The costs of increased localization for a multiple-product food supply chain: Dairy in the United States

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ABSTRACT

There is increased interest in greater localization of food supply chains but little evidence about the effects of localization on supply-chain costs. Assessing these effects is complex in multiple-product, multi-process supply chains such as the dairy industry. In this study, we develop a spatially-disaggregated transshipment model for the US dairy sector that minimizes total supply-chain costs, including assembly, processing, interplant transportation and final product distribution. We employ the cost-minimizing solution as benchmark to compare alternative scenarios of increased supply chain localization. Our results indicate: (1) short-run limits to increased localization, (2) modest impacts on overall supply-chain costs, and (3) large cost re-allocations across supply chain segments, regions and products. We find that increased localization reduces assembly costs while increase processing and distribution costs. Cost increases are larger in regions with smaller raw milk supplies and during the season when less raw milk is produced. Minimizing distances traveled by all dairy products results in tradeoffs across products in terms of cost and distance traveled. The relationship between increased localization and costs appears to be nonlinear.

Introduction

There is increased interest among consumers, private and public decision makers regarding the sustainability of food supply chains. Today, consumers are more responsive to the ways food is produced, processed and distributed, often based on perceived benefits, including environmental, health, food safety, and rural development. Policy makers, for their part, are pressuring food industries to re-examine the sustainability of their supply chains. The US dairy industry, for example, has a plan to reduce greenhouse gas (GHG) emissions by 25% by 2025 (IDFA, 2008). The initiative incorporates GHG emission reductions in production (crop and dairy farming) as well as in the supply chain (transportation, processing, distribution and retailing), which account for 70% and 30% of sector GHG emissions, respectively (EPA, 2008).

One consequence of the pressure to improve sustainability performance is the emergence of arguments in favor of more localized food supply chains. Advocates of increased localization argue that reduced GHG emissions are one possible benefit—among many potential ones—of localized food supply chains. As a result, concepts such as “food-miles” and the like often have been employed to develop metrics for evaluation of sustainability performance, primarily because they are relatively easy to measure and communicate to the public (Coley et al., 2009). Therefore, increased localization of food supply chains has become linked to (even synonymous with) the reduction of GHG emissions (Darby et al., 2008; Hein et al., 2006; Jones et al., 2007; Lang and Haesman, 2004; Peters et al., 2009; Stagl, 2002).

Although localization may be desirable, there is limited empirical evidence about how increased localization may influence costs of food supply chains and, ultimately, the price for food paid by consumers. The business model that has evolved in conventional, mainstream food supply chains delivers multiple benefits stemming from the provision of a wide variety of convenient, year-round, relatively inexpensive products (King et al., 2010a,b). There is little knowledge about possible tradeoffs between increased localization and the cost of food supply chains.

Examining possible tradeoffs between increased localization and food supply costs in the context of multi-product industries requires spatially-disaggregated models that take into account the multiple relationships among the many supply chain segments beyond the farm gate, including assembly, processing, transportation and distribution. One approach that meets these analytical

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requirements is spatial optimization modeling. To analyze the impacts of greater localization on supply-chain costs, we employ a spatial optimization model of the US dairy product supply chain. The model focuses on supply chain segments beyond the farm gate (assembly, interplant transportation, processing and distribution) for all dairy products, of which the most important are fluid milk, yogurt, cheese, butter and nonfat dry milk. We calibrate the model using data from 2006 and develop scenarios to compare impacts of alternative strategies to increase localization: one focusing on reducing the distance travelled by all dairy products and the other focusing on the reduction of one product only (fluid milk).

The dairy sector is an excellent example for examining the economic consequences of increased localization of food supply chains. First, dairy was primarily a local industry in the US before 1950. Since then, rapid innovations in food preservation and processing, huge investments in private and public infrastructure, as well as the realization of important economic benefits accruing to economies of scale and specialization, have all contributed to a transition of the US dairy supply chain from local to national (and even global). Second, although milk is produced in every US state, there are significant spatial imbalances between production and consumption regions, and these differences have grown over time (Figs. 1 and 2). The western US has experienced large increases in milk production but has a relatively low population density, while the southeastern US has gone through substantial population growth accompanied by shrinking milk production. Third, dairy is a multi-product industry with various interrelated supply chains and disentangling the consequences of increased localization efforts is not straightforward. Product diversity and the complexity of product flows in the dairy supply chain, together with the high level of perishability of raw milk and many of the intermediate and final products, make consideration of how to increase localization of this industry challenging.

This study is organized as follows. After this introduction, we discuss the literature on localization, emphasizing the links to supply-chain costs. Next, we describe our multi-product optimization model of the US dairy supply chain. In turn, we discuss our alternative scenarios, present our results and discuss the policy implications. The last section offers concluding remarks, discusses limitations of our study and proposes topics for future research.

Literature review

There have been a large number of empirical studies on food system localization in recent years. The overwhelming majority of these studies addresses demand-related aspects of food localization using a wide range of approaches, from case studies (e.g. Sirieix et al., 2008) to the implementation of laboratory experiments (e.g., Toler et al., 2009). This literature has also explored the challenges and opportunities of a local food supply chains (King et al., 2010b) and the "local food" movement advocacy as means to achieve social justice (Allen and Wilson, 2008). However, there is surprisingly little empirical evidence regarding the potential costs associated with increased localization of food supply chains.

The literature on demand explores consumer motivations for buying local foods (Onozaka et al., 2010; Sirieix et al., 2008; Thilmany et al., 2008; Toler et al., 2009; Zepeda and Deal, 2009), the meaning of the "local" attribute (Darby et al., 2008; Hand and Martinez, 2010) and the willingness to pay for locally-grown foods (Conner et al., 2009; Khan and Prior, 2010; Toler et al., 2009). This literature identifies certain regularities regarding the demand for local foods. First, price premiums for local foods are driven by heterogeneous consumer preferences, ranging from fairness, to health attributes, to environmental concerns (Onozaka et al., 2010; Zepeda and Deal, 2009). Second, although laboratory experiments suggest that consumers value local foods and care about various attributes (Toler et al., 2009), this is not always reflected in purchasing decisions (Khan and Prior, 2010). Third, consumers are often confused about the meaning of the attribute

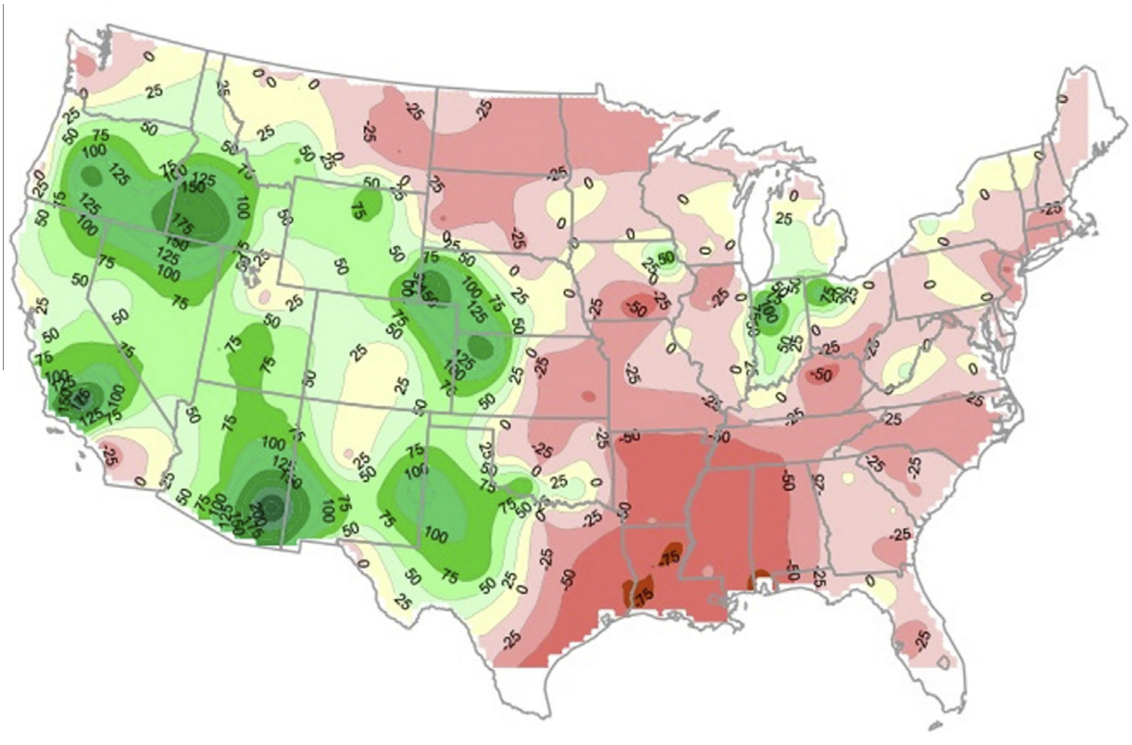

Fig. 1. Percentage change in May monthly milk production in the US from 1995 to 2006 (*Source*: Generated using data from Agricultural Marketing Service of USDA).

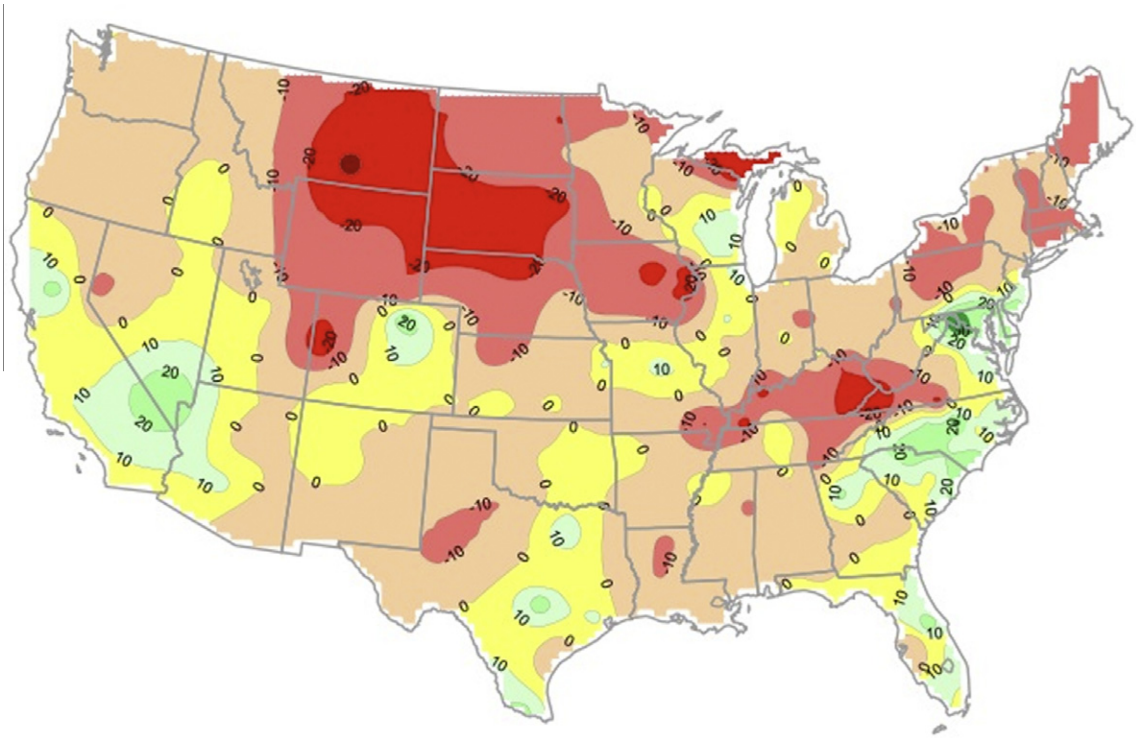

Fig. 2. Percentage change in October monthly fluid milk consumption in the US from 1995 to 2006 (*Source*: Generated using data from Agricultural Marketing Service of USDA).

"local" due to its multidimensional nature and to the difficulties for developing a unified definition of local foods (Hand and Martinez, 2010).

Researchers are turning their attention to the ability of supply chains to meet consumer demands for increased localization. In these studies, the "food-miles" concept often is employed to measure the degree of supply chain localization because this concept is easy to communicate to consumers (Coley et al., 2009; Hein et al., 2006). Peters et al. (2009) employs the "food shed" concept to assess the ability of geographical regions to feed their populations. A limitation of this approach is that it ignores the costs of a more localized food supply chain, relative to extant ones. This literature also addresses factors affecting the success of more localized food supply chains, including ability of growers to integrate into local food networks, diversification of distribution channels and opportunities for product differentiation, among others (Heer and Mann, 2010; Jones et al., 2007; King et al., 2010b). These studies suggest that the share of local foods in total food intake is still small due to difficulties that localized food supply chains face to enter mainstream channels or to compete with them (Jones et al., 2007; King et al., 2010b).

The increased localization of food supply chains is also relevant to other dimensions of sustainability such as GHG emissions and climate change. Weber and Matthews (2008) compare GHG emissions between local food production and long-distance distribution using the "food-miles" as a metric of performance. The authors conclude that changing diets is a more efficient strategy to reduce GHG emissions than localizing food supply chains. Further, a recent study on organic vegetables finds that a supply chain in which consumers travel to the farm to purchase their vegetables produce more GHG emissions relative to a large-scale home-delivery supply chain operated by a large food retailer (Coley et al., 2009). In this sprit, King et al. (2010b) find that fuel use is more affected by supply chain structure (e.g. size and number of segments) than by the distance traveled by food, and find that fuel use per unit of product is often smaller in supermarket supply chains than in local supply chains.

Regardless of the implications of increased localization on GHG emissions, efforts to localize food supply chains persist, given the value that consumers see in having localized supply chains. However, very little is known about the cost of localizing supply chains. There is only anecdotal, partial evidence, mostly provided by case studies regarding the cost of local food supply chains relative to their mainstream counterparts and the findings are inconclusive. Only one study by Hardesty (2008) finds that transaction costs for localized supply chains are larger than for mainstream supply chains, in the foodservice sector. Therefore, our contribution to the literature is to employ an optimization model of a multi-product sector, dairy in the US, to investigate possible tradeoffs between increased localization and supply-chain costs. This is an important issue for at least three reasons. First, there may be limits to localization of food supply chains, particularly in the short-run. Second, increased localization may be translated in higher prices to the average consumer. And, finally, if public decision makers decide to implement policies to localize food supply chains, our model can contribute to identify strategies that minimize negative, unintended impacts.

Methods

Our analyses employ a highly spatially-disaggregated transshipment model of the US dairy sector that determines the cost-minimizing solutions for segments of the dairy supply chain, including assembly, processing, interplant transportation and final product distribution. Milk production in the US and dairy product demand are seasonal, so we consider two months, May and October 2006 (which are the typical peak and trough milk production months in the US, respectively). On a time scale of 1 month, the supply of milk and demand for dairy products are highly price inelastic, so the analysis assumes fixed milk supplies and final product demands. The analysis determines the optimal spatial organization of the dairy supply chain and the spatial values for raw milk and its products.

Data

The supply and demand data include the location of milk production, milk composition and the total quantities of final products consumed and their composition. For most storable products, consumption calculations use the concept of "commercial disappearance", which compares sources (production, imports and reductions in stocks) and known uses (exports and additions to product stocks) to determine US aggregate consumption. This aggregate consumption is allocated to specific locations based on population, with adjustments for regional differences in per capita consumption. Fluid milk consumption is based on data from the Agricultural Marketing Service of the USDA, which regulates prices and uses of milk in much of the US The locations of processing facilities for different products and the distances between milk production locations, processing facilities and demand locations are adapted from Pratt et al. (1997). Costs are specified with different functions for raw milk shipments to processing, processing milk into products, shipments of products between plant, and for distribution to final demand.

Products

The dairy supply chain of most developed countries includes a diverse set of products and processing technologies. To represent this diversity for the US, the model includes 19 final, 18 intermediate and 17 tradable product categories (Table 1).[2] Note that some products, such as nonfat dry milk (NDM), are in all categories. In our terminology, "intermediate" products refer to those dairy products that are used in the manufacture of other dairy products, such as NDM in cheese making. "Final products" are those sold by dairy manufacturers directly to consumers or to other food manufacturers or wholesalers. The number of products in the final, intermediate and tradable categories is illustrative of the complexity of dairy supply chains in many countries, and suggests that the analysis of increased localization requires a more systemic approach if aggregated costs are to be quantified.

Table 1
Product categories included in the model. *Source*: Generated from model structure.

Product	Final product	Inter-mediate product	Tradable product
Fluid milk	X		
Yogurt	X		X
Ice cream			X
Nonfat dry milk	X	X	X
Butter	X		X
Dried buttermilk	X		
Cottage cheese	X		
American cheese	X		X
Other cheese	X		X
Dry whey	X	X	X
Whey protein concentrate 34% (WPC34)	X	X	X
Dried whey permeate (lactose)	X	X	X
Whey protein concentrate 80% (WPC80)	X	X	X
Casein	X	X	X
Caseinates	X		X
Milk protein concentrate 42% (MPC42)	X	X	X
Milk protein concentrate 56% (MPC56)	X	X	X
Milk protein concentrate 70% (MPC70)	X	X	X
Milk protein concentrate 80% (MPC80)	X	X	X
Other evaporated condensed and dried	X		X
Cream		X	
Skim milk		X	
Ice cream mix		X	
Fluid whey		X	
Separated whey		X	
Whey cream		X	
Condensed skim milk		X	
Ultrafiltered skim milk for MPC42		X	
Ultrafiltered skim milk for MPC56		X	
Ultrafiltered skim milk for MPC70		X	
Ultrafiltered skim milk for MPC80		X	

Milk supply, processing, demand and trade locations

The model uses 231 multiple-county milk supply regions, each represented with a single centrally-located point. Dairy processing plant locations are specified based on observed plant locations observed in 2005, and vary in number from 319 possible locations for fluid plants (Fig. 3) to 11 for milk protein concentrate products. Demand locations are represented as a single point for 424 major population centers and aggregations of multiple-county regions (Fig. 4). Newark, Los Angeles, and Houston are the import and export locations. Imported product can be distributed to final demand locations from each of these import locations. Exports of final products are distributed to these three locations but no further tracking of final destinations is included.

Model formulation and solution procedures

The model is structured as a large-scale transshipment problem that includes variables for assembly of milk from farms to processing facilities, separation and use of cream and skim milk at processing, amounts of final and intermediate products produced at processing locations, shipments of intermediate products from one processing location and plant type to another and distribution of domestic and imported products to final demand. The model constraints ensure that milk assembly, milk separation into cream and skim milk interplant shipments and final product distribution are consistent with mass balance. Product yields and compositions are constrained to be consistent with current processing technologies. As in all transshipment models, the quantity shipped to final demand locations from US and imported sources must be equal to demand. The objective function minimizes the overall cost of milk assembly, processing, interplant shipments and distribution to final demand locations. The resulting solution identifies the processing locations for each product, the movement of raw milk to processing facilities and the distribution of production to consumption location that minimizes overall supply-chain costs. Details on the model specification are provided in the supplementary materials of the manuscript. This information provides the baseline for comparison to evaluate alternatives that increase localization of the dairy supply chain.

Links between increased localization and supply-chain costs

To assess the impact of increased localization on total supply-chain costs, we employ a measure of distance traveled by dairy products, the total weighted average source distance (*WASD*) for

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[2] In addition to product disaggregation, the different components in milk (e.g. fat, protein, sugars and minerals) must be accounted for to accurately represent product yields and substitution possibilities. For many products, compositions are modeled using three components: fat, protein and other solids. For products made using an ultra-filtration process (e.g., whey protein, ultra-filtered milk, milk protein concentrates), six components are specified: fat, casein, whey protein, non-protein nitrogen, lactose and minerals.

Fig. 3. Aggregated US fluid milk processing facility locations, May 2006 (*Source*: Generated from model structure).

Fig. 4. Aggregated US fluid milk consumption locations, May 2006 (*Source*: Generated from model structure).

all (or selected individual) products. We employ this measure to constrain the cost-minimization problem under alternative scenarios. The *WASD* constraint applied to all dairy products is specified as:

$$\frac{\sum_i\sum_j\sum_p XRM_{ijp}\cdot DISTRM_{ij}+\sum_j\sum_{jj}\sum_{ip}\sum_p\sum_{pp} XIP_{j,jj,ip,p,pp}\cdot DISTIP_{j,jj}+\sum_j\sum_k\sum_p XFP_{jkp}\cdot DISTFP_{jk}}{\sum_j\sum_k\sum_p XFP_{jkp}}\leqslant WASD \tag{1}$$

where XRM_{ijp} is the quantity of raw material m shipped from origin location i to product p processing location j; $DISTRM_{ij}$ is the distance from raw material source location at i to processing location j; $XIP_{j,jj,ip,p,pp}$ is the quantity of intermediate product ip shipped from a processing plant for product p at location j to a processing plant for product pp at location jj, $DISTIP_{j,jj}$ is the distance between the processing location j and processing location jj (for interplant shipments), XFP_{jkp} is the quantity of product p shipped from processing location j to final consumption product location k, and $DISTFP_{jk}$ is the distance between the processing location j and final consumption location k. This formulation adds the total distances traveled by all raw materials (milk), intermediate products and final distribution of products and divides by the total volume of final products.[3] Values for the right-hand side *WASD* are selected based on a desired percentage reduction compared to the *WASD* calculated for the cost-minimizing solution without the *WASD* constraint.

For a single product p (fluid milk for subsequent analyses), the constraint ensures that the distance traveled for that product ($WASD_p$) is less than a specified value, and is written as:

$$\frac{\sum_i\sum_j XRM_{ijp}\cdot DISTRM_{ij}+\sum_j\sum_{jj}\sum_{ip}\sum_{pp} XIP_{j,jj,ip,p,pp}\cdot DISTIP_{j,jj}+\sum_j\sum_k XFP_{jkp}\cdot DISTFP_{jk}}{\sum_j\sum_k XFP_{jkp}}\leqslant WASD_p \tag{2}$$

The model is solved as a nonlinear optimization problem using the CPLEX algorithm. (The supplemental materials provide additional information about the model formulation.)

Increased localization scenarios

To assess the links between increased localization and supply-chain costs, we compare the baseline results to those for two alternative sets of scenarios. The baseline simulation minimizes the overall costs in the supply chain without a constraint on *WASD*. This provides a cost and *WASD* benchmark to which two sets of scenarios for increased localization are compared. These alternative scenarios are as follows.

Scenario Set 1: overall reduction in WASD

These scenarios analyze 10% and 20% reductions in the *WASD* traveled by all products (including imports) for the entire dairy supply chain in May and October, compared to the *WASD* calculated for the Baseline scenario. Although dairy product consumers may focus more on the degree of localization for individual products, from a policy perspective an analysis of the overall dairy supply chain is relevant.

Scenario Set 2: WASD reduction of fluid milk

This scenario focuses on reductions in the *WASD* traveled by fluid milk products only. This scenario is relevant because (a) fluid milk tends to be the most “local” of dairy products, given its bulk and transportation costs and (b) dairy product consumers may be more aware of, and perhaps attach greater value to, beverage milk products that are produced and processed closer to their point of purchase. We assess a 10% reduction in the aggregated miles traveled by fluid milk products, which was close to the maximum feasible amount given May 2006 milk supplies, processing facilities and demand locations.

For each of the scenarios, we assess the changes in costs compared to the Baseline as an indicator of the costs of greater localization. Overall costs are also disaggregated into assembly costs, processing costs, interplant shipment costs and final distribution costs. This disaggregation is important because minimizing overall distances may result in different directions and magnitudes of change for each segment in the supply chain.

Results

The Baseline simulation indicates that total supply-chain costs for May 2006 equal about $1.015 billion (Table 2) and $897 million in October 2006 (Table 3). In each month, about 60% of these costs are for processing, 27% are for interplant shipments of products, and about 6% each for milk assembly and final product distribution. The total number of plants processing is 980 and 960 in May and October, respectively. The *WASD* for a selected subset of the most important consumer products (which account for a substantial proportion of the total quantities of dairy products consumed in the US) indicates that values for products vary widely, from over 1000 miles for NDM to 112 miles for fluid milk. For a cost-minimizing dairy supply chain, the *WASD* for all products is 317 miles in May (Table 2) and 338 miles in October (Table 3). For fluid milk and yogurt, the distribution distances are considerably less than 100 miles, indicating that they tend to be processed close to final demand locations. For American cheese, butter and NDM, distribution distances are a larger component of the *WASD*, primarily because production of these products is concentrated in the western US. *WASD* values for all products are higher in May than October.

Scenario Set 1: overall reduction in WASD

Preliminary analyses indicated that the maximum feasible reduction in overall *WASD* compared to the cost-minimizing baseline was 23% in May and 21% in October. For consistency, we analyzed maximum reductions in *WASD* of 20% in each month. The simulations indicate that the increase in total costs of achieving 20% reductions in overall *WASD* is less than 4% of the cost-minimizing costs in each case (Tables 2 and 3). The *WASD* traveled for all dairy products is still larger than 250 miles under the best-case feasible scenario, the 20% reduction in May 2006. The *WASD* for many products is reduced by only a small amount (e.g., by 2–6

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[3] This constraint is equivalent to a weighted average of the *WASD* for individual products, where the weights are the proportion of each product by mass in total consumption.

Table 2
Comparison of costs and distances, cost-minimizing and *WASD* reduction simulations, May 2006. *Source*: Authors' calculations based on the Optimization Models.

Result	Baseline (cost-minimizing solution)	10% Reduction in *WASD*		20% Reduction in *WASD*	
		Change	% Change	Change ($ million or miles)	% change
Total costs summary ($ million/month)					
Assembly	69	−1	−1.4	−4	−6.4
Inter-plants shipments	271	1	0.3	7	2.7
Processing	607	0	0.0	4	0.7
Distribution	68	2	2.3	10	15.2
Total costs	1015	1	0.1	18	1.7
Plants processing	980	−7	−0.7	−68	−6.9
WASD for products (Miles)					
Fluid milk	112	−1	−1.2	−2	−1.8
Yogurt	150	−4	−2.5	−25	−16.8
American cheese	855	48	5.6	35	4.1
Butter	501	−57	−11.5	−142	−28.3
Nonfat dry milk	1039	−6	−0.6	77	7.4
WASD for all products	317	−32	−10.0	−64	−20.0
Weighted distribution distances (Miles)					
Fluid milk	28	3	10.8	17	59.6
Yogurt	65	−1	−1.5	13	20.8
American cheese	720	9	1.3	61	8.5
Butter	427	−75	−17.6	−133	−31.1
Nonfat dry milk	868	122	14.1	140	16.2

Table 3
Comparison of costs and distances, cost-minimizing and *WASD* reduction simulations, October 2006. *Source*: Authors' calculations based on the optimization models.

Result	Baseline (cost-minimizing solution)	20% Reduction in *WASD*		20% Reduction in *WASD*	
		Change	% Change	Change	% Change
Total costs summary ($ million/month)					
Assembly	69	−3	−3.7	−10	−14.0
Inter-plant shipments	224	1	0.3	8	3.7
Processing	531	0	0.0	17	3.2
Distribution	73	4	4.9	18	24.5
Total costs	897	2	0.2	34	3.7
Total plants processing	960	13	1.4	−84	−8.8
WASD for products (Miles)					
Fluid milk	133	−2	−1.7	−6	−4.2
Yogurt	179	15	8.4	−15	−8.3
American cheese	1180	57	4.9	87	7.4
Butter	802	−105	−13.1	−250	−31.2
Nonfat dry milk	1008	85	8.4	110	10.9
WASD all products	338	−35	−10.3	−68	−20.2
Weighted distribution distances (Miles)					
Fluid milk	31	10	32.1	37	132.1
Yogurt	76	−3	−4.1	65	95.9
American cheese	1012	98	9.7	202	109.7
Butter	608	−102	−16.8	−248	83.2
Nonfat dry milk	898	151	16.8	0	116.8

miles in the case of fluid milk) and actually increases for some products given the spatial reorganization: American cheese travels farther in both months, and yogurt travels farther in October (Table 3). Distribution distances increase for many products, including fluid milk, American cheese and nonfat dry milk (Tables 2 and 3). The total number of processing plants is reduced for three of the four scenarios, which is consistent with shorter assembly distances and longer distribution shipments. Thus, least-cost reductions in *WASD* in the US dairy industry would imply different effects on different products and processing facilities, and some products will travel longer distances from farm to consumer.

The reductions in *WASD* by 10% increase costs only 0.1% in May and 0.2% in October, but a 20% reduction increases costs by a larger amount, 1.7% and 3.7% in May and October, respectively. These relatively small reductions in overall costs contrast with more marked shifts in the allocation of costs within the supply chain. In each case, the costs for assembling milk from farms to plants decreases, as it is optimal to ship milk shorter distances to processing facilities. Costs for interplant shipments increase by about the same magnitude of the increase in total costs. The largest increase in costs occurs in product distribution; increases in distribution costs range from 2% to 25%–6 to 24 times as large as the overall increase in costs. These shifts in costs could imply the need for new institutional arrangements concerning supply-chain costs, because, in general, farmers currently incur assembly costs, processors incur interplant and processing costs, and retailers incur distribution costs.

Changes in costs can also be viewed from a marginal and spatial perspective. That is, it is relevant to consider how the value of a dairy product at a given location changes with the spatial reorganization required to reduce overall *WASD* in the industry. For the most highly visible consumer product, fluid milk, the changes in

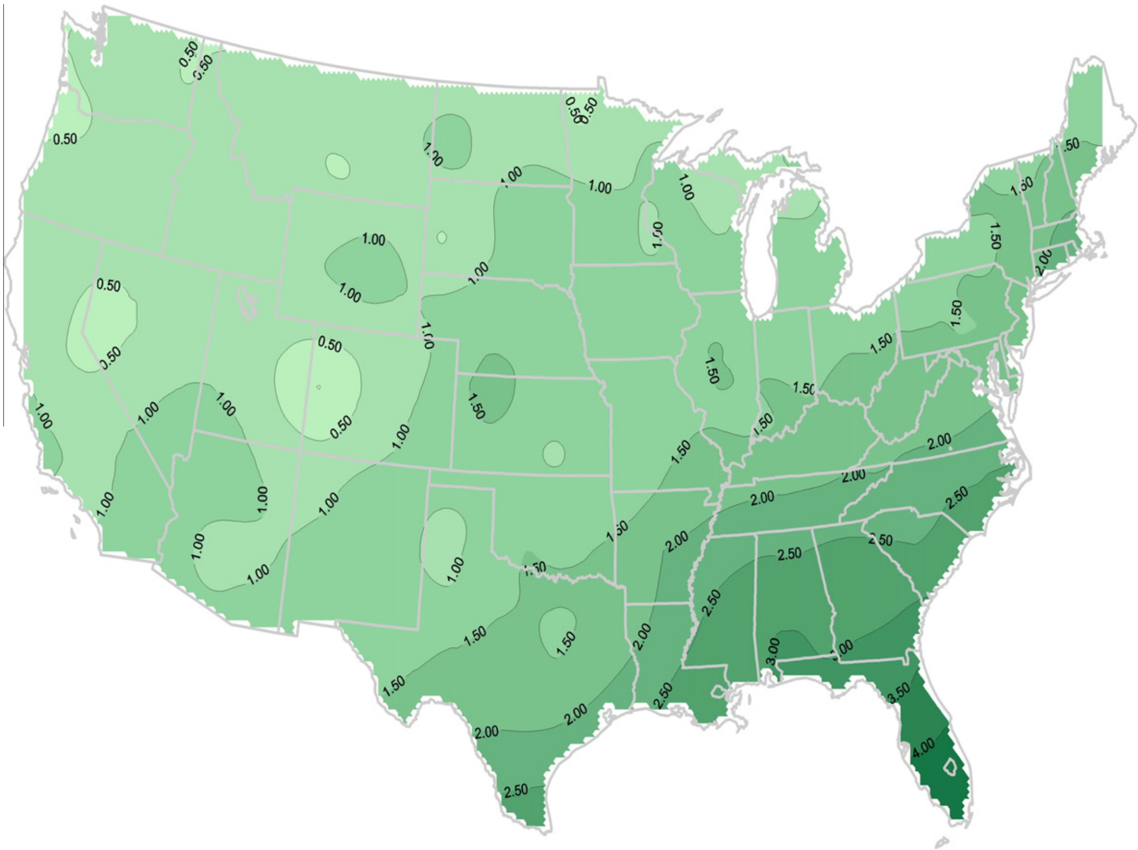

Fig. 5. Spatial changes in the marginal value of a gallon of fluid milk, May 2006, reduction in *WASD* of 20% compared to cost-minimizing distance ($/US gallon) (*Source*: Author's calculations based on the optimization models).

marginal values in May 2006 under a 20% reduction in *WASD* are significant and vary spatially (Fig. 5). The increases in the value of a gallon of milk due to reduced *WASD* vary from less than $0.50 (which is often more than 10% of the retail price) in the western US to more than $4.00 per gallon in the southeastern US, but the average for all demand locations is $1.66. The largest increases in milk values are found in the areas of the US with the greatest imbalance of dairy product demand compared to milk production. In these areas, the re-allocation of farm milk supplies to meet the allowable *WASD* constraint results in significantly higher marginal values at farm supply locations due to multiple product demands for this resource, and these increase product values throughout the remainder of the supply chain. Our results do not suggest that retail prices of milk would increase by these amounts, in part because food retailers can use milk as a "loss-leader", but they do suggest possibly large increases in consumer prices for this product if the industry as a whole restructured to reduce *WASD*.

Scenario Set 2: WASD reduction of fluid milk

Reduction of the *WASD* for only the most highly visible consumer dairy product, fluid milk, results in a markedly different pattern of change than those reported above (Table 4). The maximum feasible reduction given the current configuration is just over 10%, a reduction of *WASD* for fluid milk from 112 to 100 miles. Achievement of this 10% reduction for fluid milk, however, results in an *increase* in the overall *WASD* for the US dairy industry of nearly 100 miles, or more than 30% higher than the cost-minimizing scenario. These results occur in part because fluid milk constitutes nearly one-third of total US demand for dairy products on a milk equivalent basis and reductions for this product are therefore difficult and costly. The *WASD* for many other dairy products increases, as do distribution distances for many products (Table 4). Overall costs are increased by more than 12% under this scenario, and the allocation of costs increases differs from previous scenarios. Assembly

Table 4
Comparison of costs and distances, cost-minimizing solution and *WASD* reduction simulations for fluid milk only, May 2006. *Source*: Authors' calculations based on the optimization models.

Result	Baseline (cost-minimizing solution)	10% Reduction in *WASD* for fluid milk	
		Change	% Change
Total costs summary ($ million/month)			
Assembly	69	−5	−6.9
Inter-plant Shipments	271	1	0.3
Processing	607	119	19.6
Distribution	68	7	11.0
Total Costs	1015	123	12.1
Total Plants Processing	980	−26	−2.7
WASD for products (Miles)			
Fluid milk	112	−11	−10.0
Yogurt	150	94	62.5
American cheese	855	16	1.8
Butter	501	287	57.4
Nonfat dry milk	1039	−260	−25.0
WASD all products, miles	317	98	30.9
Weighted distribution distances (Miles)			
Fluid milk			
Yogurt	28	54	190.4
American cheese	65	12	19.3
Butter	720	−19	−2.7
Nonfat dry milk	427	503	117.6

costs are reduced, but distribution costs increase by 11%. The largest increase is in processing costs (nearly 20%) due to the increased interplant product use to substitute for previously more available milk components at many locations. A strategy to reduce the *WASD* for fluid milk, therefore, would markedly increase costs in the US dairy supply chain, and would increase the *WASD* for the industry overall.

Discussion of results

The model solutions provide several insights regarding the increased localization of multi-product supply chains. First, our model suggests important short-run barriers to localization of spatially-disaggregated multi-product supply chains. In the case of all dairy products, the maximum *WASDE* reduction was about 23% (relative to the baseline of 317 and 338 miles in May and October, respectively), which is relatively small compared to what is expected from a truly local supply chain. Further reductions are likely to require large investments in physical capital, both private and public, and may require considerable re-allocation of resources among regions and among supply chain segments. This is a particularly important aspect to consider for those food sectors promoting industry-wide initiatives to promote improved sustainability performance through increased supply chain localization.

Second, although the overall costs of greater short-run supply chain localization are modest, we find marked differences on the cost impacts across supply chain actors. Specifically, our model solutions suggest large cost-impact differences in at least three dimensions: (1) across supply chain segments, (2) across geographic locations and (3) across raw milk production seasons. For instance, when distances are minimized for the overall supply chain, increased localization tends to reduce assembly costs yet raise distribution costs. In addition, we find that consumers in locations with more limited raw milk production (e.g. Southeastern US) may bear higher costs of a more localized supply chain. Seasonality of production and demand also affect the outcomes increased localization: the costs are substantially larger during the low-supply season relative to the high-supply season (October

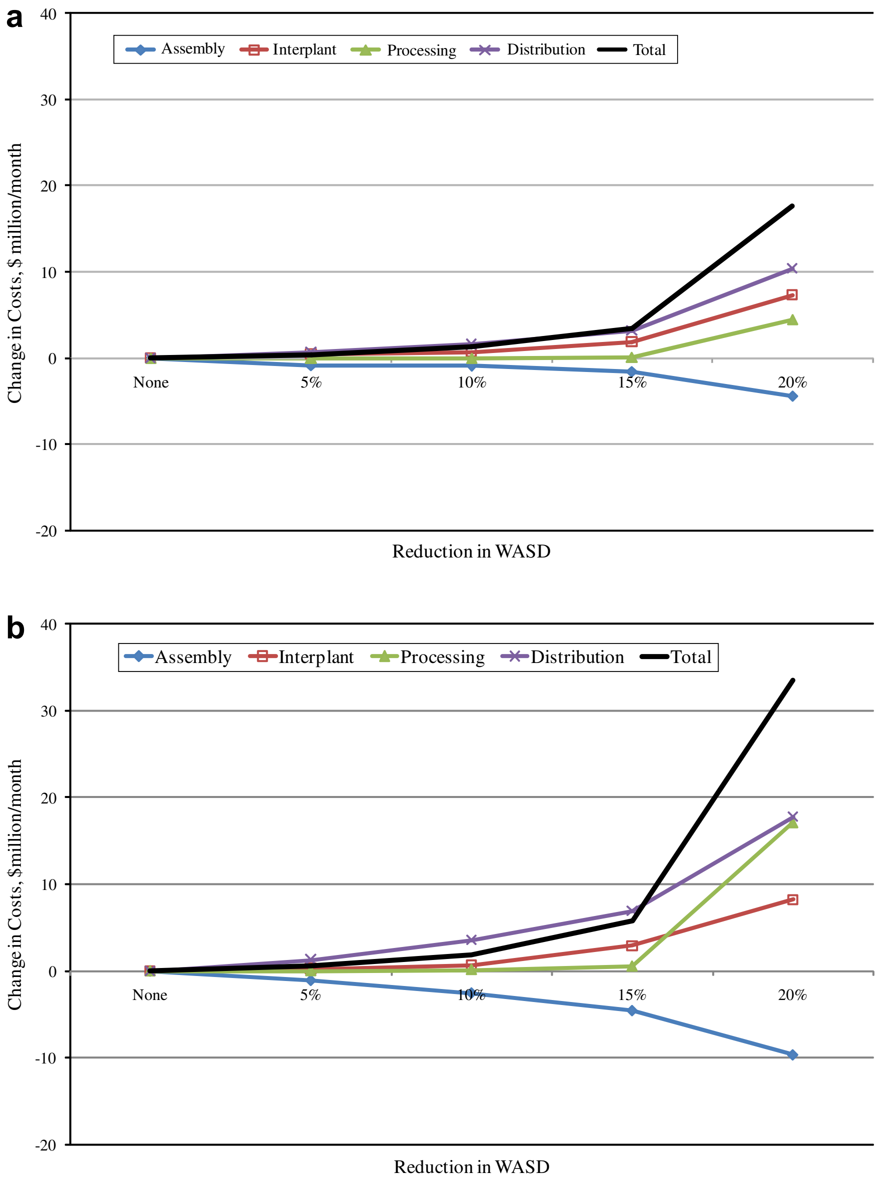

Fig. 6. Relationship between increased localization and supply-chain costs. (a) May, high-supply season and (b) October, low-supply season (*Source*: Author's calculations based on the optimization models).

and May in the case of US dairy, respectively). Taking into account these nuances is important for both the private industry strategist and for the policy maker designing policies to favor localization.

Third, our results indicate that, under supply-chain cost minimization, increasing localization leads to tradeoffs in distance traveled among products. When the objective is to achieve a given reduction of overall *WASD* (Scenario Set 1), it is impossible to reduce the *WASD* for all individual products: the *WASD* for some products decrease at the expense of increases in other products. We also find such tradeoffs in the simulations corresponding to Scenario Set 2, reductions in *WASD* for fluid milk only. Here, the overall average distance traveled by products increases by 30.9% in response to a 10% decrease in the fluid milk *WASD*. Therefore, decision makers must be careful in the design of policies to increase localization, because ignoring the multiple connections in the supply chain may lead to the design of policies that have unintended negative consequences for certain members of the supply chain.

Fourth, our results show that reductions in distance traveled by fluid milk, the most visible product to consumers, are possible but costly to the system as a whole. Therefore, for integrated multiple-product supply chains, localization efforts focused on the product of greater interest may increase substantially the costs of other products for processors, wholesalers and ultimately for consumers. Supply chain managers developing localization strategies for a particular product often ignore possible impacts on the system as a whole. Therefore, localization policies, both private and public, should adopt a systems approach to anticipate and minimize unintended negative impacts.

Finally, our results suggest that the relationship between more localization and costs may be nonlinear given the relationship between increased localization and changes in cost for various *WASD* targets for May and October (Fig. 6). Although small reductions in *WASD* are not costly to the supply chain, reductions of more than 15% in *WASD* produce larger cost increases. Fig. 6 also illustrates the differential impacts across seasons and across supply chain segments. The impacts of increased localization on supply-chain costs are larger in October – the low-supply season.

Conclusions

In this paper we employed a spatially-disaggregated transshipment model of the US dairy sector to analyze the links between increased localization and supply-chain costs under alternative scenarios. The primary conclusion is that developing a cost-effective strategy to localize a multi-product supply chain is complex. Such complexity accrues to the multiple links that exists in a multi-product supply chain including the relationships across supply chain segments, the dependency of the various products, the diversity in supply and demand across geographic regions, and the seasonality of the production process. Therefore, decision makers should adopt a systems approach to anticipate the consequences of industry wide or public policy initiatives to increase localization in the food industry.

Our model has several limitations that suggest topics for future investigation. In our transshipment model, quantities supplied and demanded are fixed, ignoring supply and demand response to price changes. Future research should treat supply and consumption decisions as endogenous variables in the optimization model. In addition, our analysis assumes that processing is possible only at current plant locations. This restriction can be relaxed to conduct longer-run assessments of costs when firms make decisions about physical capital investments in response to incentives for increased localization. An analysis that considers changes to milk production and processing locations to allow greater localization than indicated by our short-run analysis is likely to show higher costs. This is due to differences in production costs by location (which would probably be increased as milk production shifts from lower to higher cost locations) and the required investments in new farm and processing infrastructure. Thus, further localization would incur larger costs, consistent with the nonlinear relationship described above. Finally, our results assume optimizing behavior of supply chain members and the actual costs of increased localization may be higher because individual decisions may not be consistent with chain-wide cost-minimizing behavior. Nevertheless, over time there will be competitive pressures in the supply chain that would tend to move localization efforts towards cost-minimizing outcomes to achieve reductions in *WASD*. These limitations underscore the need to extend the assessment to longer-run horizons.

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Appendix A. Distance measures

Our model minimizes costs for assembly, processing, interplant product shipments and product distribution, subject to constraints on the weighted average source distance for dairy products in the US industry as a whole. This is essentially an extension of the "food-miles" concept applied to multiple products. For a single input product with a simple marketing chain, this calculation is straightforward. For the vast majority of food products, however, this simple situation is not applicable. Recognizing this, Pirog and Benjamin (2005) described a method for calculating food miles for a single product with multiple ingredients. This approach incorporates multiple ingredients for a container of yogurt (milk, strawberries, and sugar) sourced at different locations and includes transportation of raw products (such as sugar beets) needed to make the sugar used. The basic equation is a weighted average distance for ingredients, or:

$$FM_{kp} = \frac{\sum_j \left(\left(\frac{\sum_i \sum_m XRM_{ijmp} \cdot DISTRM_{ij}}{\sum_i \sum_m XRM_{ijmp}} \right) \left(\frac{XFP_{jkp}}{\sum_j XFP_{jkp}} \right) \theta_{pm} + \sum_j XFP_{jkp} \cdot DISTFP_{jk} \right)}{\sum_j XFP_{jkp}} \tag{A.1}$$

where *FM* is food miles, XRM_{ijmp} is the quantity of raw material *m* shipped from origin location *i* to product *p* to processing location *j*, $DISTRM_{ij}$ is the distance from raw material source location *i* to processing location *j*, XFP_{jkp} is the quantity of product *p* shipped from processing location *j* to final consumption location *k*, θ_{pm} is the amount of raw material *m* required per unit of final product *p*, and $DISTFP_{jk}$ is the distance between the processing location *j* and final consumption location *k*.

For the US dairy sector, milk and dairy components constitute approximately 95% of the raw material input in final products. Therefore, we ignore other ingredients (sugar, salt, fruit and bacterial cultures). Moreover, for many dairy products, the supply chain can be represented by three agents: farmers, processors and product buyers. Thus, an equation similar to the one above captures much of the product movements relevant for calculating food miles. However, often in the dairy industry, multiple dairy products processed at one location are used as inputs to the manufacturing process for another dairy product, typically at a different processing facility. An example is the use of nonfat dried milk (NDM; manufactured by drying milk from which much of the fat—in the form of cream—has been removed) in the manufacture of cheese. The addition of NDM to farm milk increases product yields because it modifies the ratio of nonfat solids to fat solids in cheese manufacturing. Thus, a *WASD* calculation for the US dairy industry must include the miles traveled by these intermediate products. For our initial scenarios, the constraint is specified to achieve a particular *WASD* value for all dairy products, rather than for a single product at a single location.

Appendix B. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.foodpol.2010.11.028.

References

Allen, P., Wilson, A.B., 2008. Agrifood inequalities: globalization and localization. Development 51 (4), 534–540.

Coley, D., Howard, M., Winter, M., 2009. Local food, food miles and carbon emissions: a comparison of farm shop and mass distribution approaches. Food Policy 34 (2), 150–155.

Conner, D.S., Montri, A.D., Montri, D.N., Hamm, M.W., 2009. Consumer demand for local produce at extended season farmers' markets: guiding farmer marketing strategies. Renew. Agric. Food Syst. 24 (4), 251–260.

Darby, K., Batte, M.T., Ernst, S., Roe, B., 2008. Decomposing local: a conjoint analysis of locally produced foods. Am. J. Agric. Econ. 90 (2), 476–486.

Hand, M., Martinez, S., 2010. Just what does local mean? Choices 25 (1).

Hardesty, S.D., 2008. The growing role of local food markets. Am. J. Agric. Econ. 90 (5), 1289–1295.

Heer, I., Mann, S., 2010. Acting under spatial restrictions: success factors of German local food-marketing networks. Br. Food J. 112 (3), 285–293.

Hein, J.R., Ilbery, B., Kneafsey, M., 2006. Distribution of local food activity in England and Wales: an index of food relocalization. Reg. Stud. 40 (3), 289–301.

International Dairy Foods Association, 2008. Greenhouse Gas Reduction Opportunities in the US Fluid Milk Value-Chain. The Sustainability Summit: Creating Value through Dairy Innovation. Briefing Paper.

Jones, P., Comfort, D., Hillier, D., 2007. Marketing and corporate social responsibility within food stores. Br. Food J. 109 (8), 582–593.

Khan, F., Prior, C., 2010. Evaluating the urban consumer with regard to sourcing local food: a heart of England study. Int. J. Consum. Stud. 34 (2), 161–168.

King, R.P., Gómez, M.I., DiGiacomo, G., 2010a. Can local food go mainstream? Choices 25 (1).

King, R.P., Hand, M.S., DiGiacomo, G., Clancy, K. Gómez, M.I., Hardesty, S.D., Lev, L., McLaughlin, E.W., 2010b. Comparing the Structure, Size, and Performance of Local and Mainstream Food Supply Chains, US Department of Agriculture, Economics Research Service.

Lang, T., Haesman, M., 2004. Food Wars. Earthscan, London.

Onozaka, Y., Nurse, G., Thilmany, D., 2010. Local food consumers: how motivations and perceptions translate to buying behavior. Choices 25 (1).

Peters, C.J., Bills, N.L., Lembo, A.J., Wilkins, J.L., Fick, G.W., 2009. Mapping potential foodsheds in New York state: a spatial model for evaluating the capacity to localize food production. Renew. Agric. Food Syst. 24 (1), 72–84.

Pirog, R., Benjamin, A., 2005. Calculating Food Miles for a Multiple-Ingredient Food Product. Leopold Center for Sustainable Agriculture, Iowa State University.

Pratt, J.E., Bishop, P.M., Erba, E.M., Novakovic, A.M., Stephenson, M.W., 1997. A Description of the Methods and Data Employed in the US Dairy Sector Simulator, Version 97.3. Department of Agricultural, Resource and Managerial Economics, Cornell University, July [Research Bulletin 97-09].

Sirieix, L., Grolleau, G., Schaer, B., 2008. Do consumers care about food miles? An empirical analysis in France. Int. J. Consum. Stud. 32 (5), 508–515.

Stagl, S., 2002. Local organic food markets: potentials and limitations for contributing to sustainable development. Empirica 29 (2), 145–162.

Thilmany, D., Bond, C.A., Bond, J.K., 2008. Going local: exploring consumer behavior and motivations for direct food purchases. Am. J. Agric. Econ. 90 (5), 1303–1309.

Toler, S., Briggeman, B.C., Lusk, J.L., Adams, D.C., 2009. Fairness, farmers markets, and local production. Am. J. Agric. Econ. 91 (5), 1272–1278.

US Environmental Protection Agency, 2008. Inventory of Greenhouse Gas Sources and Sinks, Annex 3: Methodological Descriptions for Additional Source or Sink Categories. <http://www.epa.gov/climatechange/emissions/downloads/08_CR.pdf>.

Weber, C.L., Matthews, H.S., 2008. Food-miles and the relative climate impacts of food choices in the United States. Environ. Sci. Technol. 42 (10), 3508–3513.

Zepeda, L., Deal, D., 2009. Organic and local food consumer behaviour: alphabet theory. Int. J. Consum. Stud. 33 (6), 697–705.