5. Economics

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5.1 Introduction

The FEW sectors are often strongly linked. Actions that seek to optimize outcomes for food, energy or water separately, often lead to less than optimal outcomes for the other sectors. Bazilian and colleagues (2011) conclude that treating the three areas of the FEW Nexus holistically "would lead to a more optimal allocation of resources, improved economic efficiency, lower environmental impacts, and better economic development conditions, in short, overall optimization of welfare. " Indeed, much Nexus work arises from an underlying assumption that by better managing the resources overall societal benefits arising from those resources can be increased.

Economics is frequently defined as the study of how people allocate scarce resources when needs and wants of those resources are unlimited. Economics can provide metrics which can be utilized when evaluating the benefits and costs arising from potential actions.

Economics also permits one to look at not only total regional welfare but also at the welfare of participants in the Nexus identifying who gains and who loses under alternative scenarios. This provides a way to understand the incentives needed to attain full cooperation in strategy implementation.

In this chapter, we address economic aspects of the Nexus and broader issues regarding the analysis of the Nexus. We will cover:

[1] concerns about incorporating market reactions and prices;
[2] behavioral reactions of individuals given Nexus actions;
[3] non-market valuation;
[4] welfare analysis;
[5] the value of water in alternative uses;
[6] economic influences on observed Nexus strategies;
[7] the transfer of results between studies;
[8] induced innovation;
[9] adding consideration of limits; and,
[10] designing incentives.

In broader terms, we will cover externalities, income distribution and inequality effects, dynamics, uncertainties and risk aversion, public-private roles, and cost-benefit analysis. We will also use a case study as an example to illustrate economic considerations concerning FEW Nexus metrics, data, and modeling which will be explored in greater detail in Chapters 13-16.

5.2 Economic Aspects of the Nexus

Here we discuss major economic issues when considering potential FEW Nexus actions (which we will call projects). In doing this, we will both reveal theoretical concepts and ground them in practical FEW Nexus domains to illustrate why consideration of these concepts is essential.

5.2.1 Incorporation of Demand and Supply Relations

A FEW project can both add extra supply to the market and alter input usage leading to market price changes. In turn, such price changes can alter the revenue and cost outcomes of the project. However, it is common for project evaluation to assume prices of outputs, by-products, and inputs remain unchanged. Thus, price reactions are essential considerations in Nexus project evaluation.

Bioenergy provides several illustrations of this effect. In 2005, the United States adopted a Renewable Fuel Standard or “RFS” which requires the blending of renewable biofuels into traditional hydrocarbon fuels. In practice, this primarily involves corn-based ethanol blended with gasoline and biodiesel blended with diesel. Over time the volumes required to be blended have increased, and both the price of the ethanol and the price of corn have increased exhibiting a response along the supply curve.

In fact, corn prices in 2011 were triple those in 2005 (note other forces contributed as discussed in Abbott, Hurt and Tyner 2011). In 2017, corn prices were still more than 50% greater than 2005 levels. These significant price changes have a significant impact on the economics of corn-based ethanol production.

In the bioenergy world, by-products are often advanced as valuable items that can help support bioenergy production. However, one must be careful to consider the price changes brought about by increased supply.

Consider one such by-product: glycerol arises as a by-product when producing biodiesel. The expansion in biodiesel production resulted in additional glycerol production so large (2.8 million tons) that it exceeded the market volume before the expansion (2 million tons). As a result, the market saturated, and the price crashed. Moreover, the crude glycerol by-product from biodiesel production contained toxic elements and exhibited a substantial difference in color, decreasing its market value. Consequently, the glycerol by-product became worth less than the cost of selling it and now it is an item for disposal.

This example shows the need for considering by-product demand relations when evaluating Nexus projects. Moreover, this is not always done, for example, Wooley(1999) identified glycerol as a by-product contributing to profitability while Ciriminna et al. (2014) identified glycerol as a disposal issue that costs money to dispose of.

The anticipation of price changes requires broad industry level consideration. For any single firm, the input use or by-product quantity is typically not large enough to stimulate price changes. However, when many firms pursue the same actions, then the quantities are large enough, and price changes occur. Such a process is called the **fallacy of composition** by economists. The lesson here is that industry trends also need to be considered when evaluating Nexus projects.

Demand relationships are also key when Nexus actions cause product prices to increase. For example, in an energy-only context, in the early 1970's, the state of Washington Public Power Supply System (WPPSS) responded to a 7% annual growth rate in electricity demand by initiating construction on five nuclear-generating facilities. The cost of constructing nuclear power plants was deemed too high to be covered by funds just raised by issuing bonds and WPPSS began to raise electricity rates paid by customers. This led to a demand response in the form of lowered electricity consumption. The needed revenue for the financing did not materialize and contributed to the abandonment of four of the new plants and the largest bond default in U.S. history.

Collectively, one must incorporate product demand and input supply relations in Nexus project evaluations. If this is not done, there is a high likelihood of a biased evaluation and an unanticipated result.

5.2.2 The Rebound Effect

Economists have noted in many cases that subsidizing conservation, like water conserving technology, can stimulate decision-makers to increase usage - the "Rebound Effect." However, Nexus projects are often analyzed under a strong assumption that the current economic and technical characteristics will be unchanged. However, this may not hold as increasing refrigerator efficiency and thus lowering the cost of say refrigerating food may cause people to buy more refrigerators resulting in less to no savings in energy.

As a specific example, several western U.S. states subsidized water conserving irrigation technologies, and assumed that only the equipment would change. However, Pfeiffer and Lin (2014) analyzed such a case in Kansas and found this lowered water costs to farmers and stimulated a higher production of irrigated crops, including expansions onto previously unirrigated lands. The end result was increased overall water use.

Thus, one needs to consider possible rebound effects when Nexus projects are implemented to lower water or energy usage and costs.

5.2.3 Non-Market Valuation

Nexus projects often alter abundance or characteristics of items that don't trade in marketplaces such as ecosystem functions, air and water quality, recreational access, climate, and other phenomena. Economic appraisals of the effects on these items involve what economists called nonmarket valuation.

However, placing a value on such items may make a project more or less desirable. For example, replacing a coal-fired generating plant with a solar farm may not be cost-efficient in some locations.

However, the impact of the solar farm on reducing air pollution and emissions of greenhouse gases may make the project more desirable.

Valuing non-market items involves determining how much society would need to be paid to live with the adverse effect (diminished air or water quality, loss recreation, or climate change), or conversely, how much they would be willing to pay for the more desirable outcome.

Many techniques of non-market have been introduced. Techniques are usually divided into two approaches: stated and revealed preference methods. Stated preference method measures individuals' value for environment quality directly, by asking them to state their preference for the environment. Revealed preference method seeks to recover estimates of individuals' willing to pay for environment quality by observing their behavior in related markets. (see the detailed discussion in the estimated "cost of carbon" or, various revealed or, stated preference approaches.

As reviewed in Chapter 9 (Ecosystem), economic valuation reveals the trade-offs within the Nexus and the impacts of various agricultural systems on the ecosystem services. Estimating the valuation of an ecosystem involves estimating the way that the ecosystem is involved with increasing production of market goods then estimating the marginal effect of a change in ecosystem services, (i.e., altered water quantity or quality as discussed in Hanley, Shogren, and White, 2002). These ecosystem services can involve many diverse items such as changes in spawning habitat for commercial fish species or water yields or clean water. Other ecosystem services which could be valued similarly include nutrient cycling and the provision of genetic resources. The value of the ecosystem can then be indirectly inferred from the changes in the value of goods produced due to changes in the supply of these services because of, say, a loss in the area of the ecosystem.

5.2.4 Welfare

Economic welfare is a monetary measure of the gains (or losses) achieved by consumers from having cheaper, more abundant (more expensive, scarcer) Nexus products. It also measures the gains to producers in the form of profits from having more Nexus resources available or losses under the converse. Welfare estimates the willingness to pay to avoid some negative force like pollution, or the willingness to accept compensation in the face of a Nexus management practice being adopted that worsens their well-being. The producer component is called **producers' surplus**. The consumer component is called **consumers' surplus.**

Thus, the welfare effects of adopting a Nexus practice involve both producers and consumers welfare. This is an important distinction because many Nexus type studies only estimate the effect on producers without considering any consumer effects. The consumer benefits arise from lower product prices or greater product availability at a given price. For example, when considering climate change effects on crop production one should not only consider changes in commodity prices and producer revenue but also in the cost of consumer food purchases (see Adams et al., 1990 for an example).

In general, treatment of consumer effects means incorporating demand curves and assumptions other than fixed-prices for commodities. In particular, as more is produced then, assuming that the market share is significant, this will cause prices to go down giving consumers more for their money or the converse occurs with prices going up.

Overall, it is useful to do a welfare analysis in conjunction with the evaluation of a Nexus project on recognized groups of producers and consumers (i.e., farmers, electricity producers, low-income consumers, urban dwellers, rural parties, overseas parties, etc.) as opposed to aggregate analysis. Such a welfare analysis is commonly called a **benefit-cost analysis**.

> Benefit-Cost Analysis: benefit-cost analysis is founded on a branch of economics known as welfare economics. That is, what are the benefits and costs arising when implementing an action when the action affects welfare across elements of the economy? Questions like" Who benefits and who bears costs when a project is built?" and "Considering those who benefit and those who bear costs are the benefits larger than the costs?" are where benefit-cost analysis can be applied. The formula below simply speaks of benefits and costs, i.e. $\sum_{i,t} B_{i,t} \cdot (1+s)^{-t} - \sum_{i,t} C_{i.t} \cdot (1+s)^{-t}$, where t is time, i is the ith individual, $B_{i,t}$ are benefits to the ith individual in period t and $C_{i.t}$ are corresponding costs while s is the discount rate [Discount rate needs explaining for readers unfamiliar with the concept]. The basic decision rule for judging whether a project may be desirable occurs is when the results from the above formula are greater than zero.

There is also one result that is often confusing for some that merits explanation. Often actions that increase supply decrease producer welfare but benefit consumers, while actions that reduce supply are beneficial to producers but not consumers. This occurs since agriculture and energy both typically face an inelastic demand curve. In economics, inelastic demand curve means when the percentage change in price exceeds the change in quantity demanded, thus, for example, a 10% quantity increase could cause commodity price to fall by say 20%. The more inelastic the demand, the steeper the curve and the more price will react to a quantity change. More supply typically lowers prices substantially reducing producers net incomes but causing consumers to increase the amount of goods they buy, and causing the consumer dollar to go farther.

5.2.5 Value of Water in Alternative Uses

Water has differential value in alternative uses, such as irrigation, cooling in power plants, ecological support, human consumption, and direct use, pollution dilution, hydro-electric power generation, and unconventional oil and gas production (fracking). These differential values exist because of the high costs of moving water and historical water allocation procedures (like prior appropriation which give certain users water rights regardless of use value).

Consumers also derive value from water and actions that lower its costs as this allows them to consume more water or divert money to buy other goods again causing the dollar to go farther.

Consistent methods of estimating and comparing water values are required when examining the implications of Nexus projects. Approaches to value water are discussed in Young and Loomis 2014.

Market-based methods (Colby, 1989) include:

1) A **comparable sales approach** which involves a comparison of specific water one is trying to value with the prices and characteristics of similar water that has been recently sold or leased;

2) A **capitalization approach** which involves taking the net present value of the stream of income arising from the water;

3) A land value differentials approach which assumes the value of water is capitalized into land values and involves a comparison of the values of agricultural land with and without water access;

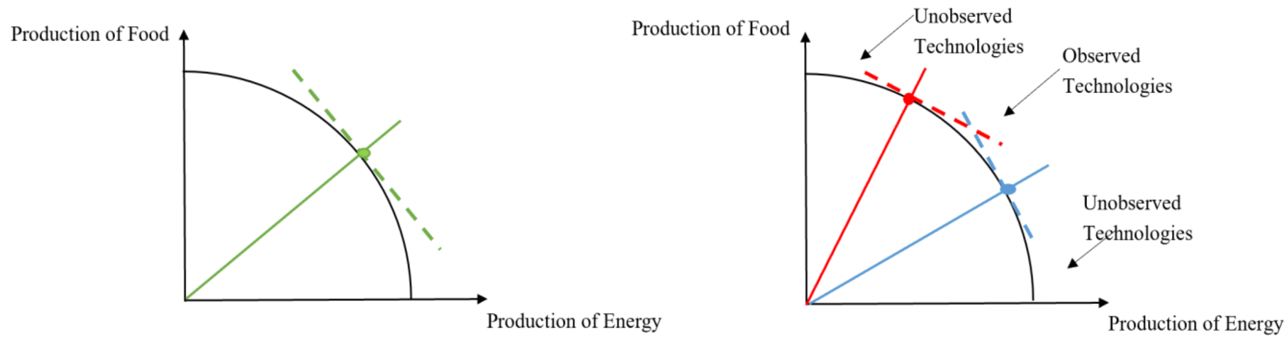
4) A **replacement approach** which involves the estimation of cost or replacing the water with the lowest cost alternative water supply source; and

5) An **econometric estimate** of water demand can be formed in some situations, where trading data can be attained along with sufficient information on other characteristics of the trade (i.e., is the water conveyed from a senior or junior right (senior or junior water right here means, for example, priority in water use when scarcity arise with senior water rights having first priority? Or, is the transfer permanent or a lease? And what are the lease terms?).

5.2.6 Economic Influences on Observed Nexus Strategies

A tempting way of identifying possible Nexus strategies is the observation of prior actions that address the Nexus either in the target region or similar regions. In such a case, there is an inherent bias in what can be observed that arises due to economic prices. In particular, the range of prices that have been observed for both output and inputs restrict what Nexus opportunities may have been chosen and thus can be observed. Let us look at theoretical and practical examples of this.

In setting up this example, we use the classical production possibilities curve as in Figure 5.1. The production possibilities curve is a graphical representation of the alternative combinations of goods an economy can produce showing how an expansion of production of one good may cause contraction of production of another. The bold black line in panels A and B gives a continuous set of energy-food production possibilities using different technologies. Each point on the curve represents a choice of a technology or a particular resource allocation which results in a certain level of food production (y-axis) and the corresponding level of energy production (x-axis). Thus, lower energy production correlates to higher food production or vice-versa.



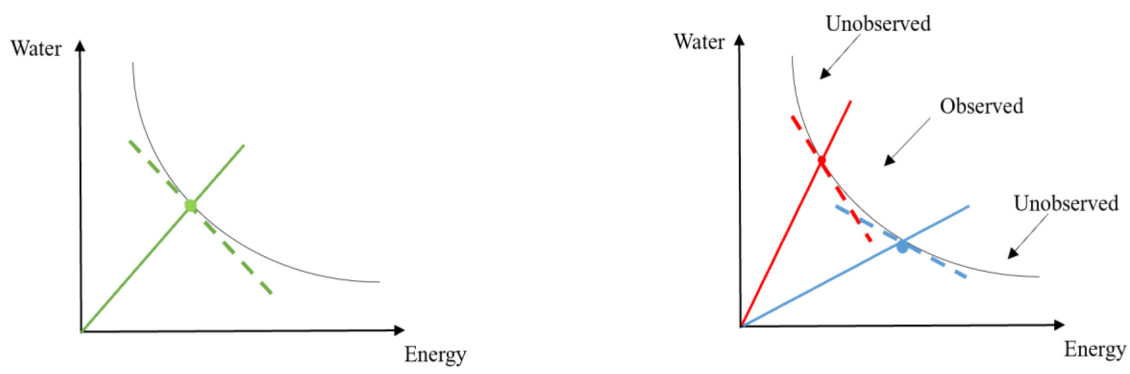
Panel A Panel B

Figure 5.1: Production Possibilities Curve and Items Chosen

In panel A, the solid green line gives the ratio of the food price to the energy price at a point in time. According to economic theory, the production technology chosen will be the one where there is a tangency between the line giving the price ratio and the production possibilities curve. This means production in our case will occur where the green dashed line is tangent to the bold black line - at the green dot.

Now given this basic setup, consider panel B where we have a solid red line representing the highest observed ratio of food price to energy price in recent history, and the blue solid line representing the lowest ratio again in recent times. Then, in this case, the only Nexus technologies we have observed fall between the red and blue dotted points and those outside that arc will not have been seen. This means for example if the ratio of say ethanol to gasoline prices has been in one interval that we would not have seen strategies appearing that allowed use of much more ethanol in cars which would only happen if much lower relative prices appeared.

A second example can be cast in terms of inputs using the classical **isoquant** that explains the relative use of two inputs given their prices as in Figure 5.2. Therein, assume the bold line in panel A gives a continuous set of possible quantities of energy and water used across the set of possible technologies. Also, assume the solid line gives the ratio of the energy price to the water price.



Panel A: Optimal Choice Given a Price Panel B: Domain of Strategies Given a Price Range

Figure 5.2: Production Isoquant and Strategies Chosen

According to economic theory, given the input price, the production technology chosen is the one at the point where there is a tangency between the line giving relative prices of energy and water and the isoquant, as occurs at the green point in panel A. Now given this basic setup, consider panel B where we have a solid red line representing the highest ratio of energy price to water price we have ever seen, and a solid blue dotted line representing the lowest ratio. Then, in this case, the only Nexus possibilities we have observed fall between the two-colored dots, and again there are a lot of unobserved possibilities that never got chosen because the prices did not favor them. This means, for example, if the ratio of say natural gas generated electricity to coal prices has been in one interval that we would not have seen strategies appearing that used much more natural gas in electricity generation which would only happen if much lower relative prices appeared.

However, Nexus actions or external forces can alter production possibilities, isoquants, and relative prices. Under such shifts, previously unattractive Nexus related production or resource usage strategies can become desirable. Thus, not all possible strategies will be observed and thus new never before seen strategies may arise.

As a consequence, identifying Nexus related strategies through surveys, interviews or other means will not generally describe the full set of possible strategies that may arise in the future.

5.2.7 Can I Transfer Results from Other Assessments into This One?

As discussed in 6.2.6 (Economic influences on observed nexus strategies), there exists prior actions that address the Nexus either in the target region or similar region. Frequently, results from other studies are used in a Nexus evaluation rather that developing primary estimates. A big issue in such a setting raises what economists called "**benefits transfer**" which refers to the transfer of benefit estimates from some other location into the differing project location. For example, Hansen and Ribaudo (2008) provide dollar-per-ton estimates for 14 categories of soil conservation projects while Young and Loomis (2014) contain an estimate of the value of water from various regions. However, using such numbers needs to be done with caution. Brouwer (2000) argues that most transfers appear to result in substantial transfer errors.

In covering benefits transfer, the Ecosystem Valuation website developed by King and Mazzotta (2000) states "The more similar the sites and the recreational experiences, the fewer biases will result" and then presents a discussion and cites the benefits of such an action as :

[1] Reductions in the cost of carrying out an appraisal;
[2] Speed of attaining the information;
[3] Ability to use the transferred estimate in constructing a rough estimate of the value of a project to see if more effort on it is justified; and
[4] Ability to use in making a gross estimate of the total item value (i.e., cost of water or reduced erosion).

It also cites the limitations as:

1) The transfer may not be accurate, except for gross estimates unless the sites share all characteristics;
2) Good estimates for the item at hand may not be available;
3) Appropriate studies may not be published and are hard to access;
4) Reporting in the studies found may not give one enough information to allow transferring the information with appropriate adjustments;
5) Quality of the other studies may be difficult to assess;
6) Extrapolation beyond what is covered in the initial study is questionable;
7) The accuracy of the transferred item is limited by that of the item itself; and
8) Estimates may be out of date.

5.2.8 Induced Innovation

New technologies are likely to evolve as input or product prices change. This involves **induced innovation**. The theory indicates that when the price of a particular input used in production increases or falls significantly relative to the price of other inputs, society will innovate by developing technologies that reduce or increases usage of that particular factor.

In a Nexus setting, an example is that when labor prices dramatically increase due to scarcity, society will invent ways of substituting other factors for labor, like going to the more capital-intensive harvesting practices. Similarly, if a fee is charged for GHG emissions, this will induce industry and others to develop strategies that produce goods with less emissions.

Induced innovation has also been observed in corn to ethanol conversions. In particular, when processing corn into ethanol, a by-product called distillers dry grains (DDGS) is produced. The rise in biofuel production resulted in a large increase in DDGS production and a fall in price. DDGS were initially only used in wet form (up to 70% moisture) and, due to transport costs, usage was limited to cattle feeding near the refinery. Eventually, innovation was induced, which transformed the wet DDGS into more valuable forms. Today high valued oil is extracted from DDGS, and the remainder is mixed with low-value corn stalks for animal feed. This product can now be processed into dry pellets, allowing long-distance shipping.

5.2.8 Adding Consideration of Limits

All strategies have factors which can limit their adoption. Such limits involve:

1) Financial capital availability, such as capital constraints and lending practices;
2) Human education and abilities, including sheer labor availability, labor skill, leadership capabilities, and educational attainment;
3) Resources available, including regional land, water, equipment, and infrastructure resources;
4) Consistency with cultural practices, such as societal values, worldviews, cultural norms and behaviors, perceptions of needs for action, and compatibility of strategies with lifestyles;
5) Availability of technology; and,
6) Knowledge of new practices, such as knowledge and awareness of water-conserving irrigation strategies as elaborated on in Chambwera et al. (2014).

Limits may be alleviated through educational programs, extension programs, loan programs, grants, and other actions. They may also render some strategies useless.

5.2.9 The Role of Incentives

It is rarely the case that a FEW Nexus action will make everyone better off (what economists commonly call an action that is **Pareto optimal**, and others call a win-win situation). Generally, at least one participant in Nexus or a group thereof will be made worse off by the given action.

In judging action desirability, economists generally utilize the **compensation principle** finding that the action is desirable if those gaining from the implementation have gains large enough to compensate those who lose (for discussion see Just, Hueth and Schmitz 2008).

When an action is implemented, there is no guarantee that the compensation will actually occur, i.e., if consumers benefit from a production increase while producers lose consumers generally do not compensate producers. However, if the individuals that would need to implement the Nexus action can choose whether or not to implement, then some form of direct compensation would be needed to get the Nexus action implemented. For example, suppose an action involves the construction of a reservoir in a valley containing a small number of farms, and that the purpose of the reservoir is supplying water to a nearby town, but it takes water away from the farmers. If the people who benefit from the reservoir, i.e., the urban population could in principle fully compensate the losers, i.e., the farmers, and farmers feel that they will be worse off as a result of the reservoir, then the reservoir may not be built. However, if compensation is actually paid, then the farmers may cooperate. Such a situation is common with water trades from agriculture to urban interests where water markets are a way that farmers can be compensated.

Compensation in the form of incentives needs to stimulate target entities to adopt costly practices which generally do not yield benefits to themselves even though others receive gains. Steps can also be taken to make current practices undesirable steering decision-makers to shift toward the Nexus action. Many different forms of incentives or steering disincentives are possible, including:

1) The introduction of markets for Nexus items, like a water market, where cities can buy the water from farmers who would lose if they lost access to the water, but the price for the water could be high enough to compensate the farmers for any losses;

2) The introduction of subsidies for equipment that a group would need to use to achieve the desired result, reducing the costs of the equipment directly or reducing the cost of money borrowed to buy the equipment. This might involve cities subsidizing the cost of more water efficient cooling equipment for use in electricity generation;

3) The introduction of taxes on equipment crucial to the continuation of current undesirable practices, such as one could tax conventional tillage equipment when one is interested in higher water use efficiency, and lower greenhouse gas emissions;

4) The use of technology standards which mandate an upgrade in technology to the desirable actions such as the automobile café standards on vehicle miles per gallon;

5) The imposition of some form of regulations such as banning appliances that do not meet certain water or energy efficiency characteristics such as high water shower heads; and,

6) The development of differentiated markets favoring products from Nexus implementing parties, for example, opportunities to purchase electricity only from renewable wind sources.

In implementing such incentives, one naturally needs to be careful about inducing such things as the rebound effect as discussed above and also will need to be flexible potentially increasing prices and decreasing prices to get the amount of resource transferred that is desirable.

5.3 Broader Items

Some other economic concepts merit mention including externalities, income distribution, dynamic concerns, uncertainty and risk aversion, public and private roles, and, cost-benefit analysis.

5.3.1 Externalities

Frequently, activities have positive or negative impacts that damage others for which they are not held liable. Such a situation is called an **externality** by economists where production or consumption of one of the Nexus items imposes negative impacts on other parties.

Here we will generally deal with negative externalities where the impacts on the other parties are adverse. Examples of such externalities commonly involve polluting emissions Such as:

1) where applications of nitrogen fertilizers on food crop impact local rivers and aquifers but is not reflected in the costs of the fertilizer appliers or their resultant crop product price;
2) GHG emissions from fossil fuel-based power generation; and,
3) pollutants entering aquifers associated with infiltration of produced fracking water.

Non-market valuation is often applied to value externality effects as discussed in Section 5.2.3. and Chapter 4.

A related concept is **maladaptation** where Nexus actions that meet the needs of one sector increase the vulnerability of sectors elsewhere or in the future. This is an important issue recognized in climate change adaptation literature (see Barnett and O'Neill 2010). Examples of maladaptation include: diverting floodwaters away from a city may result in flooding of other citizens along the path of diversion canal; and, extensive use of groundwater today depletes the resource so that it cannot be used in the future.

In dealing with negative externalities economists often state that the externality should be internalized. There are many ways of doing this including some of the incentives below:

1) Assignment of property rights, such as allocating grazing use permits on federal lands providing an incentive for those using land for grazing to avoid overgrazing;

2) Instituting markets for rights to pollute (commonly called cap and trade. For example, one can reduce GHG emissions below current levels by allocating rights to emit but than allowing the purchase and sale of those rights;

3) Imposing performance standards like the use of denitrification inhibitors or the institution of a Renewable Fuel Standard which requires certain volumes of renewable fuel; and,

4) Providing subsidies for equipment that reduces the negative impact, for example, lowering the cost of precision agriculture equipment to reduce nitrogen runoff, or lowering existing subsidies to fossil fuel production to increase price and lower consumption reducing air pollution and greenhouse gas emission externalities.

In doing this, one must be careful about adopting strategies with minimum implementation - **transaction costs,** as the magnitude of such costs, have caused some schemes to fail (Stavins 1995; Tietenberg 2003).

Externalities are critical concepts in the Nexus arena. Hoff (2011) argues Nexus thinking is concerned with addressing externalities across multiple sectors, decreasing adverse effects of some sectoral actions on others with a focus on system efficiency, rather than on the productivity of individual sectors.

5.3.2 Income Distribution and Inequality Effects

The Nexus also needs to be contextualized within the debate around social justice. Food/water poverty indicate the presence of a strong relationship between levels of poverty and levels of resource consumption—with resource consumption and resource availability decreasing as poverty indices increase.

As discussed in Chapter 3, water security involves access to, water for human and ecosystem uses; energy security involves access to clean, reliable and affordable energy services for daily uses; food security involves physical and economic access to sufficient, safe and nutritious food to meet dietary needs and food preferences for an active and healthy life. The Bonn2011 conference specifically aimed to explore "how a nexus approach can enhance water, energy, food security by increasing efficiency, reducing trade-offs, building synergies and improving governance across sectors" (Hoff 2011). Nexus decisions can alter food/water/energy availability and prices, in turn, altering the welfare of groups outside the FEW production region or domain under study including disadvantaged ones. Such potential effects increase the importance of making informed and balanced choices not only on our natural resources but also in working toward the achievement of Sustainable Development Goals as discussed in Chapter 3.

5.3.3 Incorporating dynamic concerns

Nexus interrelationships and demands for Nexus commodities are changing over time. Therefore, decision-making processes need to be proactive and consider the dynamic evolution of the FEW arenas. For example:

1) Growing populations alter FEW demands;
2) Climate change alters water supplies plus regional FEW demands;
3) Aquifer and fossil fuel reservoir depletion is ongoing;
4) Evolving technology influences FEW supplies and demands; and,
5) Regional FEW infrastructures and resource stocks/availabilities may be depreciating or being depleted.

The incidence of growing populations and climate change forces economists to consider how to balance current versus future resource allocation properly so as to maximize society's welfare over a long time horizon.

Economic effects at different points in time are not usually valued the same. The promise of payment of a dollar today is more valuable than payment ten years from now since one could buy an interest-bearing bond returning say a dollar plus 25 cents interest by ten years from now. Economists use the concept of a discount **rate** to place economic effects across different times on an equal footing. This reduces the future value by an accounting of the compound interest one would achieve by that period from investing the same amount of money currently.

Choice of the discount rate is crucial when making comparisons between decisions or impacts at different times. The use of too high a discount rate will result in too little value placed on avoiding damaging future events and too little investment in technologies that enhance sustainability. Conversely, applying too low a discount rate will result in too much investment in items that benefit the future at the expense of the current.

Investment in climate change mitigation is a clear instance where the discount rate causes different conclusions to be reached. Debate in the literature on discounting has often focused on how to select the correct discount rate (Stern 2007; W.D. Nordhaus 2007; Weitzman 2007; Zhuang et al. 2007). Regardless of the rate chosen, it is important to remember that the discount rate is a critical determinant in the outcome of an analysis, and for each project, a single rate must be applied to all future benefits and costs. For example, Stern (2007) advocates more ambitious greenhouse gas mitigation than Nordhaus does, and this is in part influenced by Stern's use of a much lower discount rate.

5.3.4 Uncertainty and Risk Aversion

Uncertainty adds complexity to Nexus systems. Uncertainty may be represented by year-to-year variations in water supplies and commodity prices caused by drought or floods plus an uncertain future for the rate of population growth, climate change incidence, technological progress or aquifer/fossil fuel reservoir depletion. Collectively, such uncertainties raise needs for stochastic modeling and scenario analysis. Stochastic modeling involves considering multiple possible say water availability situation and their probabilities. For example, in the South-Central Texas EDSIMR model (see the details in Section 5.4), shorter run uncertainty was addressed by having nine levels water availability and their historical probabilities. For long run uncertainly, the model was run under alternative scenarios involving population growth and future climate change.

Broadly following Moschini and Hennessy (2001), the main sources of uncertainty in the Nexus system as being from:

1) Production uncertainty which refers to the variation in levels of production like crop yields where the amount and quality of output that will result from a given bundle of inputs are typically not known with certainty;

2) Price uncertainty, where production decisions are made in advance of the time when the final product becomes available, so that market price for the output is typically unknown when these decisions have to be made;

3) Technology improvement uncertainty which acknowledges that increases in production output and input usage efficiency are uncertain across all sectors; and,

4) Policy uncertainty where one is unsure of the persistence and enactment of economic policies that significantly impact sectors like renewable energy subsidies or requirements.

Risk preferences and management have been widely addressed both analytically and numerically in the economic literature. Many stakeholders such as farmers or firms are typically risk-averse. The more significant the variability they experience in their profits or service supply, the more willing they will be to adopt measures that reduce risks.

In the face of climate variability, vulnerable farmers employ ex-ante (forecast-based) strategies, to protect against the possibility of catastrophic loss in the event of a climatic shock. Farmers' precautionary strategies include:

1) Selection of a portfolio including less risky but less profitable crops;
2) Overuse of fertilizers;
3) Diversifying income sources; and,
4) Avoiding investment in production assets and technology.

Arguments have been made that if farmers can trade away part of the risks on their farm at an acceptable cost, the expected utility of the farmer will increase and this provides another incentive direction – development of risk sharing mechanisms like insurance or crop share arrangements when Nexus practice adoption increases risk exposure.

Although sharing risks can increase utility, individuals are not likely to share all risks. Factors that may influence this decision include:

1) An individual's degree of risk aversion;
2) The costs involved in risk sharing;
3) The relative size of a risk;
4) The correlation of the risk with other risks;
5) Other sources of indemnity;
6) An individual's perception of the nature of risk; and,
7) An individual's income and wealth.

5.3.5 Public-Private Goods, Incentives, and Roles

Some strategic responses to Nexus issues involve adaptation strategies that occur autonomously by private individuals and through planned public actions.

McCarl (2015) presents a list of possible adaptation categories in a climate change adaptation context with an indication of whether the actions will be public or private. Individuals serving their personal interests take private actions. For example, altering crop, livestock mix, or modifying irrigation practices are primarily exercised by private individuals who manage the land. However, other strategies are not feasible or desirable for implementation by individuals (called **public goods**) which, in turn, bring in a public role. Public entities may alter policy, provide incentives, provide information, develop certain classes of technology, or build infrastructure. Examples of such public actions include:

1) technology development on FEW components through research, for example, developing ways to generate energy with less water, grow food with less irrigation and energy and utilize less energy and water for municipal use;

2) building a more efficient public utility generation and distribution system or reducing leaks in water distribution;

3) providing extension information on FEW situations, improving practices like water conserving agricultural practices;

4) financing insurance coverage for cases where for example water is limited and operations are curtailed; and,

5) creating public goods that benefit many without excluding those who have not financed implementation, for example, capital investment in reservoirs or canals.

In public cases, an individual does not capture all of the benefits and is likely to choose not to pay for the investment. Thus, in cases where the Nexus action creates a public good then broader involvement is needed to achieve implementation as private actions will underinvest in such actions.

5.3.6 Cost-Benefit - Not just Economics

Finally, let us deal with the broad issue of benefit-cost analysis inclusiveness. One quite frequently hears people say that for a project to be justified it must have a ratio greater than one of the benefits divided by costs. In fact, it is often a requirement that a benefit-cost ratio is constructed for almost any considered project.

However, it is also important to note that the benefit-cost ratio will generally not be all-inclusive relative to the items considered in making a decision. In particular, there may well be many nonmarket impacts which cannot be quantified in dollars and cents. Nexus project induced items such as reductions in the amount of erosion getting into the water, or a reduced amount of air pollution emissions, or an alteration in biodiversity in the region are difficult to represent in general and certainly in monetary terms. In such cases, one may do both a benefit-cost and a simultaneous environmental analysis and emphasize that both should be considered, not just the cost-benefit ratio as could be implemented within the systems approach discussed in Chapter 2.

5.4 FEW Nexus Metrics, Data, and Modeling

In this section, we use an ongoing Texas FEW Nexus case study to illustrate the complexity and challenges regarding the economic considerations related to FEX Nexus metrics, data, and modeling but also see the detailed discussion in Chapter 13-16.

The Nexus model is named the Edwards Aquifer and River system Simulation Model (EDSIMR). The model depicts regional dryland and irrigated farming, water diversion/pumping, river flows, environmental indicators, aquifer elevation status, thermal energy cooling, hydropower, and hydraulic fracturing. The model when solved generates output on water prices, water use, and allocation, farming crop mix, agricultural production, irrigation strategy, aquifer levels, spring flow discharge into rivers, farm incomes, municipal and agricultural pumping, pumping lifts, energy generation and energy use among other items.

A FEW Nexus model needs to be based on high-quality data. For the EDSIMR analysis we needed to integrate data from:

1) Regional aquifer simulations that employed the groundwater model (GAM) to simulate aquifer level, pump lift and spring flow discharge given alternative amounts of pumping in the region;

2) Crop growth simulations using EPIC under different irrigation strategies and climate conditions to develop estimates of dryland and irrigated crop yields along with water use plus erosion and nutrient flows;

3) River flow and groundwater infiltration where we used SWAT to simulate levels of aquifer recharge, net inflows at river locations, evaporation, reservoir operations, and water quality characteristics, given changes in agricultural production, climate and the typical regional distribution of rainfall;

4) Econometric based urban water demand equations that show water demand as a function of water price and climate conditions;

5) Engineering models of electrical power generation cooling with which we estimated the alternative cooling methods and their implications for water use, cost and power generation; and,

6) Calculations of energy use and water loss associated with many water development alternatives (reservoir construction, pipelines from distant locations, desalination, aquifer storage, and recovery and conservation incentives among others).

EDSIMR is formulated as a unifying component that includes modeling of rivers, aquifers, agricultural water use, irrigated and dryland cropping, water project development, energy generation, cooling water use, cooling water retrofits and non-agricultural water use among other things. That model is used to look at a regional welfare-maximizing allocation of water across urban, industrial, electrical generating and agricultural users coupled with an optimal choice among the water development and power cooling alternatives. As shown in Figure 5.3, the total project encompasses data collection, model development, and feedback from stakeholders.

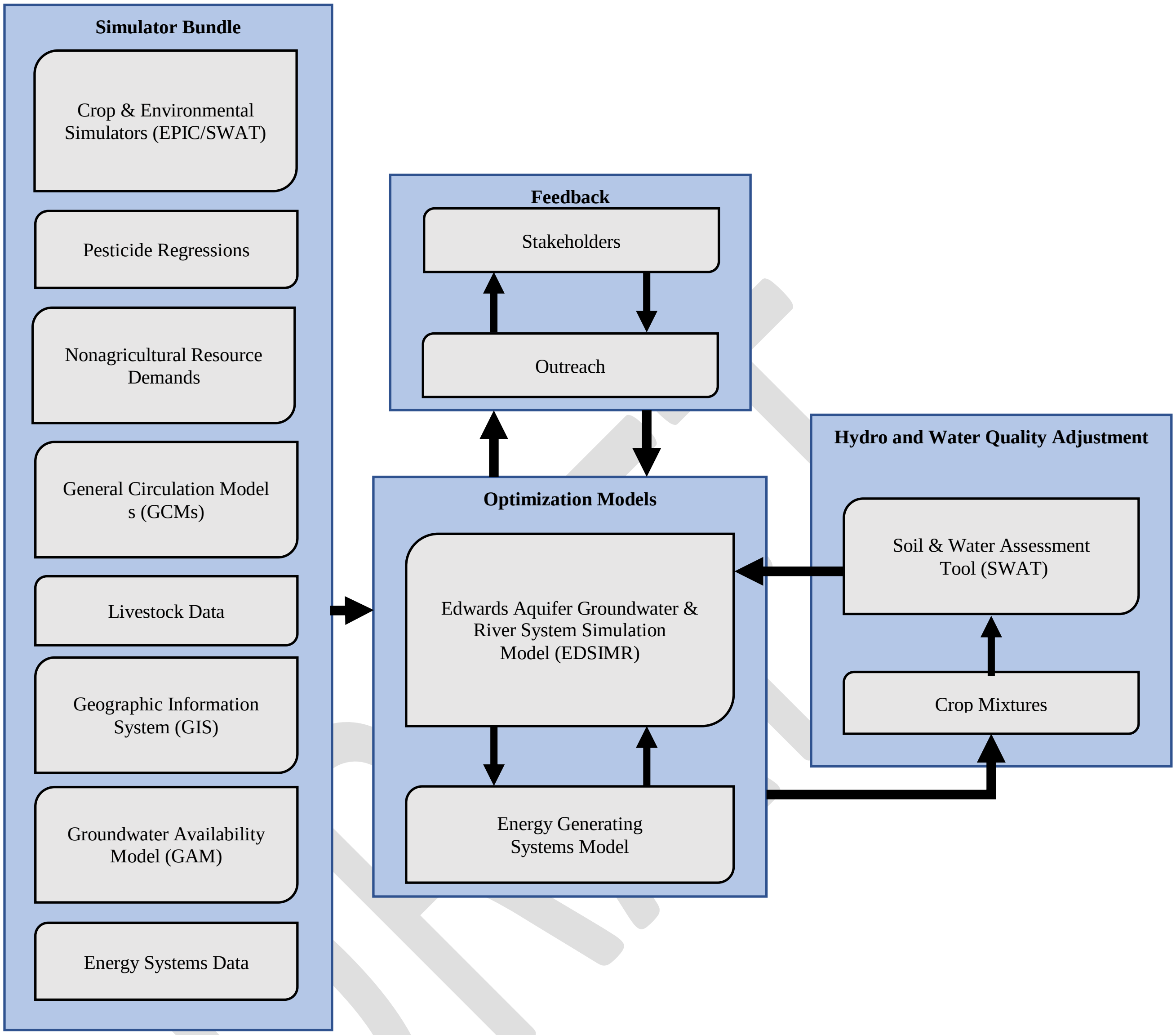


Figure 5.3 EDSIMR Framework

Key Points

- Nexus analyses can be biased if one neglects product demand and input supply price-quantity relationships. For example, using US corn for biofuel was a significant force behind corn price increases while the supply of the by-product glycerol from biodiesel refining reduced glycerol prices. Also, demand quantity projections may fall if prices are increased as expensively discovered by WPPSS power suppliers.

- Incentives to conserve can have perversely increased usage as demonstrated by the rebound effect.

- Projects may affect non-market items like water quality which may, if valued, influence an appraisal.

- Transferring evaluation estimates from elsewhere have both advantages and drawbacks.

- Water has a different value in different uses, and this needs both quantification and consideration when making decisions; also, the consideration of water movement costs and water allocation patterns between users is a crucial consideration. Introduced some techniques for estimating the value of water in alternative uses so one can look at the implications of Nexus–based reallocations or new water development activities.

- When identifying strategies based on those currently employed, one must realize this is biased by historical prices and that other strategies could be used if prices change.

- Economics provides welfare metrics that can be utilized when examining making decisions about Nexus possibilities in a benefit-cost analysis. The welfare metrics can describe not only total welfare but also the welfare of participating groups identifying who gains and who loses. One should be prepared for different effects across producers and consumers when a practice alters prices of commodities.

- One can provide Nexus action adoption incentives by introducing markets, subsidies, performance standards, or taxes to stimulate adoption by those who lose in the interest of gains to others. Incentives are needed to attain full cooperation especially to those who otherwise lose from strategy implementation.

- Nexus actions can cause negative impacts or externalities on other parties that need to be considered. Social justice is a concern when Nexus actions negatively affect disadvantaged populations.

- The Nexus arena is continually evolving given the influences of things like a growing population and climate change, so we need to consider how to properly balance current versus future resource allocation to maximize social welfare. The discount rate is a key concept here.

- Risk sharing mechanisms may be needed as Nexus adoption may alter risk and influence stakeholder decisions to adopt.

- Some Nexus actions will not be adopted by private individuals as they benefit the public, not just the individual. In such cases, the public may need to get directly involved in adoption.

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Datasets

None given

Discussion Points and Exercises

5.1. Discuss why the rebound effect might occur if you are subsidizing lower cost lawn irrigation practices in a growing municipality.

5.2. Discuss why not all nexus alternatives can be observed in usage in a setting. Discuss the role of historical commodity and water prices along with induced innovation.

5.3. Discuss why incentives may be needed to implement FEW Nexus actions by listing two to three examples.

5.4. Discuss the consequences of changing to more water efficient cooling practices for power generators in a scarce water setting where the change makes more water available for municipal use and reduces water purchases from agriculture. Could power generators lose? What might happen to agricultural producers? What would be the consequence of having this lower priced water for municipalities? Would some form of compensation possibly be needed and if so how could it be implemented as a way of resolving negative effects?

5.5. Discuss how reducing discount rates will affect the desirability of investments with significant upfront costs and benefits occurring later.

5.6. Suppose you are doing a study of changing cooling water alternatives and the one being considered eliminates the need for a cooling pond that provides spawning grounds for an endangered fish species and also reduces the discharge of pollutants into a nearby river. Would there be any need for non-market valuation in such a setting? Could benefits transfer be used and if so what qualifications might you state on the resultant estimates?

5.7. In the San Antonio region, two 140+ mile long pipelines are being considered to deliver water from one place to another. If you were appraising their FEW consequences what types of effects would you consider?

5.8. Suppose you are evaluating a US case where to generate more energy: 5% of US cropland and 5% of current grasslands will be diverted to producing energy crops which use less fertilizer than existing crops but much more than pasture. Conceptually, could this influence US and global commodity markets? What about water use and water quality?

5.9. Suppose we have several Nexus water-related alternatives: build a 150-mile pipeline, have agriculture shift to more water conserving crops, increase home appliance water efficiency and change fracking techniques to use less water. Who makes the decision to adopt the practice in each case and is a public role needed to provide funds or disseminate information?

5.10. When you are examining issues regarding water what should you use, mean water availability, drought availability, flood availability or the distribution of water availability?

5.11. Suppose a pipeline is to be built that crosses private lands and some government lands. Could any externalities be involved?

5.12. Suppose a consulting firm needs to appraise whether water could be transferred from agriculture to cities. How would you estimate the value of water to both parties?

5.13. Energy prices rose substantially between 2000 and 2011. During that period, we saw smaller cars and more miles per gallon from new models. Prices have now gone back down some, and larger cars are again selling. Which two economic concepts above are relevant to these observations?

5.14. Why should one not only look at the cheapest cost water when making an urban decision on water supply sources?

5.15. Why do we worry about policies that increase food prices? Who is affected by food prices? Also, should we only worry about the average consumer?

5.16. The formula for the elasticity of demand is $e = \frac{\Delta q}{\Delta p} \cdot \frac{p}{q}$, where p is commodity price and q is quantity consumed, and Δq, Δp are changes in quantity and price due to firm actions respectively. This formula can be manipulated to express the change in product prices or the change in quantity sold as follows:

$\Delta q = \Delta p/p*q*e$

$\Delta p = \Delta q/q*p/e$

Assume p=q=1 and answer the questions in the following two paragraphs:

How much would the sale price at which more production could be sold change if they produced 10% more under an elasticity of -0.1 versus one of -10? Does this mean FEW actions that expand production can do this more safely if they face elastic demand (e<-1 (the -10 above)) or inelastic demand (e>-1(the -0.1 above))? How does this relate to the Washington Public Power case described above?

How much would the quantity they could sell change if their cost of production increased by 10% under an elasticity of -0.1 versus one of -10? Does this mean FEW actions that expand the price they need to charge to cover the cost of production can be implemented more safely if they face elastic demand (e<-1 (the -10 above)) or inelastic demand (e>-1(the -0.1 above))? How does this relate to the glycerol case described above?

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