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Rising energy prices and the economics of water in agriculture

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Abstract

Rising energy prices will alter water allocation and distribution. Water extraction and conveyance will become more costly and demand for hydroelectric power will grow. The higher cost of energy will substantially increase the cost of groundwater, whereas increasing demand for hydroelectric power may reduce the price and increase supply of surface water. High energy prices and geopolitical considerations drive investment in land-and water-intensive biofuel technology, diverting land and water supplies to energy production at the expense of food production. Thus, rising energy prices will alter the allocation of water, increase the price of food and may have negative distributional effects. The impact of rising energy prices and the introduction of biofuels can be partly offset by the development and adoption of new technologies, including biotechnology. The models considered here can be used to determine the effects of rising energy prices on inputs, outputs, allocation decisions and impact on distribution.

Keywords: Biofuels; Conveyance; Groundwater; Surface water; Water price

1. Introduction

Much of the expansion of modern irrigation during the 20th century took place in the context of cheap energy derived from fossil fuel. At the outset of the 21st century, regulation induced by concerns about global climate change, rapid growth in energy demand and constrained supplies of fossil fuels have resulted in increasing energy prices (Rajagopal & Zilberman, 2007). High energy prices can be expected to have significant consequences for the water sector. It is therefore important to consider how energy prices affect water use and the value and allocation of water and to develop policies both to mitigate the

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negative impacts of rising energy costs and to exploit the benefits of potentially positive impacts. This paper uses economic theory to provide insights into and hypotheses about situations that are likely to occur in the future. We concentrate our analysis on irrigated agricultural systems, where the impact of rising energy prices is expected to be particularly acute.

Using the tools of applied welfare economics (Just *et al.*, 2004) and expanding basic models of water economics (see survey by Schoengold & Zilberman, 2007) to emphasize energy issues, we identify socially optimal outcomes that maximize net social benefit, or equivalently, economic welfare. We also analyze institutional frameworks that may lead to optimal outcomes and consider reform for systems characterized by subsidies and water-use defined by water rights. Our analysis also emphasizes distributional effects and proposes policies to provide more equitable and efficient outcomes.

Sections 2 and 3 consider the direct effect of higher energy prices on existing agricultural crops and water systems. We first consider simple systems that model local extraction and use. We then introduce a model that incorporates conveyance. For both systems, we analyze the energy price effects in idealized situations characterized by efficient water allocation and then consider situations that may better approximate to reality. We assess the impact of higher energy prices on the price of water, food and other resources, and on the welfare of water users and end consumers. In Section 4 we consider the effect of biofuels on agricultural water use. Section 5 concludes and offers suggestions for further research.

2. Impact of energy prices on diverse water systems

Agricultural water use is diverse across regions. The impact of rising energy prices, therefore, will be heterogeneous. The impact will be transmitted through changes in food markets and water markets. Rising energy prices have two direct impacts on these markets. The transportation cost effect increases the cost-to-market for agricultural producers. The variable input cost effect raises the cost of energy-intensive farming input, including seed, chemical fertilizer, herbicides and pesticides. These effects will increase costs and reduce agricultural supply. Because food demand is relatively price inelastic (Gardner, 1988), small decreases in food supply (induced by rising energy prices) will lead to significant food price increases. We term this effect the food price effect. It is a function of the transportation and variable input cost effects. As we will see later, these three effects will have an impact on the marginal benefit (or value of marginal product) of, and hence the demand for, water in agriculture.

According to Schoengold & Zilberman (2007), 80% of agricultural land is rain-fed agriculture and it produces 60% of world food. Rain-fed agriculture will experience transportation cost and variable input cost effects from rising energy prices. Food production will decrease, food prices will increase and farmers will substitute away from energy-intensive chemical inputs. This will improve water quality by reducing chemical runoff and leaching. The substitution of fuels and chemicals by land may increase soil erosion and the loss of natural habitat.

In contrast to rain-fed agricultural systems, irrigated systems constitute 20% of agricultural land and produce 40% of agricultural output by volume and more than half of the value of agricultural production. Sixty percent of irrigated land uses surface water and a majority relies on energy for diversion, pressurization and/or irrigation. For surface water systems with negligible energy use, including those relying on gravity for diversion and irrigation, the effects of rising energy prices are similar to those for rain-fed systems: less output, higher food prices, less chemical input and runoff and more labor, land, erosion and loss of natural land. The key difference for these gravitational systems is that producers with access to additional water will expand water use as they expand land use. This will reduce water availability for environmental purposes.

Rising energy prices will have a most significant impact on irrigation systems that rely on energy for pumping groundwater, diverting surface water and irrigation, as well as irrigation systems that are part of larger water projects that include dams. Groundwater is used on 40% of irrigated land (8% of total agricultural land) and in 2000, energy for irrigation accounted for between 4 and 25% of groundwater system production costs. Groundwater is a dominant form of irrigation in regions like China and India. Ten percent of irrigated land relies on pressurized irrigation, including sprinkler and drip irrigation. The rest of this paper will investigate agricultural water systems that are energy dependent. We will to refer to them as "water systems".

At the outset, we consider a generic system in which water supply is energy dependent. For example, it could be a groundwater system with local pumping or a surface system that relies on energy for diversion. We examine the case of a competitive water market without externalities, dynamic considerations or free-riding. In this case, optimal water use and price are determined by the condition that the marginal benefit of water (water demand) is equal to the marginal cost of water (water supply). An increase in the price of energy increases the marginal cost of water and thus reduces water supply. It also affects water demand through the food price effect, the transportation cost effect and the input cost effect. The food price effect increases net farmer earnings and consequently, water demand. The transportation cost effect reduces net farmer earnings and, consequently, water demand. The variable input cost effect may increase or decrease the marginal benefit of water depending on whether water is a substitute or complement to variable inputs for which prices increase.

In the likely case that the food price effect dominates because of price inelastic food demand, high energy prices will increase water demand and reduce water supply. This will yield an increase in water prices; water use may increase or decrease. An increase in energy prices is more likely to reduce water use the more price inelastic is water demand. However, in regions that are far away from markets and where the transportation cost effect dominates, increasing energy prices will reduce both water demand and water supply, yielding a reduction in water use, but an ambiguous affect on water prices. Again, the more price inelastic is water demand, the greater is the probability that these effects will produce a fall in water use and water price.

This analysis assumes that the demand for food does not change and that increases in the food price result from decreased supply owing to high energy prices. It should be noted, however, that the same forces responsible for rising fuel demand, such as income growth in developing countries like India and China, may also increase demand for food. This income effect leads to increased food prices during periods of increased energy prices and the compounded food price effect will cause an extra increase in the price of water and reduce the likelihood of situations where higher energy prices increase the price of water but reduce its use.

2.1. Future and environmental considerations

Water is a natural resource and its extraction may impose environmental costs. Taking this into consideration, Schoengold & Zilberman (2007) suggest that the optimal condition for water use in systems without conveyance, obtained by maximizing social benefit, is:

$$\mathrm{MB}(x, p_e) = p_w = \mathrm{MEC}(x, p_e) + \mathrm{MFC}(x, p_e) + \mathrm{MNC}(x, p_e) \quad (1)$$

where MB(x,p_e) is the marginal benefit of water use in agriculture as a function of quantity of water, x and price of energy, p_e. This represents the agricultural demand for water and embodies the food price, transportation cost and variable input cost effects. MEC(x,p_e) represents the marginal extraction cost of water, which, broadly interpreted, is either the cost of pumping groundwater or the cost of diverting surface water. MFC(x,p_e) is the user cost (Burt & Cummings, 1970), defined as the discounted marginal cost of reduced future benefits because of increased water use today. MNC(x,p_e) is the marginal externality cost of water use. The change in optimal quantity depends on how rising energy prices will affect each element of condition (1). The equilibrium before energy price increases is depicted graphically as point A in Figure 1.

Rising energy prices will increase marginal extraction costs and marginal benefits if the food price effect dominates the transportation effect and variable input effect. This is depicted by the shifting curves in Figure 1, where subscripts 0 denote pre-energy price increases and subscripts 1 denote post-energy price increases. The marginal externality costs for a given amount of water are increasing with the application of chemicals. As discussed previously, the variable input cost effect predicts a reduction in chemical use as energy prices increase. Therefore, we expect rising energy costs to reduce marginal externality costs. The user cost of water, which reflects the discounted scarcity value of water, is the difference between the discounted marginal benefit of water and the discounted marginal cost of water, including externality costs. In Shah *et al.*'s (1995) dynamic model of groundwater management, marginal benefit is unchanged by increases in extraction costs, so the effect of the extraction cost increases is to reduce user costs; the benefits of future extraction decrease.

In the model presented here, it is possible that high energy costs will increase the marginal benefit of water more than they increase marginal cost (inclusive of externality costs) and result in increased user cost. This can occur in situations in which dynamic constraints are not binding and water use is increasing as energy prices increase. Open-access problems in groundwater systems, characterized by either or both excessive extraction and excessive pollution relative to the social optimum, are principally

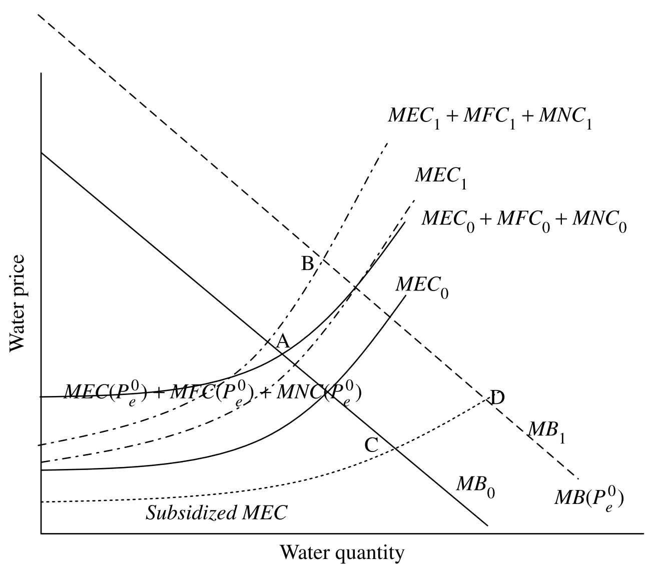

Fig. 1. Water pricing and use with higher energy prices.

caused by the failure of economic agents to consider user costs in their determination of optimal water use. When energy prices lead to an increase in the user cost, as is likely with a significant food price effect, then the distortion associated with open-access grows and the demand for corrective policy intervention increases. On the other hand, when the food price effect is small, rising energy prices will reduce the distortion associated with failure to consider the user and marginal externality costs and can lessen demand for corrective policy.

If we assume the impact of rising energy prices on extraction costs dominates their impact on user and externality costs and if we further assume the food price effect of higher energy costs is the dominant impact on the marginal benefit of water, then increasing energy prices will raise the socially optimal price of water and may increase or reduce the optimal level of water use. When the food price effect is compounded by the effect of increased incomes, higher energy prices are more likely to cause an increase in water use. We depict a situation in which increasing energy prices raise both water use and water price by point B in Figure 1. For cases in which the transportation cost effect is the dominant effect on water demand and the extraction cost effect dominates changes in water supply, the effect of increasing energy prices will be to reduce optimal water use. In theory, these conditions can also lead to a reduction in water price.

The outcomes considered in the foregoing analysis do not reflect reality in many situations. The marginal cost of water considered by farmers is often well below the social optimum because of direct subsidies of water or energy for pumping and because of disregard of user cost and externality costs. Therefore, in many cases, water use exceeds the consumption that would result from consideration of extraction costs even without considering environmental externalities issues. In these cases, water use far exceeds the social optimum. In Figure 1, the *laissez-faire* market equilibrium before energy price increases occurs at point C. Rising energy prices may increase the gap between the socially optimal price and the subsidized price (as seen at point D in Figure 1), making water subsidization more costly and perhaps inducing demand for policy reform.

2.2. Institutional constraints and technology adoption

Water subsidization is a welfare policy, the burden of which is shared by taxpayers, future generations and the environment. Under our assumptions, higher energy costs significantly increase the cash cost of subsidized water extraction and diversion, which might make subsidization less politically feasible. High energy prices may, therefore, provide a catalyst for change. Crises often trigger policy reform in the arena of natural resources (Rausser & Zusman, 1991). Moreover, when high energy prices are associated with significantly higher net food prices for producers, farm income is likely to increase significantly and allow farmers to absorb higher costs. Gardner (1988) provides evidence that support for agriculture policy tends to decrease during periods of high prices. While in most cases this evidence applies to support of output prices and incomes, one might expect this to hold true for subsidization of inputs like water and energy. In some cases, an increase in water prices and reduction of subsidies may harm poor farmers, but a welfare system of income support which does not distort production decisions is preferable to water subsidization for all. Direct income support might be politically infeasible in some circumstances. An alternative would be to introduce tiered pricing that offers a minimal amount of water at a low price and charges higher prices to users of high volumes.

Water markets can also be distorted by systems that allocate water by queuing or restrict water trading. In queuing regimes, producers with senior water rights are likely to use water excessively so that the marginal benefit of water is lower than the opportunity cost and the productivity of water resources is low relative to the social optimum. Water productivity can be enhanced by introducing water trading. The transition to water trading is associated with high infrastructure and transaction costs which may be exceed the benefits of improved productivity (Schoengold & Zilberman, 2007). Increasing energy prices that lead to increased food prices are likely to increase the efficiency loss associated with the misallocation of water by queuing systems. This may justify the cost associated with the introduction of trading. Political economic considerations may require that the introduction of trading does not harm senior water rights owners. This can be accomplished by the introduction of transferable rights on the basis of historical use. This approach will allow poorer and less-efficient farmers to gain from selling, renting or trading their water rights.

Rising energy prices might induce the adoption of improved production technologies, such as modern irrigation, and improved seed varietals and extraction technologies, such as pumps. Technology adoption becomes more likely if energy prices also lead to the reduction or elimination of water subsidies and energy subsidies for pumping. In these cases, technology adoption increases operational profits but also increases fixed costs (Schoengold & Zilberman, 2007). Under likely conditions, adoption of modern irrigation technologies improves water-use efficiency and thereby increases yields and reduces water use. Adoption of efficient pumping reduces the marginal cost of water and therefore tends to increase yields and water use, which increase water-use efficiency, tend to increase yield per acre and reduce water use. Before energy price increases, the fixed costs of adoption deter widespread use of modern irrigation and extraction technologies. Higher energy prices and the resulting increase in food prices may give farmers the incentive to upgrade their technologies for a gain in revenue and decline in energy costs.

The gains from adopting improved pumping are smaller for farmers who employ modern irrigation technologies. Similarly, the gains from modern irrigation are smaller for farmers who employ better pumping. Therefore, there exists a range of energy price increases in which only one of the two technologies is adopted. If energy price increases are sufficiently high, both technologies will be adopted, further increasing yields and saving energy. The net effect of adoption of both technologies on water use is ambiguous. Water use may increase if the effect of the improved pumping is stronger than that of improved irrigation.

3. Water systems with extraction, conveyance and use

Water extraction and use often occur at different locations. Therefore, a key element of water systems is the transfer of water from the source to the location of use through the use of canals. Water projects often move water downhill and can generate hydroelectric power. In some cases, however, water projects must move water uphill, in which case energy is consumed, not produced. Increasing energy prices can therefore impose higher costs on or afford higher earnings to operators of water conveyance systems. Changes in costs and earnings are expected to affect the availability and productivity of water.

Complete analysis of water systems must incorporate conveyance and extraction issues, as well as future and externality costs. The analysis of the previous section provides the general qualitative assessment and basic formulas to address externalities and user cost issues and their implications. For simplicity and tractability of the present analysis, we assume away externality and user costs and further assume (1) irrigation and extraction technologies are fixed and (2) all extracted water moves through the system, in other words, there are no transmission losses. Let NE(x) be the net energy generated by conveyance. It is positive when the transfer of water generates energy and negative when conveyance consumes energy. The net conveyance (energy) benefit associated with the transfer of x units of water is $\mathrm{NCB}(x, p_e)\acute{Z} = p_e\mathrm{NE}(x)$. The benefit from use of water in irrigation is $\mathrm{B}(x, p_e)$ and the extraction cost is $\mathrm{EC}(x, p_e)$. Under these assumptions, the social optimization problem with conveyance is:

$$\max_x \ \mathrm{B}(x, p_e) - \mathrm{EC}(x, p_e)\acute{Z} + \mathrm{NCB}(x, p_e) \tag{2}$$

The optimal extraction of water and its price are determined according to:

$$\mathrm{MB}(x, p_e) + \mathrm{MNCB}(x, p_e) = \mathrm{MEC}(x, p_e) = p_w^X(x, p_e) \tag{3}$$

where $p_w^X(x, p_e)$ is the socially optimal price of extracted water. If water transfer produces more power than it uses (MNBC is positive) and energy prices increase, then conveyance considerations will act to increase water price and use. Thus, there may be situations in which conveyance causes water use to increase amid rising energy prices. Conversely, if water transfer requires energy (MNCB is negative), increases in energy prices will act to reduce the extraction of water and its price.

With conveyance, there is a gap between the price of extracted water, p_w^X and the price of water to the final users, p_w. The optimal price of water for final users is the price of the extracted water minus the marginal net benefits from energy:

$$p_w(x, p_e)\acute{Z} = \mathrm{MEC}(x, p_e) - \mathrm{MNCB}(x, p_e) \tag{4}$$

If there is a net energy gain from the production of hydroelectric power, then the optimal price of water to the farmer is lower than the optimal price to a farmer in a system without conveyance. If there is a net energy loss in conveyance, then the optimal price of water to the farmer is greater than the optimal price to a farmer in a system without conveyance. These results imply that geography matters. Water systems that transport water downhill to users and which generate hydroelectric power may be expanded, whereas water systems that move water uphill may decline.

Let us now relax our assumption of fixed technologies and consider the availability of conservation technologies for extraction and irrigation. If conveyance consumes energy overall, then conveyance considerations will act to increase the likelihood of adoption of water conservation technologies when energy prices increase. However, if conveyance provides a positive benefit from hydropower, conveyance considerations will reduce the likelihood of technology adoption when energy prices increase.

If we further relax our assumptions and permit the possibility of transmission losses, we can consider the role of investment in conveyance. Conveyance losses can be reduced by investment in conveyance. Chakravorty *et al.* (1995) demonstrate that the effective price of water to farmers is decreasing in conveyance efficiency. Regardless of energy gains or losses in conveyance, increased energy prices will make transmission losses more costly. More costly transmission losses may lead to investment in improved conveyance. Since improved conveyance lowers the effective price of water to farmers

(Chakravorty *et al.*, 1995), higher energy prices may indirectly contribute to increased water use and reduced water prices for farmers through their effect on investment in conveyance.

We previously argued that farmers might benefit from higher energy prices because of a dominant food price effect. Our analysis of conveyance suggests that even with constant food prices, final water users do not necessarily lose from higher energy prices. Farmers who receive water from systems that are net generators of energy will benefit from increased energy prices, while farmers relying on systems that require energy, like groundwater extraction, will lose. Thus, higher energy prices may lead to a reduction of water use by groundwater systems, but an increase in water use by some surface water systems. The results also suggest that regardless of whether water is transferred uphill or downhill, higher energy prices will increase the value of investment in conveyance.

4. Biofuels and alternative energy

The rise in energy prices in recent years reflects growing demand spurred by high economic growth in Asia and physical and political constraints on the supply of fuels. The growth in energy demand is likely to continue; the International Energy Agency predicts energy demand will increase by 53% between 2005 and 2030. This demand growth, coupled with concern about global warming and the depletion of oil reserves, has fueled a scramble for alternative fuels. Biofuels appear to be highly competitive among alternatives, especially in the short run. Thus, provision of crops for fuel production is likely to become an increasingly important agricultural activity. Furthermore, significant water resources will be diverted for the generation of biofuels and other alternative fuels, including oils from coal, gas, tar sands and from deep, partially depleted wells. Consequently, analysis of the impact of increasing energy prices and scarcity on the water sector should incorporate the growing demand for water in energy production.

We will analyze the impact of biofuels within large systems that affect food prices (national water systems) in Figure 2. Let the demand for water used for food production, under the initial and new energy prices be denoted by D_F^0 and D_F^1, respectively. These demand curves are functions of energy price and water price and are adjusted for general equilibrium effects on food price (Just *et al.*, 2004). We assume that D_F^0 is below D_F^1, implying that higher energy prices increase the demand for agricultural water (the food price effect is dominant). Let the demand for water for biofuels with initial low energy prices be denoted by D_E^0 and the demand for water for biofuels at the high-energy price be denoted D_E^1. Because the demand for food is inelastic, the derived demand for water for food is inelastic and has a steeper slope than the demand for water for biofuels, since energy has a relatively more elastic demand than food.

The marginal cost of water is MC_0 amid low energy prices and MC_1 with high energy prices. In Figure 2, the demand for water for food production in the first period intersects with the supply of water at point A, which is above the intersection of supply and demand for water for energy. Water is not used for energy in the early period. As the price of energy increases, biofuels can compete with food production for the use of water, so the joint demand for water is GEF in Figure 2. The demand and marginal cost of water intersect at point B. Figure 2 shows that the higher marginal cost of water and the increase in demand, mostly owing to the introduction of biofuels, will increase the market-clearing price of water. The quantity of water demanded may increase, while the amount of water for agriculture declines.

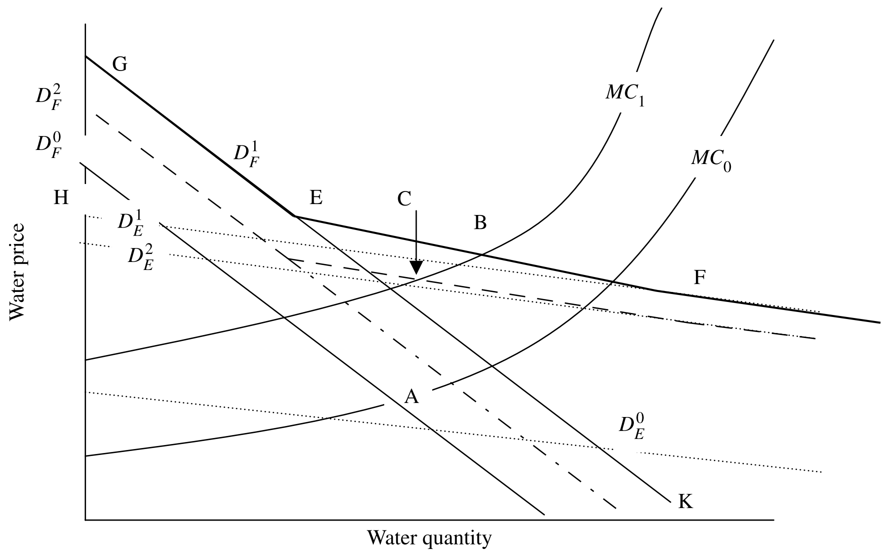

Fig. 2. The equilibrium of water pricing and use with biofuel.

The decline in the amount of water flowing to agriculture will reduce the production of food from irrigated agriculture, reducing the availability of food and rising food prices. Lower food availability and the resulting higher costs are likely to disproportionately affect the poor, especially in developing countries. As a result of increased demand for ethanol, corn prices in 2007 are at historic highs and the stock-consumption ratio for corn is at the lowest level it has been for a long time. Higher prices for agricultural commodities can be beneficial to the landholding poor, but damaging to the urban and landless poor.

The negative affects of biofuels on the poor can be mitigated by research that increases the productivity of biofuels and conventional crops. Biofuels have been derived from plant parts used for food like grains and seed, but more than half of the absolute dry matter in the global harvest is composed of cellulosic substances like straws, stover, leaves, and so on, which are largely unused in energy production. Commercial technologies that allow conversion of cellulose to fuel will increase the productivity of food crops in producing biofuels. It will also enable cultivation of perennial grasses like *Miscanthus* and switchgrass that have higher potential for biofuel generation than food crops. Introduction of conservation technologies, like improved irrigation and yield-enhancing technologies, like new seed varieties, may also reduce the impact of biofuels on the food sector.

Since the demand for food is relatively price inelastic, introduction of technologies to increase food crop yields will increase food production and lower food prices. Water-conserving technologies, like drip irrigation, also tend to increase yields. In Figure 2, a new equilibrium resulting from the adoption of new technology is depicted at point C, which is characterized by lower water use and a lower water price relative to the *status quo*. In specific cases (not illustrated), where new seeds result in drastic productivity improvements, the new technologies may increase food production and lower food prices while increasing water price and use. New technologies will counter the effect of biofuels on food prices even more if the technologies can be used to increase productivity of food and energy crop production.

Expansion of water use for agricultural production has environmental costs (that were not explicitly modeled here). The introduction of new technologies that increases the productivity both of biofuels and of traditional food crops not only reduces the pressure on consumers, but also reduces depletion of water resources and addresses environmental problems. The analysis in this section assumes that water pricing is determined by the intersection of extraction costs and demand, and we do not consider environmental or future costs. Of course, current water pricing does not include these costs either. Therefore, the analysis presented here is a roughly accurate portrayal of reality, except that water is subsidized. Because biofuel production raises the price of water, the introduction of biofuels increases the distortion associated with water subsidies. Subsidization of water amid rising energy costs and rising demand for biofuels may exacerbate the depletion of water resources, increase the environmental cost of water use and delay adoption of water-efficient technologies. The increased financial burden on government agencies associated with continued subsidization, combined with the improvement in farm sector welfare because of higher food prices and earnings from biofuels, will provide opportunities to wean agricultural producers from, or reduce their dependence on, water subsidies and other forms of support.

Gains in productivity of food and biofuel production can mitigate the effects of rising energy prices. In particular, transgenic crops have proven to increase crop yields while reducing demand for inputs like pesticides. The next generation of genetically modified crops will also require less water than current crops. Despite these significant benefits, agricultural biotechnology has faced political opposition that is not supported by scientific research. Bans in Europe and opposition elsewhere around the world are crippling the growth of this technology and its ability to reduce water demand.

A comprehensive solution to the pressures imposed on water systems by rising energy prices must include more than just improved technologies for crop production, water extraction and conveyance. Incentives need to be aligned. In particular, externality costs of energy and water use need to be internalized to induce conservation. Energy conservation, in particular, can reduce demand for biofuels and, consequently, demand for water for energy production.

5. Conclusion

Rising energy prices will make the extraction and conveyance of water more costly and may result in greater demand for hydroelectric energy. High energy prices and political considerations are producing a greater demand for alternative fuels, including biofuels, which are both land and water intensive. Food prices have increased and are expected to continue to rise because land and water supplies have been diverted to biofuels and because food production becomes more costly with higher energy prices. These trends will alter the allocation of water and may induce distributional problems for poor and dry regions of the world.

The development of technologies to extract water more cheaply and transport water more efficiently can offset the effects of rising energy prices, which are expected to induce adoption of new and better technologies. Perversely, the adoption of such innovations can improve the productivity of water, raising demand for water and potentially worsening over-extraction problems. Technologies that improve agricultural productivity can mitigate the impact of increased energy prices on food markets and sometimes, on water prices and use. Efficient water allocation mechanisms will become increasingly important. Higher energy prices increase the cost of flawed institutions, such as poor distribution systems, restrictions on water trading and water subsidy regimes. Because the likelihood of reform is increasing with the potential gain, increased energy prices will be likely to encourage reform of water policy to more efficient systems.

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