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Understanding Supply Chains Is Crucial for Good Agricultural Policy

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Introduction

Agricultural economists recognized long ago that agriculture and the food sector have high rates of innovation, with new products and technologies emerging continuously. Further, an increasing percentage of the value of food and other farm-grown products is generated outside the farm gate (Cochrane, 1979). The transition from ideas for new products to the actual goods and services utilized by consumers is through multiple supply chains that evolve and intersect over time. These supply chains include multiple institutions (like firms, farms, and universities); understanding the design of agricultural and other policies requires understanding the forces that affect the performance of supply chains. In this paper, we introduce two major types of symbiotic supply chains—innovation supply chain and product supply chain—and analyze some of the factors that affect their performance, discuss how supply chains evolve considering recent events, and assess how supply chain considerations should affect policy interventions.

Innovation and Product Supply Chains

New products and services originate from an idea. This can be a scientific discovery with a practical implication, a realization of a new need, a marketing-driven product development for which the firm needs to promote demand, or an improvement in existing technology. The transition from the idea to an implementable innovation occurs in the innovation supply chain. We identify three types of innovation supply chains: First, the *educational-industrial complex*, where university scientists may make a discovery that could lead to supply chain innovations. Frequently, it is further tested and developed by applied researchers in experiment stations and extension units In other cases, it is developed by private companies (start-ups or major corporations) that acquire the right to obtain a technology through offices of technology transfer. Second is *recombinant innovation*, where a practitioner or entrepreneur develops a new idea and modifies existing technologies to develop a product or service. Third is *relentless innovation*, where companies constantly improve their existing product. The development of modern agricultural biotechnology is an example of the educational-industrial complex in action. The discovery of DNA led to further research on which genetic material influenced certain aspects of performance (yield, drought tolerance). Companies use this knowledge to develop new products. Farm and irrigation improvements have frequently resulted from recombinant innovation, where companies modify technologies from the automobile and oil industries to produce new farm machinery and irrigation equipment. Relentless innovation improves food products, agricultural crop varieties, pest control techniques, and machinery. For example, precut salads have improved over time to include multiple greens and dressings and to have a longer shelf life (Lugg, Shim, and Zilberman, 2017).

Implementable innovations are developed into commercial services and products sold and utilized by consumers through multistage product supply chains. Each supply chain has a hierarchy, starting with an upstream, going through midstream, and then downstream. At each stage, there may be several levels. For example, it is helpful to consider the input suppliers who provide the seed and farm equipment upstream of the food supply chain in the United States. Further, inputs have their own supply chain, so we emphasize the symbiotic relationship between input and output supply chains (Reardon and Timmer, 2012). Farms and ranches are the midstream in the production of food. The downstream has several levels: processors, wholesalers, and retailers. In earlier periods in U.S. history, many agricultural products were introduced by migrants who moved from Italy to California. Later, agricultural scientists and extension specialists developed new varieties appropriate for specific soil and climatic conditions (Cochrane, 1979). In 2021, the farm share was only 14.5% of the total food expenditure

(USDA, 2022). Some of the new agricultural products were introduced by organizations that became intermediaries. Biofuel supply chains were induced by regulations subsidizing and mandating the use of biofuels and, frequently, investors in refineries were managing the supply chains. They contracted the farmers to grow the feedstock and sold the biofuel to the oil companies and other byproducts (e.g., dried distiller's grains, DDGs) to feed distributors. The organization that introduced prepackaged salads and baby carrots concentrated on processing the carrots and other vegetables that, to a large extent, they contract others to grow (Zilberman et al., 2023).

The Operation of Supply Chains

Entrepreneurs who design product supply chains to implement innovations may start by assessing demand, maybe through marketing research, and then develop a strategy that makes financial sense and aim to pursue net discounted profits, adjusted for risk (Reardon et al., 2021). The plan must determine how much, what, and where to produce in each period, the extent to which internal resources (vertical integration) or others (through contracts or markets) should be relied upon, how much to invest in each period, and what output quantities to market at different locations. Introducing technologies requires adaptive learning, and entrepreneurs may modify their plans as they go. They are constrained by market demand, human capital and knowledge, regulation, and financial considerations. The performance of the supply chain is affected by dynamic processes of learning by doing (the reduction of the cost of production as knowledge accumulates); learning by using, which increases demand for the product; imitation, which may increase both supply (new entrants) and demand; and actions of competitors, which may reduce demand. Further, the design choices are shrouded in uncertainty. Therefore, managing a supply chain is an adaptive exercise in which plans are modified over time in response to learning and reality.

Supply chains will likely start production and marketing in the most favorable locations and extend their reach and product mix. After McDonald's got its start in California and the Midwest, where the company refined their product and business model, it spread throughout the United States to Europe and then the rest of the world. Tyson Foods started shipping chicken from Arkansas, moved to providing chicks to contractors, and processed them to sell throughout the United States. They expanded their product mix to include processed chicken and then moved to other livestock, establishing subsidiaries globally. Gallo started as a small winery in Modesto, California, developed new methods (steel barrels) to increase efficiency, and increased their product mix and marketing network. They still grow grapes but contract with other farmers for most of their grapes.

Finance and marketing are crucial in designing and managing supply chains. Most entrepreneurs must raise funds for investments and ongoing operations, and potential lenders may not provide the requested amount. So, financial constraints may shape the design of the supply chain. The precut salad was initiated by a large lettuce producer (Bruce Church), who sold all his land to finance the processing activities. As enterprises grow and expand geographically, they establish partnerships to obtain local knowledge and new sources of finance. Similarly, marketing analysis is crucial in product design, pricing, and location selection. MARS Inc., a large producer of dog food, has invested in assuring their products are palatable to the dog (since if your dog doesn't like the food, you will switch to another brand). Finally, supply chain design is responsive to policy situations: Reduced interest rates are likely to increase investments, locations that provide preferential treatment will be more attractive for investment, and regulatory uncertainty may reduce the likelihood of investment and deter entrepreneurship. Uncertainties about agricultural biotechnology regulation have led to significant underinvestment in the industry (Zilberman, Reardon, et al., 2022).

The Evolution Pivoting and Adjustment of Supply Chains

Our supply chain perspective has some implications for economic analysis. First, it suggests that goods, markets, and trading arrangements are endogenous. Innovation in supply chains leads to the emergence of new goods and services, which require establishing supply chains that lead to the emergence of markets and other mechanisms of exchange. As products become more differentiated and have detailed specifications, spot market transactions are replaced by contracts. In modern industries like computers, companies like Apple have established contracts with suppliers that detail product specifications, prices, time of delivery, etc. Such developments are likely to occur in the agri-food sector as it evolves. Broilers, eggs, and—to some extent—hogs already have high contracting levels. Use of contracts is increasing in fresh fruits and vegetables and may increase in other sectors with more precise product specifications.

Second, new agricultural industries are not perfectly competitive. The patent system provides innovators with intellectual property rights and monopoly powers. Companies that anchor supply chains have market power, resulting from patents, trade secrets, or scale both in their input and output markets. Over time, as new innovators enter, they introduce competing products and establish their own supply chains. As a result, the industrial structures become monopolistically competitive. Namely, several firms could be competing on similar products, but each has some market power. For example, several competing fast-food chains have

somewhat unique products. Still, each has significant market power, although that power is constrained given the availability of close substitutes. The market power of incumbent firms is reduced, and competition is enhanced when there are fewer barriers establishment of new supply chains and organizations and entry into markets (Reardon et al., 2021).

Supply chains are living organisms that adapt to changes and shocks. The recent pandemic provides many examples. Social distancing regulations, as well as restrictions on travel, led to drastic changes in agri-food supply chains. Digitization of the food system has been promoted but has proceeded slowly. The pandemic accelerated this digitization. In particular, e-commerce adoption increased by 70% in India and 80% in Mexico in 2020 (Reardon et al., 2021). In China, online orders quadrupled during the pandemic. The food delivery sector expanded worldwide, many retailers started providing delivery services, and direct sales from farmers or processors to consumers expanded (Reardon et al., 2021). Restaurants that pivoted to emphasize takeout survived and thrived during the pandemic, and others failed (Reardon et al., 2021). The farming sector adapted to labor shortages and supply bottlenecks through automation; modification of production, harvesting, and processing procedures and sources of labor; and innovative marketing (Kaplan, Lefler, and Zilberman, 2022). The adjustment to the pandemic is one example of supply chain adaptation. Water supply chains have adapted to increased demand and shocks like drought by developing physical infrastructure like storage, new technologies like drip irrigation, and introducing institutions like water trading (Zilberman, Huang, et al., 2022). In these cases, adaptation has involved interaction between innovation, product supply chain, and policy makers. California's 1987–1991 drought accelerated the modification of drip irrigation to fit a larger set of California crops and to expand the network of irrigation dealers, which contributed to increased adoption of the technology and led to the introduction of water banking, which enabled saving much of the fruit and vegetable production in the state (Zilberman et al., 1994).

A supply chain perspective is essential when considering the impact of climate change on agriculture. Most of the literature emphasizes the direct effect of climate change on the farm. Climate change may affect food supply chains by affecting production regions, input supply sources, and market access capacity. If a farming region loses access to a port or a road connecting them to the rest of the world, its ability to export its food or obtain inputs is limited and may cause significant harm. Similarly, consumers may be affected by climate change, not because of a reduction in food production but lack of access. Reardon and Zilberman (2018) suggest that climate change concerns may cause some retailers to increase redundancy and rely on multiple suppliers, expanding inventory, and purchasing options to obtain extra supply. Climate change concerns, thus, enhance the value of increased resiliency of the supply chain (Reardon and Zilberman, 2018).

Policy

Economic policy analysis should recognize the importance of supply chains and their evolution and behavior. Our analysis suggests several important policy implications.

Public Investment in Research, Education, Extension, and Cyber-Infrastructure Is Essential

As we have seen, the educational-industrial complex, the source of many substantial innovations, leads to the establishment of new products and the emergence of new supply chains. Academics are part of the entrepreneurial environment and play a key management role in start-ups that lead to new industries. Students in land grant and other universities are the future entrepreneurs who create continuous industrial renewal (Graff, Heiman, and Zilberman, 2002). One question is whether the decreasing ratio of public versus private investment in agricultural research over time has or will have negative implications for agricultural productivity growth, given that public research may have a comparative advantage in foundational research (Clancy, Fuglie, and Helsey, 2016).

Academic research is essential for other reasons. New industries and supply chains may generate externalities regarding pollution and health effects. Private sectors do not have the incentive or capacity to investigate these implications. Governments need the capacity to regulate industries, assure consumers that their food is safe and protect the environment. Knowledge created by academic research is crucial for these purposes.

Further, research and education are crucial to establish the bioeconomy. Humanity is facing the combined challenges of climate change, loss of biodiversity, and food insecurity. With the modern tools of biology and information technologies, natural resources in agriculture can be expanded to establish the bioeconomy, where agriculture and natural resources will produce much more than food. In the bioeconomy, using modern knowledge, agriculture will produce food, fuel, and chemicals and enhance the transition from nonrenewable reliance on fossil fuels to a renewable economy (Zilberman et al., 2018; Wesseler and von Braun, 2017).

Historically, the government's role in maintaining and developing supply chains has been to provide or assure the provision of goods that would allow the emergence of new industries that will improve human welfare and lead to sustainable development. That includes investment in public goods like research, education, and

other infrastructure needed to develop new modern sectors. One key element is ensuring accessible and affordable cyber-infrastructure that will enable connectivity to the internet and the web throughout the country and would otherwise hamper the capabilities of rural regions to contribute to the bioeconomy and upscaling of agriculture.

Incentives for Socially Desirable Activities

Innovations are commercialized and developed when individuals have incentives to pursue them. Addressing climate change and other problems will require creative solutions and new industries. Research is essential for finding solutions, but the development of supply chains for industries that implement these solutions requires that investors will expect to be rewarded for their efforts. Thus, policies like carbon taxes can trigger both research and new industries that will reduce greenhouse gases. However, when such policies are politically infeasible, it may be necessary to pursue alternative strategies, such as subsidizing green technologies, regulating polluting activities, or providing credit to implement green innovation.

Acceptance of Nonmarket Exchanges and Wise Regulation of Market Power

As we have seen, new innovative sectors frequently have noncompetitive structures where the entrepreneurs that implement an innovation make monopoly profits. Further, supply chains that introduce new products or technologies may rely on contracting or may be vertically integrated rather than rely on competitive market transactions. Accepting this reality is important and attempts to enforce competitive markets and reduce the profitability of investment in new industries may retard innovation. At the same time, there is a place for anti-trust policies that regulate against arrangements that limit entry to industries and restrict choices. Investment in public goods and in research that will lead to innovation—as well as the development of mechanisms (including the provision of credit and other support) to support new entrants and new entrepreneurships and protect them against sanctions by incumbents—will be important to maintain well-functioning and innovative sectors and economy.

Conclusion

Addressing the challenges of climate change and food security will require the introduction of innovations and the establishment of supply chains that will be the foundation of a bioeconomy that will utilize new knowledge in the life sciences and natural resources to produce renewable and clean alternatives to products produced by nonrenewable and greenhouse gas-emitting industries. New innovations are developed into commercial products through the innovation supply chain, and these products are implemented through the product supply chain. Applied economic research should emphasize research on supply chain and can play an important role in the design of policies that would lead to improved research direction and the establishment of new, well-functioning industries.

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