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Identifying Critical Thresholds for Resilient Regional Food Flows: A Case Study From the U.S. Upper Midwest

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Improving the regional organization of food flow requires an understanding of system constraints. System transformation is necessary if the system is to include regional, independent wholesale food suppliers and to distribute food in an equitable and sustainable manner. Regional suppliers play a pivotal role in overall food system resilience, an emerging issue in wake of the numerous failures in conventional food supply chains exacerbated by COVID-19-related disruptions. Yet alternative supply chains that link local producers with towns and urban centers regionally, represent a small fraction of our nation's food suppliers. They struggle to compete with larger distribution networks that can supply products in-and out-of-season by global procurement. The upper Midwest harbors numerous local and regional food supply chains consisting of farms, processors, trucking companies, wholesalers and other firms that share a commitment to sustainability and local economic development. A constellation of challenges hamper their emergence, however, even as larger scale food supply chains flounder or fail to effectively serve communities. Informed by Donella Meadows's work on leverage points for systemic change, a collaborative, transdisciplinary and systems research effort examined conventional food supply networks and identified key opportunities for shifting food supply chain relationships. System concepts such as stock and flow, leverage points, and critical thresholds helped us to frame and identify challenges and opportunities in the current system. The second and third phase of our collaborative research effort occurred over 4 years (2013–2016) and involved twenty-six people in co-generation of knowledge as a loose-knit team. The team included farmers, supply chain practitioners, students, academic staff and faculty from multiple departments and colleges. Our primary method was to host public workshops with practitioner speakers and participants to identify dominant narratives and key concepts within discourses of different participants in distribution networks. The literature review was iterative, based on challenges, ideas and specific questions discussed at workshops. Our research exposed two meta-narratives shaping the supply chain: diversity and efficiency. In addition to these high-leverage narratives, we identified and examined five key operational thresholds in the Upper Midwest regional food system that could be leveraged to improve food flow in the region. Attention to these areas makes it possible for businesses to operate within environmental limits and develop social structures that can meet scale efficiencies

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necessary for economic success. We iteratively shared this co-produced knowledge with decision-makers via local food policy councils, local government, and national policy circles with the goal of supplying actionable information. This phased action research project created the environment necessary for a group of food system entrepreneurs to emerge and collaborate, poised to improve system resilience in anticipation of food system disruptions. It forms the basis for on-going research on food flow, regional resilience, and supply chain policy.

Keywords: supply chain, agricultural resilience, market access, food distribution, leverage points, midwest

INTRODUCTION

Over the last half century, smaller scale, regionally focused wholesale regional food supply networks have faced seemingly insurmountable barriers in gaining market share as they compete with national and global food supply chains (Day-Farnsworth and Miller, 2014). While large-scale food supply networks efficiently move food at a low cost, their configuration burdens society in critical ways. This paper discusses current system limitations and ways that regional food systems can support innovation and competition in the marketplace, improve food access in both rural and urban areas, and increase resilience through redundancy that is critical to rapid and flexible responses in crises such as the COVID-19 pandemic and shocks due to extreme weather associated with climate change. Using the Upper Midwest as a case study to understand national and regional food system interactions, this transdisciplinary system diagnosis points to ways to meet multiple societal goals through system redesign.

Costs to society from large-scale agriculture and supply chains are well-documented and largely born by vulnerable populations or left to governments to address. Water quality and quantity concerns are foremost among these: Dead Zones in the Gulf of Mexico and Lake Michigan due to fertilizer and manure runoff from farms that pollute surface waters, groundwater and private wells polluted with fertilizers and pesticides, and rivers diverted for irrigation purposes that leave indigenous communities without water. Other concerns are soil erosion, depletion and salinization; labor abuses; systemic waste; and the financialization of land. Tello and de Molina (2017) term this the "dis-ecology of scale." Instead of the current heavily extractive systems, their case for re-localizing the food system is to close nutrient cycles, improve biodiversity at a landscape scale, improve overall systems energy efficiency, build on local, expert knowledge that farmers and practitioners possess, and make the urban-rural relationship fairer and more democratic.

Local food and farming movements in metropolitan regions demonstrate the potential of symbiotic enterprises in food supply chains to restructure relationships between urban and rural communities in ways that enhance the well-being of both (Jennings et al., 2015). In research to understand economic sustainability using network flow analysis, Goerner et al. (2009) found that small and mid-scale enterprises can balance both diversity and efficiency in ways that sustain regional economic flows in the face of disturbances, Infrastructure to support regional and local wholesale markets are good public investments. Research has shown that they tend to operate with a civic commitment to local economies, including the retail sector (Croushorn, 1990; Tangires, 1997), improve rural and urban food access (Beilock et al., 1990; Tangires, 1997; King et al., 2010; Walker et al., 2010; Pomponi et al., 2013) and meet culturally specific food needs for diverse communities (Walker et al., 2010; Day-Farnsworth, in Preparation[1]). Smaller-scale supply chains have also been shown to be more flexible and responsive to system shocks such as regional weather disruptions, rapid urbanization, political crises, and market shocks (Tendall et al., 2015). In addition, by operating at mid-to-high volumes but over short distances, regionally-organized supply chains can optimize transportation efficiencies reducing emissions (Roeth, 2016; Mihelic and Roeth, 2019) and provide affordable, regionally sourced foods (Croushorn, 1990; Tangires, 1997; Day-Farnsworth, in Preparation[1]).

Regional distribution is linked with diversity in urban food enterprise scale as well. In their study of New York's "last mile" food system, the city's Economic Development Corporation (EDC) documented the importance of the multi-tenant terminal market at Hunts Point. Its tenants supply independent corner stores and restaurants, especially those under 5,000 square feet (Economic Development Corporation, 2016). Significantly, regional distributors at Hunts Point were important suppliers to schools and other institutional kitchens and commissaries. In total, regional companies distributed 53% of the goods in the city, while national grocery and food service distributors moved half that volume (Economic Development Corporation, 2016). Croushorn (1990) identified food distribution as a high-leverage point to counteract market concentration, strengthen independent wholesalers, and improve food access.

The Center for Integrated Agricultural Systems, a sustainable agriculture research center at the University of Wisconsin's College of Agricultural and Life Sciences, has engaged with farmers since 1989 to identify system-based solutions to food system challenges through participatory action research. Early in the Center's history, farmers voiced concern over market access, especially for food produced using sustainable agriculture methods. These entrepreneurial farmers had to create separate, smaller, wholesale supply chains to move their produce. They found it difficult to link their smaller chains with wholesale

[1]Day-Farnsworth, L. (in Preparation). "Wholesale terminal markets as regional food system assets."

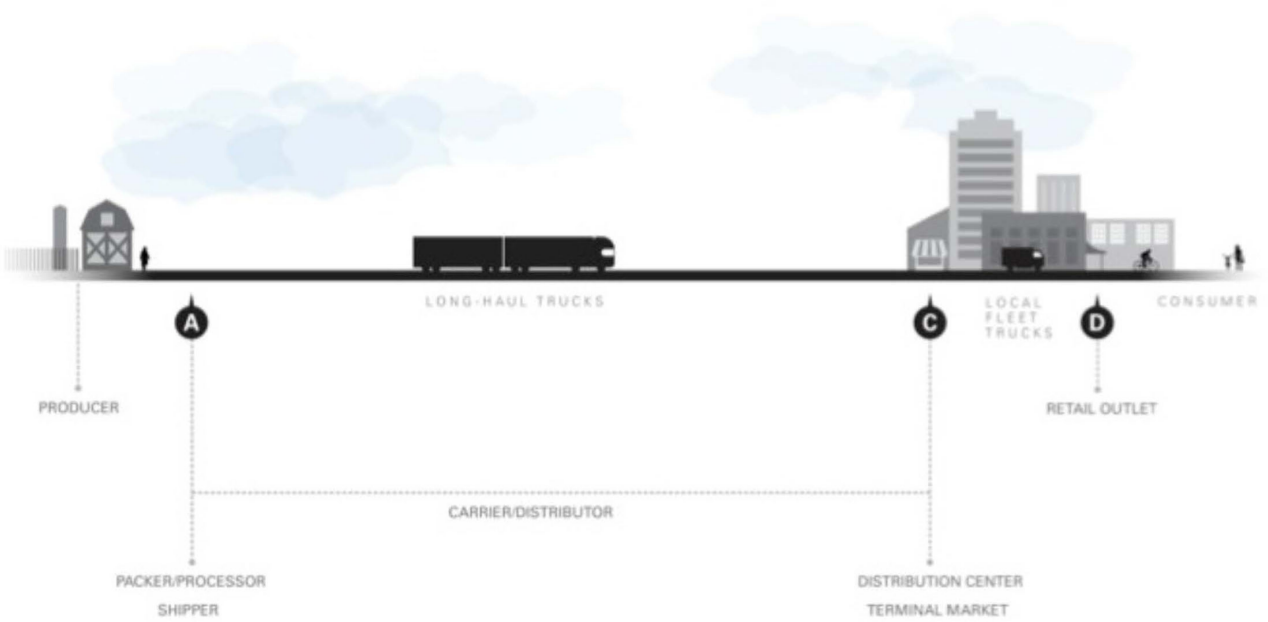

FIGURE 1 | This figure illustrates how food flows from farm to retail market. First mile movements are those from farm to packer or processor for aggregation, who then is responsible for shipping costs to market. Over-the-road trucks haul product from point **(A)** to point **(C)**, the private distribution center or public terminal market. Here product is disaggregated and moves to retail markets, point **(D)**. What is missing is point **(B)** - the infrastructure necessary to improve the organization of food movements from **(A)** to **(C)** at the regional level.

markets in major urban regions, especially Chicago, where national and global suppliers dominate, as documented by trade consultants (MWPVL, 2010), freight flow analysis [Chicago Metropolitan Agency for Planning (CMAP), 2012] and network food flow analysis (Lin et al., 2014). This is discussed in more detail in section Food Flow in the Upper Midwest of this paper.

The driving objective of this work is to understand why Wisconsin farmers are unable to access the nearby Chicago market with perishable products at a reasonable distribution cost, and identify ways to rectify the situation. This objective emerged from a regional needs assessment the Center conducted in 2011–2012, The Center conducted a series of workshops on local food and sustainable agriculture in the Four-state Drift less region. Local speakers shared their perspectives and insights and participants formed working groups on topics of interest and concern. One of those working groups identified transportation and distribution challenges as a key roadblock to rural economic development in the region.

To follow up on farmer interest in distribution challenges, the Center partnered with the USDA Agricultural Market Service's Transportation Services Division to convene a 2-day workshop entitled "Networking Across the Supply Chain." We organized this event as a pre-conference workshop at the Drift-less region's premier farming conference, the Organic Farming Conference in February 2013. More than 100 representatives from food and farming businesses in the region participated. Speaker panels discussed challenges from the perspective of farmers, distributors, processors and retailers, and participants discussed their take-away in small groups. For more detail on the process and findings see Day-Farnsworth and Miller (2014).

We then embarked on a third phase in 2014 to further explore issues that surfaced at the 2013 conference. **Figure 1** illustrates the food supply chain and was used early in the third phase to explain how food freight moves so that all participants could get quickly up-to-speed. A full report on the third phase details methods and findings (Miller et al., 2016). This article summarizes findings from this series of projects and continues the iterative research process by linking our past project findings with additional proof of concepts and current literature in preparation for new projects. Five new projects that further investigate regional food systems are in process. They are (1) a multi-university collaborative led by economist Hikaru Peterson at the University of Minnesota looking at three distinct megaregions to assess lessons that can be learned about resilient food systems from an analysis of the COVID-19 pandemic; (2) a closer look at cold chain food flows led by the author in collaboration with the Konar lab at the University of Illinois Urbana at Champaign; (3) a comparative study of rural and urban food access in a transportation context, led by the author in collaboration with the New Jersey Institute of Technology; (4) a project on dairy supply management policy led by the author to provide dairy farmers with policy research; and 5) a multi-university collaboration to explore ways to democratize analytics, using "smart foodsheds" as a use case, led by Dhabaleswar Panda & Casey Hoy at Ohio State University, Thomas Tomich,

University of California-Davis, and Alfonso Morales, University of Wisconsin-Madison.

THEORY

Food systems are non-linear. This means that they hinge on critical thresholds that can be leverage points for change. System concepts such as stock and flow (in our case, defined as sustainably produced food grown within the Upper Midwest region and the movement of food between point of shipment and wholesale market), as well as the concepts of leverage points helped us frame our work. There are multiple critical thresholds in the food system, both naturally occurring and human-constructed. We identified narratives and critical operational thresholds at the heart of challenges and opportunities that farmers face (Meadows, 2008).

Meadows defines leverage points as "places within a complex system (a corporation, an economy, a living body, a city, an ecosystem) where a small shift in one thing can produce big changes in everything." Narratives and critical thresholds are types of leverage points. Meadows identifies twelve types of leverage points within a system and ranks them from most to least effective. The most powerful points of leverage are those that shape how people think about their world, the narrative(s) that drive our everyday actions. Narratives have a logic of their own, so narrative differences are based on different logics, or understanding of how a system works (Frankova et al., 2017). The least powerful leverage points are those that "rearrange the deck chairs on the Titanic," the smallest changes that may seem easiest to make but that may make little difference in the overall system structure.

Ecological systems theory applied to human—natural systems helped our team to understand narrative bias. Emerging from quantitative work in South Florida's Cypress wetland ecological system, researchers engaged in ecological network analysis and found that the most efficient food network supported the most life (i.e., largest carbon flows), but was not resilient (Ulanowicz et al., 1996). Simply maximizing diversity in the system reduced carbon transfer and efficiency. Optimizing both efficiency and diversity resulted in slightly more carbon transfer (i.e., organisms in the system) and a more stable system overall. Resilience is quantified as the balance between the efficiency and redundancy of resource flow through the network (Fath, 2015). System level indices such as these highlight the relationship between internal processes and whole system performance. They identify a sweet spot between diversity and efficiency.

Most supply chain literature emphasizes negative feedback, such as regulation and top-down intervention to control a system and slow growth, but others observe that emergent patterns in complex adaptive supply networks can be better managed with positive feedback through reward systems that allow for autonomy of supply chain businesses (Choi et al., 2001). Rather than focusing on what we do not want and controlling it, the focus shifts to articulating a shared vision, such as sustainability, and articulating the steps necessary to create it. This is the purpose of crafting compelling narratives.

Critical thresholds are the parameters around how material, information, and capital flows through a system. Critical thresholds are further down on Meadow's list of effective tools for systems change than are narratives. Nonetheless, they provide other avenues for change. While Meadows' notions of systems change have been widely applied, less has been done with these ideas in the context of food systems and agricultural transformation. Recently, Tendall et al. (2015) and Rosenzweig et al. (2020) have addressed the opportunity by articulating key leverage points in the food system as a whole. They argue, as do we, that it is necessary to examine the larger system in order to improve system resilience and proactively prepare for disruption. This is done by listing opportunities at various functional and scaler point to broaden the narrative around agriculture, food systems, resilience and climate change, from field level change to systems transformation.

We found European literature on food systems especially useful. In 2015, the first Mediterranean Conference on Food Supply and Distribution Systems in Urban Environments convened scholars and decision makers in the fields of complex systems and system dynamics to find practical tools to improve food systems (Armendariz et al., 2015). Their use of stock and flow diagrams show how urbanization drives the need for food systems reorganization. System archetypes are common feedback or interaction patterns that arise from the structure of the system. The relationship between urbanization and the food system indicate a system archetype of "eroding goals," where long-term goals are not met because the underlying causes of failure are not addressed. The current food system also shows signs of "shifting the burden" and "fixes that fail."

The United Nations Food and Agriculture Organization (FAO, 2017) identified four trends that are stressing our food systems, and we found evidence of these trends in the Upper Midwest, as well. The trends are: (1) patterns of urbanization and related traffic congestion and patterns of food production, (2) business sector concentration as a result of weak and outdated market rules and lack of anti-trust enforcement, (3) pressures to increase labor and fuel efficiencies, and (4) climate change and other major social disruptions, such as COVID19. Climate change is thought to have the highest impact on trends because of its long-term nature and global scale (Calicioglu et al., 2019).

METHODS

The targeted objective for the project's third phase was to investigate how we can make our food system more resilient by undergirding national and global supply chains with robust regional food supply chains. We began with collecting feedback on findings from the second phase. Presentations on these findings at transportation conferences, particularly the leverage points identified in the second phase of the project, were tested (Day-Farnsworth and Miller, 2014). Examples of conferences include a paper presentation at the National Logistics, Trade and Transportation Symposium, Gulfport, MS, February 2014, a local food panel convened at Northwestern University, Chicago,

IL, November 2013, and a panel at the American Planning Association, Chicago, IL April 2013.

Understanding how food flows through our food system requires a transdisciplinary approach, most easily accomplished through a targeted case study. We chose the Upper Midwest, with Chicago as the primary market. Akin to Maani's Learning Lab 2013, over the project's third phase, we engaged a research and advisory team of twenty-six, including farmers, supply chain actors, students, academic staff and faculty from multiple departments and colleges to collaboratively explore food flow in the Upper Midwest. We started the project with a core group from phase two. As the project progressed we added other interested practitioners, students and faculty in a snowball fashion. We relied heavily on practitioner involvement to identify intersections between supply chain functions and incentives for innovation (Ruben et al., 2018). The formal project culminated in a workshop hosted by the Chicago Metropolitan Agency for Planning in Chicago's Willis Tower. The project produced a final report with detailed descriptions of methods and findings with many of the core team participating as co-authors (Miller et al., 2016).

To identify and explore leverage points in the food system, we hosted three 1-day meetings with regional food supply chain businesses and stakeholders. The first meeting was a write shop that resulted in an early concept paper. The second meeting used scenario-building methods to discuss four groups of trends that shape food systems: public health and food access; climate change and population growth; fuel and labor costs; traffic congestion and public infrastructure. We then grouped potential solutions into four approaches: policy and regulation, data and information technology, private and public sector engagement/opportunity; and infrastructure and other innovations. Our final workshop highlighted the experience of people working in food distribution, and equal time for participants to discuss what they heard in small groups. We had the good fortune to engage two teams of professionals in phase three as part of their degree programs on the University of Wisconsin-Madison campus. The team from the Department of Landscape Architecture worked on land use challenges. A team from the Grainger Center for Supply Chain Management worked on supply chain challenges and transportation logistics.

This process supported the co-generation of knowledge. Our collective understanding of the system evolved over the course of this phased project, based on feedback from within and outside the team. The large and diverse team, public meeting presenters, and practitioners involved created the system diagnosis. The literature review is iterative as this fast-evolving field of study expands. Every meeting and discussion built on the work done before. Our work necessitated that we piece together divergent narratives from a number of professional "languages" to build trust and a common language among team members. This process helped us to identify powerful narratives that both limit and support food system improvement.

As a group, we synthesized findings from multiple perspectives and disciplines such as history, ecology, geography, regional and transportation planning, engineering, business, economics, law and food production in order to gain insight into continental and regional food systems. We diagnosed the challenges and obstacles to improvement, and how long-term food shipment trends impact current and future food production and markets. We explored the history of food supply chains through the lens of business development, using academic and professional writing as well as oral histories from research partners and meeting participants. We looked for proof of concept throughout the process. We also shared co-produced knowledge with decision makers.

One of the approaches that was particularly helpful was path dependency analysis, a historical, sociological method (Mahoney, 2000). In this approach, we looked at the beginnings of food distribution to understand the impact of early technology adoption—the diesel truck—and how it shaped market development. The CR England proof of concept (Section Identifying Critical Thresholds in the Context of Efficiency and Diversity below) arose from practitioner knowledge shared during the course of the project and illustrates the arc of food system development from pre-diesel distribution to the current lock-in, to distribution reorganization during climate change and the Anthropocene.

Ultimately, this led to the creation of a local team linked to a food policy council, city and state governments, local businesses, and private firms, all of which are now acting on findings in an effort to reorganize our regional food system in the Upper Midwest. Our approach helped us to clarify "nested" system complexities identified by Meadows (2008) as critical "places to intervene in a system." Our historical analysis pointed to some potential leverage points for improving the current food system infrastructure that are less effective at changing the system than addressing narratives may be, but nonetheless have the potential to improve system design at the regional level. We identified specific types of businesses that are systemically alleviating transportation barriers to regional food supply chains for mid-scale businesses. Our inclusive analysis also identified elements like traffic safety, congestion, and inadequate public resources for infrastructure and logistics planning. Thus, our analysis of regional food networks speaks to challenges faced by transportation and city planners, especially in a region critically important to national food flow like Chicago and the Upper Midwest.

REGIONAL FOOD SYSTEM REVIEW AND DIAGNOSIS

Over the last 75 years, the US food system has evolved from a system of regional food flows between arable land proximate to cities, to a food system wholly reliant on national and global food flows. While direct marketing through farmers markets and other means is highly popular with consumers, from a farmer perspective these direct markets are a mixed blessing. They give farmers, especially beginning farmers, a chance to interact directly with their customers and build a business, although inefficiencies cut into profit margins. In a review of USDA data, Bauman et al. indicate that until a farm is of sufficient scale to sell into wholesale markets, their farm business is unlikely

to succeed without off-farm income (Bauman et al., 2018). Some research indicates that driving produce to farmers markets further than about fifty miles is simply cost-prohibitive (Grigsby and Hellwinckel, 2016).

Historically, wholesale food distribution capacity and urban development go hand-in-hand (Baics, 2016) because it improves how the system organizes food distribution to fulfill basic human needs. Public (as opposed to private) wholesale markets have played a significant role in food supply distribution, as documented in Maryland (Croushorn, 1990; Tangires, 1997). Privately held multi-tenant terminal markets are less common in North America but are found in other parts of the world. The World Union of Wholesale Markets has 217 members, in over 40 countries worldwide, and covering 5 continents. Some of these markets are privately owned and operate within government guidelines to serve public needs. Public-private partnerships are the most common governance arrangement and they share the primary objective of organizing the movement of fresh produce to market to reduce waste and realize energy savings by organizing truck movements (Escoffier, 2021).

For instance, Rungis Market, outside Paris, France, is operated by SEMMARIS, a self-described "semi-public company which includes public and private partners." Rungis is a member of the French Federation of Wholesale Markets. This Federation is made up of "all national interest markets and certain Wholesale markets in France." These markets place a high priority on local commerce and regional food production (Rungis International Market, 2017). Another example is the Central de Abasto, serving Mexico City and is the largest wholesale market in the world. A 99-year government trust initiated in 1981 oversees operations managed privately. The trust also provides financing to farmers so that they may access principle Mexican and global markets (Open Source, 2021).

Over the last 60 years in the United States public participation in wholesale food terminals has gradually decreased, deferring to private interests. Vertically integrated private distribution centers are made possible by the interstate road network and refrigeration technology. Beilock et al. (1990) documented the fading of multitenant wholesale produce markets as the food sector was consolidating, and how suburbanization contributed to the trend, from the 1950s onward. Tangires (1997) documents municipal and federal leadership in wholesale market development as early as 1913. The ability to meet the public goal to feed urban populations at the neighborhood level eroded as private sector efforts to maximize distribution efficiency took precedence (Tangires, 1997). Concentration in the grocery industry pushed independent community-based grocers out and replaced them with big box grocery stores that served a regional customer base (Pinard et al., 2016). Now, in a second wave, rural areas are experiencing another retreat of groceries, as rural population density falls below the critical mass necessary to be connected in with the increasingly dominant mega-supply chains (Parker, 2020).

Section Regional Food System Review and Diagnosis reflects insights and experiences shared in the presentations and discussions held at the meetings given throughout the project. We found that moving food from rural areas into large metropolitan regions is an expensive proposition. Regional shippers are looking for ways to reduce labor costs and improve fuel efficiency. Distribution centers are interested in securing more regionally-produced food to meet consumer demand and differentiate their stores. Planners are looking for ways to reduce traffic congestion and improve air quality. Food activists want to see food businesses owned by community members bloom in their neighborhoods. For more detail on meeting agendas, presenter topics, participants, and comments, see Day-Farnsworth and Miller (2014) and Miller et al. (2016).

Food Flow in the Upper Midwest

The Upper Midwest includes a constellation of cities in relationship with different farm production eco-regions and a unique food flow, one that supports regional food production while also serving as a hub for national and global food flows. The Upper Midwest food economy is built on innumerable food system interactions between Chicago, Milwaukee, Madison and the Twin Cities in Minnesota, and all the people and communities in-between. Overall, this region is home to more than 21 million people—and growing. Regional food production in the Upper Midwest is relatively diverse, with commodity dairy, meat and grain production, as well as remnants of a once-vigorous specialty crop economy around fruits and vegetables. This production pattern is shared by other states in USDA's "Northern Crescent region," loosely defined by the Great Lakes states. Regional crop diversity has contributed to the development of thriving direct marketing networks, centered around urban areas like Minneapolis/St. Paul and Madison, involving farmers markets, CSAs, and grocery cooperatives.

Meanwhile, fruit and vegetable production regions have shifted from city-proximate regional production to the "Fruitful Rim"—coastal states where production is unhampered by severe winter conditions, supported by irrigation and transportation subsidies (Aguilar et al., 2015). The ability to efficiently transport refrigerated produce also contributed to this shift from fruit and vegetable production near northern cities to the Fruitful Rim regions.

In Chicago, however, the story is different from the rest of the Upper Midwest. As more farmer-centric regional food systems emerged in and between the Twin Cities and Madison, the urban corridor of Chicago developed as a gateway for national and global food freight. Even though Chicago hosts O'Hare airport and is a rail and barge nexus, an insignificant portion of perishable food moves via air, rail and barge. Over a quarter of all US freight originates, terminates or passes through the Chicago region (CMAP Chicago Metropolitan Agency for Planning, 2021). Two hundred and sixty-nine million tons of freight worth over $564 billion moved through metropolitan Chicago in 2017 [Chicago Metropolitan Agency for Planning (CMAP), 2017]. The Chicago urban corridor now serves as a hub for the transportation of food produced in Western states moving east, and Milwaukee functions as a spur of Chicago. Urban sprawl whittles away at food production opportunities near this great city, further driving land prices up and subsequent urban development in a positive feedback loop. Federal farm policy supported commodity production (i.e., large scale corn,

soybean, and meat) and did little to support more diversified regional food production to serve nearby cities.

Over 95% of cooled produce moving through North America travels by truck and refrigerated trailer (Pullman and Wu, 2012). Lin et al. (2014) work on national food flow found that the Chicago region is central to the national food network, as evidenced by findings that it has the largest square footage of food warehousing—pre-dominantly privately owned (MWPVL, 2010). Freight moves vary by trip type, and "through traffic"—which initiates and terminates elsewhere—is the largest component of truck freight in Chicagoland. In-bound truck freight that serves the city constitutes only 17% of freight traffic, indicating that much of Chicago's freight traffic is simply "passing through" [Chicago Metropolitan Agency for Planning (CMAP), 2012]. A 2017 Texas Transportation Institute analysis of the cost of congestion in Chicago estimated that over 15 million annual hours of truck delay, more than 30,737 gallons of wasted fuel from trucks, and congestion costs to shippers of over $753 million (Eisele et al., 2013; TTI, 2017), the price paid by the region for freight through-traffic.

Driving goods into cities thus involves surmounting several challenges. Historically, traffic congestion has pushed many multitenant produce terminals to relocate from the inner city to the outskirts. In Chicago, Haymarket, South Water Market, and now the International Produce Terminal located near I-55, are examples of this progression (Block and Rosing, 2015). By 1940, Chicago's centrally located public wholesale market was overwhelmed with traffic congestion, so the city replaced the downtown market with the South Water Market, and eventually in 2003 with the International Produce Market, geared for larger scale shippers and buyers, especially those selling global produce, as its name signifies. In turn, large, vertically integrated, and privately held supply businesses emerged, able to take advantage of efficiencies of scale and logistics analytics. Smaller distributors and farmers struggled to compete, and last-mile efficiencies associated with central city locations were lost.

This context exposes how the Midwest's *regional* wholesale food flow is profoundly depressed by the national and global flow of food and capital into Chicago, leading to both rural and urban areas experiencing insufficient access to farmland, markets and food (Miller et al., 2016). As described by Block and Rosing (2015), Chicago became a national and global food distribution center at the expense of serving regional farmers.

Our research identified seventeen companies that do business from Chicago's International Produce Market; currently only three produce houses list locally sourced product (potatoes, onions, and beets) at the height of the local growing season. This is despite its accessibility to the I-55 corridor, one of the major interstate corridors in the US, connecting the Great Lakes to the Gulf of Mexico [Merchant Directory (n.d.)]. Mandal et al. (1993) documented the underutilization of Chicago wholesale markets by Illinois fruit and vegetable farmers in their 1993 report, produced at the time planners began to advocate for the creation of the International Produce Market. They highlighted the efficiencies that could accrue to mid-size farms, as well as the high transportation costs to move product the last mile into the city by improving the market (Mandal et al., 1993).

Many crops once grown in the Northern Crescent for wholesale fresh market fell below critical production levels (or thresholds) necessary for efficient transportation to regional markets. Farmers we interviewed indicated that predatory pricing strategies from grower/shipper alliances in the Fruitful Rim states and Mexico undercut their ability to participate as regional producers. Chicago's central role in the development of national distribution and resultant evolution in market structure contributes to the atrophy of the Upper Midwest's regional distribution sector.

Key Global Trends That Influence Regional Food Systems

Our analysis of the Upper Midwest regional food system resonates with the four dominant global trends currently shaping the North American food distribution system, as well as food access world-wide. These trends point to opportunities for changes beneficial to local and regional business networks. The current Pandemic has proven to be a good testing ground for food system resilience, or lack of it. Because the Pandemic is also a global disruption, and because it came on quickly with little warning, it illuminates systemic weaknesses in the structure of our food system and opportunities for systemic change.

Urbanization is a primary driver of market concentration and has slowly warped the structure of the food system. Market dynamics related to urbanization have the potential to devolve into colonial, extractive relationships with farmers and rural areas. In these market relationships, urbanites give little thought to outlying regions, except as tourist and supply sources, assuming they lack autonomy or cultural significance. The sheer scale of urban markets, and accompanying transportation challenges may disrupt regional distribution that then stunts small, independent, entrepreneurial, and community-responsive business development, from farm to retail.

Considering *concentration across the food system* as a whole, market concentration is only one aspect of supply chain concentration prevalent today (Pullman and Wu, 2012; Howard, 2016). From seed companies to retail stores, the system favors large, vertically integrated businesses that can manage risk by controlling for costs across multiple supply chain sectors, (Howard, 2016). The entire food supply chain has undergone concentration and as a result, is less competitive and barriers to small business are high. Howard (2016) notes that of the top five hundred firms in the world according to market capitalization, forty were engaged in food and agriculture. Of these, eighteen focused on packaged goods, eleven in retail, and nine in agricultural inputs. Distributors and commodity firms were represented by one company each, and there are no farms at this scale. This creates a system in which a dwindling farming population produces the dietary ingredients of an increasing population of consumers with just a few firms controlling the flow from farm to plate (William et al., 1999).

Anti-trust enforcement began with a wide focus and over time has devolved into looking at only one measure: price paid by consumers (Baker, 2019). Current US anti-trust laws also assume that markets are sufficiently competitive, so that the courts can

manage the edges in such a way that competition is protected. Unfortunately, this has not been the case. Independent businesses such as locally owned grocery stores, mid-size farms that produce fresh produce, meat, and dairy, small processors developing new products such as organic salsas or grass-based specialty cheeses struggle to enter markets dominated by vertically integrated companies, including cooperatives. Market rules are needed to assure opportunities for price discovery (where sellers can see what prices are being paid in the market for their goods), technology and information access, and protection from market power abuse (Carstensen, 2008). Updating market rules to reflect 21st century supply chain operations is a necessary next step to ensure small business success and an "economy-of-the-middle." It is possible to restore a competitive economy, as was done in the US in 1946 with the creation of programs such as USDA's Agricultural Marketing Service to set market rules (Baker, 2019), or even earlier in 1913 with the USDA Office of Markets (Tangires, 1997). In contrast, the European Union and Canada take an administrative rather than an adversarial approach to regulate mergers and acquisitions effectively, (Baker, 2019).

Pressure to increase *fuel and labor efficiencies* contribute to sector concentration, although the need for innovation can also open up opportunities for more local and regional producers and distributors. Roughly 6% of energy used in the food system is used to move food, mostly its transport by truck. That figure is low, as it does not include delivery from farm to processor, diesel truck trailer refrigeration (Heller and Keoleian, 2000) or transport from store to home or restaurant, also referred to as the "last mile" (Wakeland et al., 2012). These studies neglected to investigate how changes in distribution could potentially change energy use downstream, such as with home refrigeration and wasted food (Verma et al., 2019) or fuel and labor waste from traffic congestion (TTI, 2017). These are examples of unintended systemic outcomes of how food is distributed. As Rosenzweig et al. (2020) point out supply chain opportunities for reducing Green House Gas (GHG) emissions are linked to overall systems design, and the consumption and distribution end of the system can drive improvements at the farm and processing end.

In response to pressures to increase fuel and labor efficiencies, and more recently to *reduce carbon emissions*, engineers are innovating truck design so that they are specialized for the type of use or "duty cycle." The trend is away from "jack-of-all-trade" trucks, toward specialization that correlates to trip segments (Roeth, 2016, 2020). Many innovations optimize truck design for specific segments illustrated in **Figure 1**—first mile, Over-The-Road (OTR), regional, and last-mile trips. First mile is the distance from field to packing house or processor; OTR is 400+ miles; regional is loosely defined as $<$400 miles but $>$50 miles; and last mile is the distance from retail (or its warehouse) to consumer. There is also a move away from diesel-driven trailer refrigeration to battery dependent systems as a carbon reduction measure, and now a move to all-electric regional freight systems (see Roeth, 2021 for a call for industry participants to participate in a study on the topic).

In addition, newly implemented Hours of Service (HoS) regulations (FMCSA-USDOT, 2020) rely on geographic positioning systems (GPS) asset tracking technologies and require drivers to follow strict driving schedules that also push the system to regionalize. For these reasons, many larger logistics and distribution companies are adding regional warehouses with state-of-the-art material handling and traceability technologies to improve system performance. Regional distribution logistics are replacing OTR, making it easier to adopt alternative fueling infrastructure, improve driver working conditions, and improve road safety and congestion (Mihelic and Roeth, 2019).

Optimizing for Efficiency and Diversity-Merging Two Powerful Narratives

Bringing together innovative farmers with innovative transportation planners and practitioners was eye-opening. Farmers tended to discuss how diversity at the farm and landscape level was critical to the biological health of their systems and expressed frustration that they were unable to attain necessary transportation efficiencies to economically thrive. The transportation sector is steeped in narratives about efficiencies and struggles with diversity issues, such as the size of businesses, their ownership and access to capital; labor relations; supply chain concentration; and the fallout from overefficiency, such as-insufficient food access, as well as urban congestion, poor driver retention, and unnecessary GHG emissions. The acceleration of on-line food purchasing and delivery exacerbates systemic inequity when rural people, poor people, and their community businesses lack access to the internet, and don't have capital assets to support it.

As people interested in making the food system more fair, resilient and sustainable, our ability to recognize this either-or tendency that system actors take toward efficiency or diversity creates an opportunity for change. As Meadows articulated, the stories we tell ourselves frame what we do, so changing the narrative is one of the most powerful leverage points available to us as change agents. Transcending a single narrative or mindset is tantamount to expanding one's toolbox—realizing that we no longer need to see a nail, since we have more than a hammer to respond. When we encourage and support system actors to successfully optimize for both efficiency and diversity throughout the supply chain, we realize a more resilient food system that has the potential to elegantly address multiple business and public sector goals. Network analysis reinforces this conclusion. Solutions that tackle food systems efficiency and diversity, address governance and ownership challenges, and build resilience to crises have an indirect and systemic effect on all aspects of food security and need to be prioritized (Calicioglu et al., 2019). Multiple narratives allow us to think more broadly about food system design and open the discussion for improving the regional organization of food flow.

Improving the regional organization of food flow, based on an understanding of the non-linear constraints in regional food movements, may allow private sector entrepreneurs to seize opportunities to optimize fuel use without sacrificing food access and other measures of diversity. Transportation is a non-linear system of human design; certain minimums must be reached for the system to operate efficiently. Sustainable agricultural production is both of human and ecological design

and is also non-linear. It involves understanding system limits and optimizing diversity for specific environmental conditions. Attaining transportation efficiencies requires that individual crop production minimums be met for markets of varying sizes. Our discussions clarified how optimizing both diversity and efficiency is in the public interest, whether from the perspective of supply chain infrastructure or food production.

A growing body of research suggests that undergirding national and global supply chains by relinking cities with proximate production regions shows promise for realizing system efficiencies while promoting socioeconomic and agro-ecological resilience (Lengnick et al., 2015; Frankova et al., 2017; Clancy and Ruhf, 2018). A European study found that "urban consolidation centers" achieve an overall reduction in costs (5%), reduction in carbon emissions (7%), reduction in vehicles used (10%), reduction in total distance traveled (19%), and an increase in total number of delivery points visited per trip (11%), (UTURN, 2018). Such efficiencies save the public and private sectors money and improve service to those in need. To know where collaborative logistics are best placed to realize these and other benefits, planners need to know the network structure for food flow.

If regional food systems are optimized for logistics and fuel-efficiency, shorter distance food movements have the potential to successfully "compete on proximity" with large-scale growers at great distance to markets. This could allow farmers using sustainable agriculture practices to fine-tune their production in agro-ecosystems so that they may optimize crop diversity on-farm as well as within growing regions. It is unclear if seasonal advantages for producers in warmer climates will outcompete the advantages of proximity. Setting explicit market rules that support regional food production may be necessary in order to balance production advantages between regions. For instance, federal market orders for dairy production are explicit federal rules developed in the 1930s to encourage regional fluid milk production, but similar measures were not enacted for other perishable products. These dimensions of regional food distribution have significant ecological, economic, and governance implications that remain underexplored.

Supply chain and market governance, whether it is formal or informal, is developed from our mental models of the system. Our narratives must be explicit and ultimately, they must be shared. Innovative supply chain governance may expand regional producers' access to markets and access to affordable, regionally sourced products (King et al., 2010). A public commitment to once again support regionally based wholesale food supply chains could offset food system consolidation in the private sector and stimulate entrepreneurial business development (Beilock et al., 1990; Croushorn, 1990). Lengnick et al. (2015) suggest that enhancing the modularity and diversity of regional food production and distribution in tandem with optimizing system efficiencies is crucial to fostering sustainable and climate resilient food systems nation-wide.

Farms that aggregate products for shipment use multi-firm collaboration. Smaller and larger farms commonly work together to aggregate products for market. Forward-thinking businesses and the public sector could organize and support similar efforts within food supply chains to improve collaboration between shippers, trucking firms and wholesale buyers. Public terminal food markets are one way to aggregate product and are realizing a renaissance in major cities such as San Francisco, Toronto, Syracuse, NY, Jessup, Maryland, and Atlanta, and new ventures are emerging in San Jose, CA and Madison, WI (BAE Urban Economics, 2016; Karst, 2018; Wholesale Market Stakeholder Meeting—NAPMM, 2018; Gottwals, 2019). Business investment in multi-firm collaboration puts innovative entrepreneurs in the lead as investors who develop societal assets (Miles et al., 2005). Collaboration is possible when a core group of firms have a shared vision, common set of values, competence in teamwork, and interest in continuous innovation, as we see with farms committed to sustainable agriculture. For continuous innovation and collaboration to emerge, supply chains need redesigned reward and control systems. Choi et al. (2001) support the idea that positive interaction through rewards is more effective at managing complex adaptive systems than is regulation or other controls. Governing multi-tenant cold storage is another area for future research and development. Determining when and how decisions are made and how disputes are resolved is important for timely supply chain management and building trusted working relationships.

Factoring in social equity, more broadly than simply through food access measures, is important as we attempt to optimize efficiency and diversity, if we intend to make lasting food system improvements (HLPE, 2019). Other characteristics of the human component of system relationships, such as predation, competition, collaboration and cooperation, deserve a closer look, especially from a governance perspective.

Identifying Critical Thresholds in the Context of Efficiency and Diversity

Even as the system is currently structured, practitioners identified leverage points where supply chain collaborations can create regional efficiencies that support bioregional diversity. Our diagnosis indicates how simple, targeted public and private investments in regional logistics can improve regional food distribution now and in the future. As Armendariz et al. (2015, 2016) conclude, food distribution is often insufficiently organized to meet current and future urban and rural needs. Transportation and distribution infrastructure that supports small and medium supply chains could encourage entrepreneurial responses to rapidly changing circumstances and extend food access to underserved urban neighborhoods and rural communities.

A team member alerted us to the story of CR England, North America's largest wholesale cold chain trucking company (Miller et al., 2016). It's story, as told on their web site, follows the food system's trajectory. Founded in 1920, the company began as a regional food carrier in Utah. They bought their first refrigerated trailer ("reefer") in 1950 and by 1960 the company was operating regular cross-country runs from Western producers to a public terminal market on the East Coast. In 1978, the company opened its first private distribution center in New Jersey, and now operates three more terminals in California, Indiana, and Texas (CR England, 2015). As the largest cold

chain company, CR England is at the forefront of logistics innovation. EPA's Smart Way program has honored CR England for its high environmental performance multiple times and most recently in 2015 (U.S. Environmental Protection Agency, 2015). The company serves as a beacon for innovation in food supply chain logistics. Its business trajectory demonstrates the importance of public food terminals to smaller businesses in realizing efficiencies and increasing regional resilience.

In 2015, CR England reorganized their business in Southern California. They built drop yard infrastructure just 56 miles outside of Los Angeles. As a dedicated contract carrier—that is, a trucking company that contracts with a specific shipper to move product along regular routes—it is relatively straightforward to swap a truck tractor designed for long-distance hauling with another tractor for the urban segment of a trip. This practice has allowed the company to power some of its urban trucks with more efficient alternative fuels, adopt technologies to improve long-haul efficiency on other tractors, and improve overall fleet efficiency.

The Southern California facility includes a maintenance shop, Driver Resource Center, and parking for more than 250 tractors and 350 trailers. The new facility made it possible to expand their local fleet with Liquefied Natural Gas (LNG) tractors. The company credits collaboration with vendors and shippers–positive freight market dynamics-as critical to the success of converting to LNG tractors (CR England, 2014). A contracted rate structure allowed for greater efficiencies between the urban and rural segments of the trip. Now, the OTR fleet moving product from the shipper to the drop yard can move continuously, while the local fleet can drive the shorter distance inside the urban area with LNG vehicles. This reduces fuel costs, and reduces air pollution that is released while trucks wait in queues at congested delivery points, such as the Port of Los Angeles. It also allows the company to make better use of drivers, where newer drivers can take OTR routes and more experienced drivers can handle urban routes.

A more granular look at the food system that took place in meetings with practitioners helped us to identify quantifiable critical thresholds that can leverage change for this improved food system organization, as discussed in Ruben et al. (2018). These thresholds are a function of human-designed systems that operate within environmental limits *and* scale efficiencies. Some thresholds are common knowledge within freight transportation and sustainable agriculture circles, while others may require additional research, especially region-specific research with analytics. Many studies detailing these practices and research into public logistics for regional food supply chains are reviewed in Mittal and Krejci (2018), and they reinforce findings from our Chicagoland case. Additional cases from other regions also reflect these thresholds (Martinez et al., 2009; Miller et al., 2016; Wellborn and Lamie, 2017; Mittal and Krejci, 2018).

Cropping Diversification

There is a need for greater farming diversification, especially near urban mega regions, to hit the sweet spot between efficiency and diversity. The Chicago mega region is a case in point, where Illinois farmers are less diverse than farmers in Wisconsin and Michigan. Restoring agricultural diversification throughout the US Corn Belt is important to regional resiliency, especially within the 400-mile regional radius of large urban wholesale markets, and within a 200-mile radius for smaller cities and rural regions. Cities that protect farmland in this zone and improve the flow of capital and information to support food supply chains (as opposed to commodity production) are investing in food resilience, as we found in an Ontario proof of concept.

Producer and Distributor Collaboration

Sustainable agriculture practitioners are identifying bio-physical critical thresholds for food production at the farm level that are specific to the agricultural production region (Lengnick, 2014). In turn, they seek supply chain partners in transportation and markets that share their commitment to sustainability. In order for regional food production to feed into wholesale markets, there must be sufficient availability of products, both seasonal and year-round. This can be accomplished through producer collaboration. Offering a mix of products that require refrigeration–fruits, vegetables, meat, dairy, beverages–can improve the efficient use of trucks, warehousing, and service contracts, and maintain consumer loyalty for "local." Regionally produced, in-season food must have market access and consumer demand to successfully compete with the national flow of the same products. As an example, California carrots may be available for 12 months, while carrots grown in the more northern states are likely available for 9 months or less. Creating a marketplace where smaller growers may develop new relationships with wholesale buyers may soften long-term relationships between larger national supply chains and add regional resilience. Protecting smaller producers from predatory markets is a role for governments to create and enforce market rules. Historic proof of concept from the 1930s US could be applied.

Contracts

Regular contracts along the supply chain are more efficient than erratic, irregular relationships that carry high transactional costs. Seasonal farming constraints in the Upper Midwest, and extreme weather impacts on food production mean that shippers and trucking companies must find creative ways to overcome volatile conditions and associated uncertainty. Regular professional meetings and relationships at point of purchase between small supply chain businesses may improve communication and build trust. Another approach may be to encourage north-south collaborative intra-regional supply chains mid-continent, such as those on the East and West Coasts.

Transportation Efficiencies

Based on efficiency research, farmers may want to handle their own first mile distribution when located within a 50-mile radius to market. Farmers interested in pooling product for regional wholesale markets could limit their regional markets to about 200 miles. Markets between regions (from one region to another) could stretch to 400 miles, especially in the more rural center of the continent. To boost access to significant local wholesale markets, shippers might partner with mid-size cities

in developing combination facilities that both aggregate products for more distant markets and weave together multiple smaller supply chains so that they may sell to wholesale buyers, especially independent businesses within about fifty miles to the terminal.

- In terms of **vehicle efficiency**, 53' trucks must be fully loaded (30 pallets or weight limit) for shippers to realize efficiency and must meet a financial threshold for product value. Farmers must have sufficient production and/or aggregate their products for shipment at this scale to efficiently reach regional markets.
- Trucks designed to be used for shorter hauls save fuel. If city deliveries and deliveries navigating extensive traffic congestion are made with trucks designed for that purpose, companies can invest in more efficient engineering for longer hauls. Considerable research on engine efficiencies is underway and can shape how we invest in food infrastructure to create positive incentives to adopt these engineering innovations. For instance, we know that longer haul vehicles operate best at constant, higher speeds. We know that public investment in alternative fuel vehicles and infrastructure, such as charging stations, will support private sector investments and help us meet GHG emissions targets. Advances in hybrid technology may alter existing critical thresholds, as may other engineering innovations. Engineers are setting the pace for change so there is opportunity in anticipating and matching this pace. Hosting design sessions with supply chain practitioners-farmer to wholesale buyers-may yield unexpected innovation.

Public Support for Infrastructure

Large cities that invest in distribution infrastructure could prioritize service to smaller, community-owned supply chains that are unable to invest in their own private warehouses, and work with shippers doing business no further than 400 miles outside metro limits. Numerous proofs of concept exist outside the US. An important public role may be to convene and assist with business collaboration and to serve as a champion. Capital investment may pose a significant hurdle for large infrastructure projects with public interest at their core. Public facilities ownership, low-or no-interest loans, or on-going investment in operations may accelerate change. Distribution infrastructure can ease logistical challenges near large cities where congestion is an issue or where natural features such as the Great Lakes or mountains complicate direct routes. For regional wholesale food shippers to gain efficiency, they need one point to transfer ownership of the product. Combining regional hauling with last mile deliveries is inefficient. Terminals that operate with an explicit goal to serve small wholesale supply chains are increasingly necessary as private national supply chains continue to consolidate even while extreme weather threatens those supply chains. Terminal redundancy can also improve logistical efficiency for drivers adhering to HoS regulations and allow smaller businesses to access new technologies such as automated warehousing, block chain ledgers, and digital twins software. If they collaborate, software technology to match loads is affordable for wholesale businesses in small supply chains.

CONCLUSIONS

The U.S. Upper Midwest has fostered numerous local and regional food supply chains made up of farms, processors, trucking companies, wholesalers and other firms that invest in sustainability and local economic development. These businesses are committed to operating within environmental limits and at a scale where economic efficiencies can be realized. At the same time, they have struggled to gain economic access to markets dominated by larger scale, concentrated food distribution systems. Transportation congestion around cities creates significant barriers to freight efficiency and drives associated costs that are shouldered by trucking companies and shippers. Big box stores outside the city center act as small distribution centers, where consumers incur the transportation costs when driving the last mile. This unchecked tendency of the system as currently designed leads to limited food access in poorer regions of cities and further contributes to congestion. Rural and remote regions lack food access when there is a lack of regional food production diversity and where supply chains are too large to efficiently serve them.

Improving the regional organization of food flow requires an understanding of the relationships that create system constraints. It is in the public interest to create an ecosystem where private sector entrepreneurs may respond to opportunities in their communities to concurrently optimize fuel use, food access and sustainable farming practices. First mile, regional, and last-mile transportation businesses; product aggregation intended for regional wholesale markets; and regional supply chain aggregation in mega-regions are just a few opportunities for small business development in the food processing, distribution and retailing sectors.

Additional research to better understand the ebb and flow of food through the seasons, in different regions, as it moves through the food system would be of use to supply chain managers and logistics professionals and could improve market rules. Developing measures of food enterprise diversity could provide regional planners with a tool to gage the strength of food flow into urban and rural communities. Other characteristics of business relationships along supply chains deserve a closer look so that we may understand how supply chain actors may better collaborate to meet their business and public goals, and how truly competitive markets can thrive and innovate.

Public and private investment in multi-firm collaboration supports innovation at the community level, so that entrepreneurs may take the lead as primary investors in developing societal assets. Midsize farms that aggregate products for shipment currently practice multi-firm collaboration. Forward-thinking businesses, with encouragement from the public sector, could also organize and support similar efforts within regional food supply chains to improve collaboration between shippers, trucking firms and wholesale buyers. Given the unique importance of food in a healthy society, it is our civic responsibility to improve food supply chain organization so that the food sector may meet increasingly urgent public goals.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

MM developed and managed the study.

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