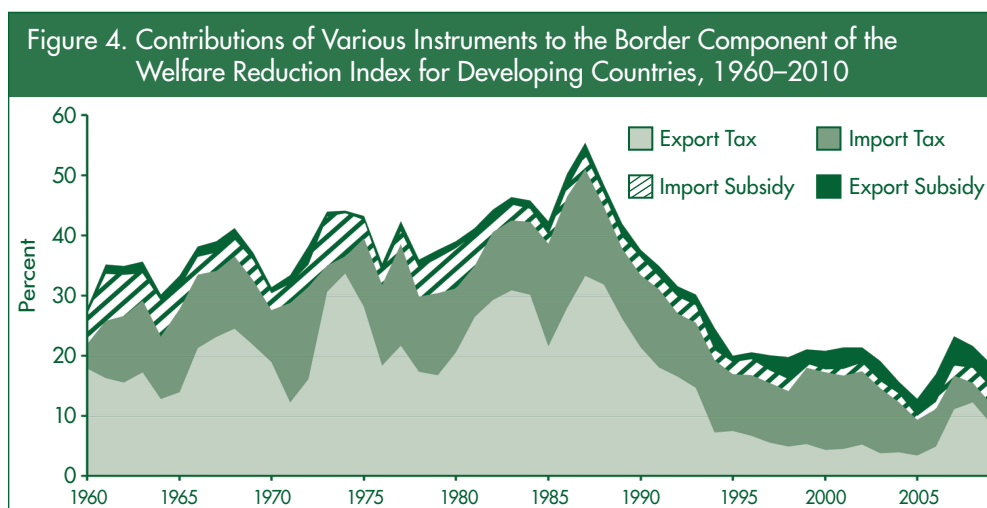
Some high-income countries are reducing assistance to farmers, and a few have also greatly reduced manufacturing

protections that previously had indirectly harmed agricultural producers. But in all high-income countries, the relative importance of various farm-policy instruments has changed significantly, and the contribution of price-distorting measures has declined.

Some important common patterns hold over time, as well as across both high-income and developing countries. One is the propensity to insulate domestic markets from international price fluctuations despite globalization tendencies elsewhere in the economy. The second pattern is the continuing anti-trade bias for agricultural industries, even though significant market-opening policy reforms have been instituted over the past few decades. The third pattern is the persistence of the individual dispersion in commodity assistance within the agricultural sectors of most countries. Overall, the observed correlations between RRAs and economic development can be explained largely by fundamental economic forces, including growth, structural adjustments, information costs, and changes in governance structures.

Implications for the Future

Cautious optimism is evident about the prospects for future agricultural-policy reform. Admittedly, it is troubling that some developing countries have moved from negative to positive RRAs and that agricultural protection and market distortion have recently increased in two of the most important developing countries, China and India. In high-income countries, too, although the World Bank data reveals declining trends for NRAs, these trends do not necessarily reflect actual changes in their distorting policy instruments. Instead, higher world food prices largely explain these outcomes. But many other countries' RRAs do appear to have converged at zero (that is, where their subsidies to agricultural and non-agricultural tradables are about equal), and other high-income countries have been lowering their RRAs



non-trivially since the late 1980s.

Global and regional institutions appear to have played an important role in contributing to those reforms. Of particular importance to the decline in the RRA for the European Union has been the institution of the General Agreement on Tariffs and Trade (and now the World Trade Organization).

However, the recent shift in agricultural policies focusing on renewable energy (particularly in the United States, European Union, and Brazil) has major implications for world food prices and security. Ongoing research should make as transparent as possible the continued pursuit of protectionist measures by various countries in the form of biofuels policies, which tend to raise world food prices, in contrast to traditional agriculture policies, which historically depressed those prices.

Prospects for policy reform will be influenced by the changing landscape of organized economic interests. Interactions between farmers and landowners, agribusiness, food and retail companies, and other groups clearly influence agricultural-policy negotiations and debates in all countries. The vertical relationships between farmers and agribusinesses are often critical in sustaining policy reforms. Capturing opportunities to form new coalitions among the interests of farmers, downstream agribusiness, food consumers, and environmental groups will largely

dictate sustainable policy reforms that promote the provision of local public goods, agricultural productivity, and markets for environmental services.

In the final analysis, the many complex factors that contribute to distortion of agricultural and food markets can impede as well as promote progress. But the hope is that continued reform of entrenched policies and practices, along with heightened scrutiny of new developments, will promote greater transparency and cooperation.

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For additional information, the author recommends:

Anderson, K., G. Rausser, and J. Swinnen. "Political Economy of Public Policies: Insights from Distortions to Agricultural and Food Markets." *Journal of Economic Literature* (forthcoming).

Rausser, G.J. Swinnen, and P. Zusman. *Political Power and Economic Policy: Theory, Analysis, and Empirical Applications*. Cambridge University Press (2011).

Animal Waste Regulation and Transboundary Water Quality

Antti Iho, Doug Parker, and David Zilberman

Control of animal waste has been a major policy challenge. We identify the properties of efficient regulation and suggest that effective policies to control animal waste will enhance utilization of manure in local production and may change land allocation among crops. We also show that policies that aim to control local environmental problems, ignoring spillover among regions, may be significantly suboptimal and need to be replaced by policies with a global perspective.

The range and magnitude of impacts of animal waste are worldwide and vary among different regions. Animal waste is a key source of nitrates and salts impairing groundwater quality in California's San Joaquin Valley. Hypoxia in the northern Gulf of Mexico is linked to nitrogen and phosphorus loadings from the immense Mississippi River Basin. There, agriculture is by far the most important source of both nutrients, and manure is the biggest source of phosphorus and an important source of nitrogen. In the Chesapeake Bay, manure surpluses from the basin's animal husbandry accelerate eutrophication, which is harmful for commercial fisheries and recreational activities.

Over the past few decades, the number of animals per production facility has increased substantially and production has been concentrated geographically. As a result, local feed production cannot satisfy the nutritional needs of these growing production units. Feed is largely purchased from

markets outside the production region, while the manure by-products from animals remain in the region. This leads to an accumulation of nutrients which, in turn, increases nutrient loading to ground and surface water systems. The challenge is to achieve profitable animal production while contaminating the environment as little as possible.

Any production tends to generate pollution as an unintended by-product. Without government intervention, no individual operator will factor the amount of pollution into decisions regarding the number of animals cared for on the land, manure-management technologies, crop choices, etc. Generally, it would be beneficial for society to pollute less than what is observed under a free market system. Yet, eliminating pollution altogether is too costly and regulation is needed to keep it at desirable levels that maximize societal welfare.

Regulation, on the other hand, is always defined for, and often differs among, given regions. In the United States, regulation of water quality is guided by the federal Clean Water Act (CWA). States emphasize designing, imposing, and enforcing the actual regulations imposed at the federal level. When regulating concentrated animal feeding operations (CAFO), for instance, states may establish rules that influence manure-application practices. As our economic analysis will demonstrate, regional regulation has serious caveats.

For this study, we create a stylized framework to illustrate regional regulation and its potential failure. Hereby, we establish a need for applied economic analysis to further clarify the problem and help improve existing policies. We

examine the effects of regional (state level) regulation on the generation of residual nitrogen and phosphorus from animal and crop production.

We also show that stricter but uncoordinated environmental protection in one region may lead to increased environmental damage in the other. The two main reasons for this are: 1) Measures that reduce nutrient residuals, particularly crop choice, exhibit trade-offs between phosphorus and nitrogen residuals; and, 2) The role of nitrogen and phosphorus in generating externalities differs between regions.

Nitrogen and Phosphorus

Manure nutrients are useful in enhancing crop productivity, and can be utilized in production as fertilizers. The crucial difference between manure and chemical fertilizers is that a farmer is only able to choose the overall level of manure application, which determines the applied amounts of both nutrients. With chemical fertilizers, any combination of nitrogen and phosphorus are commercially available.

Nutrient requirements of crops vary significantly. Corn needs about 140 pounds of nitrogen and between 20 and 30 pounds of phosphorus per acre (at medium soil phosphorus values). Soybeans, on the other hand, can utilize atmospheric nitrogen and recommended phosphorus rates vary between 20 and 45 pounds per acre.

Also, the concentration of phosphorus and nitrogen in animal manure differ. Dairy manure contains about 1.5 times more nitrogen than phosphorus, while dry hog manure contains roughly equal amounts of both. To avoid the costs of applying both chemical fertilizers and manure,

Table 1. Decomposing the Decision-Making Process

Decision Variable	Economic Outcomes	Nutrient Residuals
LIVESTOCK FARMER		
Number of Animals	Revenues from animal products Cost savings from utilizing manure;	Amount of manure increasing with the number of animals; N-P concentration in manure fixed for each production animal
	Production costs; Feed costs	
Application of Manure on Own Land	Savings in chemical fertilizers;	Relatively scarce nutrient generates zero residual, positive residual for the other
	Hauling and application costs	
Export of Manure to Crop Production Area	Revenues from selling manure;	Relatively scarce nutrient generates zero residual, positive residual for the other
	Hauling and application costs	
Deposit Area for Excessive Manure	Free disposal on own land;	All applied manure excessive of crops needs adds to residual nutrients, regardless of location
	Hauling costs if on crop farm	
Crop Choice	Savings in feed costs/revenues from selling;	Crop specific N-P uptake
	Fertilization costs	
CROP FARMER		
Manure Import	Substitute chemical fertilizers	N-P of manure net of crop specific N-P uptake
Crop Choice	Revenues from selling;	Relatively scarce nutrient generates zero residual, positive residual for the other
	Fertilization costs	

farmers choose the manure quantities on the basis of one nutrient, often nitrogen; while the other, often phosphorus, is applied excessively.

Residual nutrients, often coming in the form of runoff, are harmful for ground and surface waters. Protecting groundwater requires controlling nitrogen loading, and mitigating eutrophication requires reducing loading of either or both of the nutrients, depending on the watershed characteristics. Arid regions with little surface water, like California, tend to suffer from groundwater quality problems but face very little eutrophication. Agricultural regions draining into the Chesapeake Bay, on the other hand, may suffer from both problems. Regions located directly on the Bay may be more concerned with phosphorus than nitrogen, depending on the (perceived) effects nutrients have on eutrophication.

This discrepancy may cause one region to emphasize controlling nitrogen and another to control phosphorus. Problems can arise if regions share common surface waters, as one region may undertake measures that mitigate

problems they experience but aggravate problems experienced by the other.

Two Farm–Two Region Model

We consider a stylized model of an upstream and a downstream region. The upstream agricultural region is comprised of a livestock farm and a crop farm. The downstream recreational region has no agricultural production but derives benefits from surface water quality. Nutrient residuals in the agricultural region are the only determinants of nutrient loading in both regions.

We assume that the agricultural region suffers from elevated nitrate concentrations in its groundwater and nitrogen-driven eutrophication in its rivers. Hence, its regulation focuses on nitrogen. The downstream recreational region is concerned with regulating phosphorus to protect its coastal waters.

The decision-making framework for total livestock and crop production relies on basic economic and technical characteristics. While it does not capture the complexities of economic decision-making or the nutrient

loading governed by hydrology, it allows for sufficient details needed to obtain qualitative policy conclusions.

The objective in our model is profitability of the farms while accounting for the adverse effects of nutrient loading on the downstream region. We vary the way that profits and nutrient loading are weighed by assigning four alternative decision makers to conduct the optimization: the crop farmer, the livestock farmer, a regional policy maker, and a global (federal) policy maker.

The farmers' choices and the associated costs and benefits are presented in Table 1. The dark green color in Table 1 stands for revenues and the light green for costs associated with the choice variable given in the left column.

Manure nutrients used as substitutes for chemical fertilizers create economic value. The costs are created by hauling and application. The environmental damage is linked to residual nutrients, i.e., the differences in nutrients applied and nutrient uptake. The literature recognizes that under expected profit maximization of the farms, there will typically be some residuals generated.

Table 2. Numerical Example of Three Potential Outcomes

Decision Maker	Number of Animals	Crop	Manure Generation (million gallons)	Application Livestock Farm (acres)	Application Crop Farm (acres)	Excessive Application (million gallons)	Nitrogen Residual (lb/acre)	Phosphorous Residual (lb/acre)
Crop and Livestock Farmers	1000	Double-crop soybean	3.94	800	0	1.81	72.5	97.7
Regional Policy Maker	990	Corn	3.90	800	91	0.0	0.0	103.0
Global Policy Maker	990	Double-crop soybean	3.90	800	450	0.58	14.8	40.0

We want to focus on characteristics of residuals when manure is the source of nutrients and policies differ regionally. Therefore, we assume chemical fertilizers create some residual nutrients, but we normalize this to zero. Furthermore, we assume that manure is applied at least according to crops' agronomic nitrogen needs but, due to the nutrient phosphorus ratio of manure, phosphorus is always applied excessively.

Given these guidelines, what do the choices of our decision makers look like? Table 2 considers three alternative situations representative of Midwestern farms. First, both livestock and field crop farmers interact, pursuing profitability without awareness of nutrient loading to ground and surface waters. This prompts policy makers to intervene. The regional policy maker considers only surface and groundwater quality problems in the agricultural region, while the global policy maker additionally considers the eutrophication of surface waters in the recreational region.

We assume a cow produces 12 gallons of fresh manure daily, and 126 pounds of plant-available nitrogen and 115 pounds of phosphate phosphorus annually. The crop choice is between corn and double-cropped soybeans after small-grain silage. The agronomic needs for corn and soybeans are 140 and 85 pounds of nitrogen and 25 and 52.5 pounds of phosphorus per acre, respectively (at optimal soil phosphorus value as per Maryland recommendations).

The first row in Table 2 presents the choices of the farmers who do not

consider nutrient loading. Considering only profits, the livestock farmer ends up having 1000 animals (milking cows with an average weight of 900 pounds), which generate about four million gallons of fresh manure annually. The most profitable crop choice is the double-cropped soybean.

In this case, the farmer substitutes chemical fertilization with manure as long as the costs of hauling and application are below or at the costs of buying chemical fertilizers. Regarding this, the farmer ends up applying manure on all her farmland, but does not import anything.

The price received from the crop farm does not cover the costs of hauling and applying for farther distances. The excessive manure application is about two million pounds. The farmers' overall solution generates residual nitrogen of 72.5 pounds per acre and residual phosphorus of 97.7 pounds per acre.

Regional policy standards aim to eliminate nitrogen residues from the upstream region. At the livestock farm level, it leads to a switch to corn, a slight reduction in herd sizes, export of manure to the crop production farm, and reduced profits of the livestock farmer. Since corn consumes less phosphorous than soybeans, transition to corn increases the phosphorous residual. This happens despite the fact that the regional policy maker's solution utilizes the almost two million pounds of manure that were applied excessively.

The global policy maker (for example, state instead of counties)

recognizes that rivers carry most of the dissolved phosphorus to the other region, and places more weight on phosphorus loading. She concurs with the regional policy maker's slight cut on animal numbers but maintains the farmers' initial choice of crops. She requires farmers to incur high costs from hauling manure to the crop production area, but allows some excessive application of manure. This creates about 15 pounds per acre of residual nitrogen and about 40 pounds of residual phosphorus per acre.

As a summary, the regional policy maker's intervention always improves surface and groundwater quality in the upstream region, but may simultaneously worsen surface water quality downstream. This follows from reductions in residual nitrogen but potential increases in residual phosphorus, which occur because the agricultural regional decision maker does not account for the phosphorous loading problem in downstream regions and simply focuses on the nitrogen loading problem of the agricultural region.

Discussion and Policy Implications

In the United States, nutrient management plans (NMP) are key to mitigating the impacts of excess nutrients from animal waste. Concentrated animal feeding operations (CAFO), i.e., large animal facilities, have to conduct and follow NMPs to balance the application and uptake of nutrients. NMPs follow either nitrogen or phosphorus standards and, in

most cases, only apply to farmland controlled by the livestock facility.

In accordance with the Clean Water Act, each state has created a list of impaired waters and defined their critical pollutants. A phosphorus standard should be followed if *local* waters are designated phosphorus-critical and if there are significant risks for phosphorus loading. Otherwise, a nitrogen standard is often followed due to its lower compliance costs. If it is designated as critical for certain downstream waters to be free of phosphorous loading, a regional approach may aggravate downstream pollution. In our example, the regional policy maker's solution coincided with a nitrogen standard.

Our framework could be used to assess manure regulation in California. Here, two relevant pollutants for NMPs and environmental concern would be nitrates and other salts. Choosing techniques that allow nitrogen to evaporate in compliance with a nitrogen standard might aggravate problems of salt sequestration in soils and groundwater. If these techniques allow farmers to meet regulatory standards while applying more manure per acre, more salts per acre would be applied.

This paper raises further questions for economic and empirical analysis. Since NMPs are controlling the manure applications only on livestock farms, will tighter nutrient-use limitations as a result of residual effects induce unwanted and even illegal manure-handling practices? Dairy management plans in the San Jacinto watershed report manure as being both imported and exported from the region. They also suggest that illegal dumping is taking place. The challenge is not only to introduce regulation but also to enforce it; and the more costly the regulation, the more incentives there are for noncompliance.

Furthermore, there are suggestions that NMPs should be applied not only to livestock farms, but also to all



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farmland utilizing manure. This, too, might have unintended consequences. Crop farmers' willingness to accept manure as a substitute for chemical fertilizers depends, for instance, on his/her perceptions of its nutrient content. If these do not coincide with those set by NMPs, crop farmers' willingness to substitute manure would decrease. This would force the livestock farmers to either directly subsidize crop farmers' manure applications or to find manure application areas farther away. Both practices would increase livestock farms' compliance costs—and strengthen the desire for noncompliance.

Finally, introducing policies based on a global perspective may be very beneficial to the United States or the state as a whole, but could have negative impacts in some of the affected regions. An example of this would be seen if the upstream region is forced to take uncompensated actions that improve the downstream region's water quality. This distributional conflict may lead to the use of political processes to prevent enactment of certain policies.

Lobbying by different regional groups could carry major implications

for policy formation. Therefore, policy design may require incorporation of compensation mechanisms that will reduce the loss to upstream producers as they modify their actions to improve water quality downstream. The incorporation of political-economic considerations is becoming an important part of environmental policy design, and will have major effects on total societal welfare as well as the welfare of individual groups.

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