Addressing the societal problems of climate change and food insecurity will depend on bringing innovations in renewable energy and food production to market. For David Zilberman, Robinson Chair of Agricultural and Resource Economics at the University of California, Berkeley, “our biggest challenge is to change the economy here and across the world, to move to a renewable system, to develop new supply chains that won’t rely on fossil fuel and that will be able to provide resources to the poor and everyone else.” Elected to the National Academy of Sciences in 2019, Zilberman has spent his career applying the lens of economics to agricultural issues such as irrigation, pesticide use, and genetically modified organisms. In his Inaugural Article, Zilberman examines the road from innovation to market, focusing on how policies and technologies affect the creation of supply chains (1).

Raw Material

Born in Jerusalem, Israel, Zilberman remembers carrying ice blocks for miles and chopping wood with his father every week to heat the house. “I was born before the war of independence in Israel. We were poor.” His parents encouraged Zilberman to pursue medicine or science. “They wanted me to be a scientist,” he says. “If you asked me, I wanted to be a basketball player and soccer player, but the raw material wasn’t there.”

Instead, Zilberman excelled in school. “I loved geography and I was good in math.” In 1965 he began mandatory service in the Israel Defense Forces. For much of the time he was stationed on a kibbutz, where he picked apples, drove tractors, assisted builders, and vaccinated chickens. Zilberman credits many of these early experiences in the army with his introduction to agriculture.

At the age of 22, having served during the Six-Day War of 1967, Zilberman left the army and enrolled at Tel Aviv University. He majored in economics and statistics, while selling advertisements as a side gig. He also took a computer programming class. “This was the smartest thing I did in my life.” The teacher ended up offering Zilberman a position in which he eventually wrote payroll programs. Zilberman appreciated the newfound financial freedom and graduated in 1969. However, he realized that computer programming was not his calling. Instead, his teacher suggested he pursue graduate studies in the United States.

Upon arriving at Berkeley, Zilberman joined visiting agricultural economist and fellow Israeli Eithan Hockman, who was studying regulation of animal waste in California dairies. “How many people start their careers in economics that way?” Zilberman recalls with amusement. Part of the work involved visiting farms where Zilberman remembers impressing the farmers. “I wasn’t afraid of the cows, and I knew enough to milk.” He built a model to predict and compare how short-term outputs and competing management strategies vary in the face of environmental policies, such as taxation. “It was nice mathematics, the economics was good, the English was terrible, but we wrote some papers,” he says (2, 3).

Drips and Droughts

Zilberman completed his doctorate in environmental economics in 1979. Around the same time, a faculty position opened up at Berkeley, but it was in agricultural policy, an area in which he had no experience. At the time, he recalls, Berkeley was home to leading agricultural policy expert Gordon Rausser. “I needed to develop my own path to stand out.” Zilberman decided to work at the intersection of agricultural technology and the environment and...
continued collaborating with his advisor, Richard Just, to study how agricultural technology is adopted.

The partnership proved fruitful. One article from the collaboration is currently Zilberman's most cited (4), and in another study they explored the arguments for and against technological change, concluding that technological change, which might lead to accumulation of land and wealth, should be regulated in a manner that preserves competition (5). "Together, we wrote an incredible amount of papers. I was more a theorist, and he was really good with empirical data," says Zilberman. "He has unbelievable intuition."

In the mid-1980s, Zilberman began to study irrigation in California. At the time, drip irrigation was not in prominent use, and the challenge was to determine where it would be financially feasible to use drip irrigation instead of other methods. Zilberman approached the question pragmatically, learning how irrigation interacts with soils and plants.

"The biggest problem in economics today is that economists take a theory that is too general to be useful and apply [it] as if it's the truth."

"When you irrigate with flood irrigation, if you have flat land and heavy soil, you don't need drip. But if you have steep hills and sandy soil, you need drip," explains Zilberman. In other words, the location determines the technology. "I developed the formula [for] where you do it [and] where you don't. I started a theory that is very powerful today (6). The basic idea is that modern technology, like drip irrigation, increases input use efficiency," Zilberman explains. Adopting the appropriate type of technology for a specific situation optimizes efficiency. "It's not only irrigation. The same thing is true for electricity," he says.

In the 1990s, as issues of drought and climate change came to the fore, he explored how water pricing and trading can address droughts and drainage problems (7, 8). Zilberman notes that he gets many calls for his water expertise in a California drought year but few during a rainy one. "When there's no drought, no one cares about water economics," he says.

**Pesticides as Medicine**

Zilberman's focus shifted to another environmental policy area when he received funding from the US Environmental Protection Agency to study the economic impacts of pesticides regulations. "I realized that the way to look at pesticides is to look at them as medicines that basically reduce crop damage from disease and pests." In 1991, Zilberman collaborated on an article with agricultural economist Erik Lichtenberg and others, showing that fees for pesticide use or partial bans could be more effective than outright bans to accomplish environmental goals and guard against deleterious side effects (9). The article also argued that bans do not discriminate between major or minor cost increases that they may impose.

In the 2000s, Zilberman collaborated with agricultural economist Matin Qaim, applying the techniques of the models created for pesticide use to study productivity tied to genetically modified crops (10). "I suddenly was so excited about it, because I realized the potential of genetic engineering is unbelievable now." In 2014, Zilberman and agricultural economist Justus Wesseler developed an economic model to calculate the costs of approval delays for golden rice, a genetically modified plant enriched with vitamin A and intended to reduce infection and provide increased nutrition, especially in the Global South. Applying the model to India revealed 1.4 million life-years lost over a 10-year period of implementation delays (11). "I still believe what happened with golden rice was a travesty," he laments.

**Key Supply Chains**

The work on genetically modified organisms led directly to Zilberman's interest in the bioeconomy, which relies on plants and other renewable resources, such as wind, solar power, and biofuels. "To fight climate change, we need all the tools, including modern biotechnology." In 2002 he published work on what he describes as the key role of the "educational industrial complex," in which discoveries made at universities, supported largely by public funding, lead to innovations through technology transfer to the private sector (12).

Next, Zilberman examined how innovations reach the consumer. "When I started working on biotech and biofuels, I realized something very, very important," he says (13). "There's a key for implementing all new innovations, and that is the supply chain." Zilberman approached agricultural economist Tom Reardon for a collaboration. Unlike a standard model with existing competitive markets, Zilberman explains, making the supply chain implement an innovation helps establish new markets. "When agribusiness introduces a new biofuel, their supply chain includes the production of plants, the processing of the plants to produce fuel, and marketing the fuels. The entrepreneurs have to decide how much of the plants to produce in-house and how much production to contract out," he explains. "In modern agribusiness, people rely heavily on contracts and the markets for most products are not competitive. The agribusiness firms have monopolistic powers, and they use it" (14).

Introducing innovations requires understanding technology adoption (4). "When I studied adoption, I realized that economists tend to look at adoption from a perspective of the adopter, and no one really looks at marketers." Together with marketing scholar Amir Heiman, Zilberman developed models and analyses that incorporated technology adoption with marketing tools, such as product demonstration or money-back guarantees (15). The implementation of an innovation may also require the establishment of multiple supply chains. Zilberman evokes the case of hydrogen fuels. "It's two supply chains: one for hydrogen and another for trucks that can use hydrogen. That really led me to this new chapter on my research on the innovation of supply chains."

Markets are typically thought of as the major driver of economic activity but, for Zilberman, it goes back to innovations and their supply chains spawning new markets. "It changed the way I think about economics," he says. "Supply chains change in response to shocks, both natural and political. For example, if you have an international crisis and you cannot import oil, then you may create..."
alternative products, different supply chains, and a totally different economy."

Supply chain work is in its infancy, according to Zilberman. “We need to go beyond economics and incorporate political and technological considerations in analysis of supply chains,” he explains. “The best way to make sure that there is real competition in the economy is to invest in research and education.”

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