THESIS

# REVISITING THE "HOT POTATOES" OF AGRI-SUPPLY CHAINS: EXPLORING INTERACTIONS AND TRADEOFFS IN COLORADO POTATO MARKETS AND FARM-TO-SCHOOL PROCUREMENT

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# ABSTRACT

## REVISITING THE "HOT POTATOES" OF AGRI-SUPPLY CHAINS: EXPLORING INTERACTIONS AND TRADEOFFS IN COLORADO POTATO MARKETS AND FARM-TO-SCHOOL PROCUREMENT

Agricultural and food systems generate externalities, some of which have been linked to achieving economic development goals in rural areas. Historically, agriculture has occupied an important role in rural development policy. But not all agricultural and food supply chains have the same economic linkages and impacts on their communities. We hypothesize that certain types of agricultural and food systems structures and processes are better suited to achieving the goal of local economic development, depending on the location and nature of the market activity. The literature suggests that there is a tradeoff between efficiency and positive externalities in agri-supply chains, which we call the "Efficiency-Externality Tradeoff." We analyze the Efficiency-Externality Tradeoff in two essays. First, we conduct a time-series econometric analysis of Colorado and national potato supply chains. Second, we develop an optimization model of school food procurement, with emphasis on supply chain route. We find that Colorado farmers face asymmetric price influence when participating in national commodity potato markets, implying they have low bargaining power and high downside risk with regards to prices. We also find that in the absence of policy mechanisms, school districts are unlikely to participate in local food procurement, which previous work has documented has a positive impact on local economies. We frame farmer bargaining power and local economic development as potential positive externalities of local and regional supply chains, and since the latter are sometimes less efficient, exploring the tradeoffs between the "costs and benefits" is of interest. Our results indicate that mainstream supply chains, which tend to be

more efficient and cost effective, may offer fewer positive externalities, and the effectiveness of policy levers to incentivize positive choices varies. This finding has implications for economic development policies, particularly those targeted at strengthening economic activity in agriculturally dependent areas.

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# INTRODUCTION

Although invisible to many U.S. households, food supply chains are where the "invisible hand" of rapidly changing supply and demand conditions intersect to influence product prices and characteristics, as well as who interacts in buying and selling transactions and how they do so. Agricultural and food supply chains, or "agri-supply chains," have evolved to become more complex and efficient over the years (Aramyan et al., 2007; Baldwin, 2012; Boehlje, 1999; Bunte et al., 1998; Li & O'Brien, 1999; Moss & Taylor, 2014; Van der Vorst, 2005). Increased efficiency brings benefits to producers and consumers in the form of cost savings. However, these benefits may be less equitably distributed along the supply chain when economies of scale concentrate gains in certain parts of the supply chain (Sexton, 2013). Efficiency gains are sometimes associated with losses of desirable characteristics intrinsic to less efficient supply chains. Some of these characteristics or outcomes include positive externalities, such as farmers' ability to capture gains from business investments, as well as local economic development (Calvin et al., 2001; McBride & Key, 2003; Saitone & Sexton, 2017; Willingham & Green, 2019). These externalities contribute to wealth creation in agriculturally dependent areas (Ashley & Maxwell, 2002; Aubry & Kebir, 2013; Harrison et al., 2019; Marsden, Banks, et al., 2000; Marsden, Flynn, et al., 2000; Pender et al., 2012; Renting et al., 2003), many of which are rural and have experienced economic decline in the past several decades (Alig et al., 2004; Cromartie, 2017). We label the tension between efficiency and positive externalities in agri-supply chains the "Efficiency-Externality Tradeoff," and it is the focal point of this research.

Prioritizing efficiency in agri-supply chains may have led unintentionally to sub-optimal levels of a variety of positive externalities, including bargaining power for farmers and capturing local economic activity to support community development goals in rural areas. We explore this possibility with two examples from different supply chain contexts: the dynamics underlying the Colorado and national potato supply chain and the choices made within the Colorado Farm-to-School supply chain. The potato supply chain analysis allows us to examine the market price dynamics of an individual product sector at the state and national levels, and the school food procurement model allows us to examine a system of linkages across multiple product sectors at the multi-county, state, and national levels. Examining the Efficiency-Externality Tradeoff in more than one context will allow us to understand it in a deeper, more nuanced, and more generalizable way. The two specific research questions we address are (1) Do the pricing dynamics for a key potato variety at different levels of the national potato supply chain suggest there are shortcomings from a singular focus on efficiency in commodity markets? If so, are other less efficient marketing channels worth exploring to diversify revenue streams for Colorado potato farmers? and (2) Taking a closer look at the demand-side factors of one alternative marketing mechanism that potato farmers might investigate, what are the tradeoffs with respect to food prices, other costs associated with Farm-to-School distribution, and the contribution to local economic development school districts might consider when optimizing their choice of food procurement supply chain routes?

In the more efficient agri-supply chains of the commodity potato supply chain and traditional school food procurement, there are some signals from policy organizations (e.g., United States Department of Agriculture Rural Development, American Farmland Trust, Rocky Mountain Farmers Union) that the positive externalities of (1) farmer bargaining power and (2) local economic development are undervalued (American Farmland Trust, 2020; Rocky Mountain Farmers Union, 2019; USDA Rural Development, 2020). One primary contribution of this study is to offer econometrically rigorous evidence to support anecdotal claims of asymmetric market price dynamics in potato markets that do not allow farmers to fully capture favorable demand conditions. A second is to develop an innovative conceptual model to frame a customizable Farm-to-School procurement optimization model that is informed by primary data and recent literature from various local food supply chain studies.

In the next section, we will discuss literature relevant to the unifying themes of agri-supply chain efficiency, positive externalities of food systems, and local economic development related to agriculture and food systems activities. Then we will move into two essays. The first essay analyzes Colorado and national potato market dynamics, with a focus on market power and farmer bargaining power, as key considerations when considering the role of agriculture in rural economies. The second essay presents an optimization model of school food procurement, with a focus on supply chain routes and policy levers. Each essay begins by providing background information in the form of key literature and statistics to provide the reader context that is more specific than the broader thematic literature discussed in the next section. Data, methods, results, and discussion sections follow for each essay. Finally, we will conclude with a comparison of findings and presentation of policy implications.

# Literature Review

## Agricultural and Food Supply Chains

Supply chains consist of actors and firms who make, grow, or develop products, with each successive link adding value and collecting a rent for that service. Food supply chains usually begin on a farm or ranch, where primary ingredients are grown or raised. As the primary ingredients continue through various processing, distribution, and retail steps, numerous economic forces impact prices and the margins that each enterprise in the supply chain receives until the finished food product reaches the end consumer. If one considers the key focus of many agricultural and food policies carefully, these supply chain linkages and relationships are commonly at the core of concerns and opportunities the public sees as important to the viability of the agricultural sector.

Agri-supply chains have several special characteristics that make them different from other types of supply chains such as, for example, plastic goods manufacturing (Aramyan et al., 2007; Sporleder & Boland, 2011). Production is often seasonal and can take a planning horizon of many months or years. Quantity and quality of products depend on factors outside the producers' control, such as weather and climate conditions. Products are often perishable and require storage and transportation with particular temperature or humidity conditions. Specific physical features, such as taste, odor, size, appearance, and product safety (Sporleder & Boland, 2011), as well as credence attributes (Belletti et al., 2017), are important to consumers. Managing these particular features and relationships to bring food to our tables in a timely and reliable manner requires expert execution and coordination of many processes by various individuals and firms.

Agri-supply chains have become increasingly complex over the past several decades, a shift that was partially driven by technological evolution and increasing consumer demand for more differentiated and prepared products (Van der Spiegel, 2004; Van der Vorst, 2005). Lazzarini et al. (2001) acknowledge this complexity by introducing the concept of a "netchain," a hybrid of a supply chain and a network, that aids in recognizing the many types of interactions amongst various actors along and between supply chains. Supply chains can vary in geographic location or product type and, increasingly, by the values some producers and buyers are integrating into their business models and household choices.

In order to manage complexity, efficiency continues to be a guiding, primary goal and metric of success in supply chain organization (Aramyan et al., 2007; Baldwin, 2012; Boehlje, 1999; Bunte et al., 1998; Li & O'Brien, 1999; Moss & Taylor, 2014; Van der Vorst, 2005). Yet, as firms have focused more on achieving efficiency, other important factors or externalities, such as desirable characteristics, byproducts, or outcomes of less efficient agri-supply chains, may have been deprioritized, or at least, need to be reconsidered in light of new market and policy forces. Therefore, the Efficiency-Externality Tradeoff is central to our discussion.

**Producers' Share of the Food Dollar**

As supply chain efficiency and delivery of more differentiated products to consumers have increased, the distribution of revenues along agri-supply chains has changed (Van der Spiegel, 2004; Van der Vorst, 2005). Every dollar spent by consumers at the retail level must be divided amongst all the parties that contributed to the production, processing, distribution, and retailing of the final product (Cucagna & Goldsmith, 2018). In 2018 only 7.7% of every dollar spent by consumers on food made its way back along the supply chain to the farmer who grew the raw product, down from 21% in 2000 and 40% in 1952 (Fig. 1; Coltrain et al., 2000; USDA ERS, 2020).

The various supply chain parties who capture food revenues generally include agricultural producers, storage facilities, processors, shippers/distributors, retailers, restaurants, and consumers, all of which may or may not have aligned values, missions, and governance with one another (Cucagna & Goldsmith, 2018). Some businesses achieve economies of scale and cost savings through vertical integration, which combines several supply chain links into a single enterprise (Saitone & Sexton, 2017; Sexton, 2000). Happe et al. (2008) and LeRoux et al. (2010) find that many possible strategies to improve producer outcomes, specifically revenues, must address how to change the roles, transparency, and competitive market behaviors all along the supply chain. Therefore, it is imperative to consider the entire supply chain, even when the outcome of interest is concentrated in one stage (e.g., producers). Price transmission and influence, market power, and other factors that reflect dynamics amongst actors at various stages of the supply chain are important for farmer outcomes, and therefore, for rural economic development (Happe et al., 2008; LeRoux et al., 2010; Rogers & Sexton, 1994; Saitone & Sexton, 2017; Sexton, 2000, 2013; Willingham & Green, 2019).

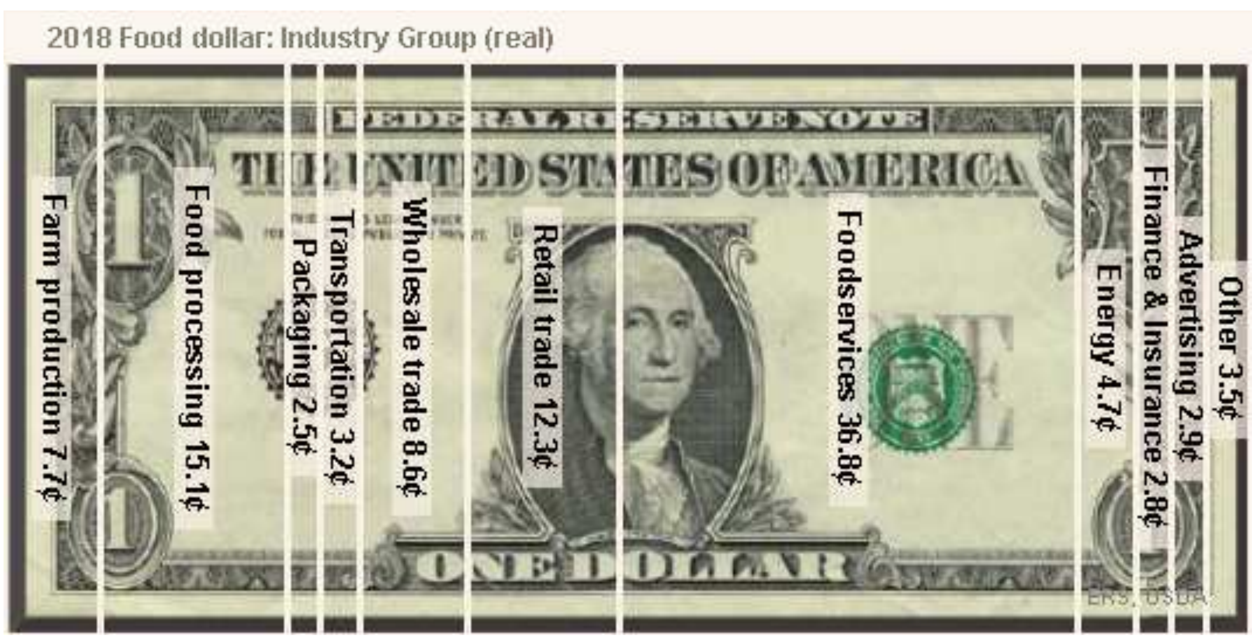


Figure 1. Percentage of retail dollar spent on food received by farmers versus all other parties who add value to a food product over time (USDA ERS, 2020)

**Market Power and Price Setting at the Farm Gate**

Consolidation of supply chains over the past several decades has contributed to increased efficiency in the distribution of agricultural goods around the country (Azzam & Schroeter, 1995; Hausman & Leibtag, 2007; Morrison Paul, 2001; Rogers & Sexton, 1994; Saitone & Sexton, 2017; Willingham & Green, 2019). Commonly that focus on efficiency unintentionally resulted in the concentration of buying power into fewer agribusinesses, which some would argue had negative impacts on family farms or farms without sufficient market power to challenge the requirements of corporate buyers, manufacturers, processors, and distributors (Rogers & Sexton, 1994; Sexton, 2000, 2013; Willingham & Green, 2019). Saitone et al. (2015) and Saitone and Sexton (2017) found that concentrated market power among agricultural buyers was associated with a decrease in farmer market access and opportunities to fully realize any gains from investments in quality improvement measures or increased consumer demand. Instead downstream supply chain actors captured a disproportionate share of gains from these changes. Moreover, McBride and Key (2003) point out that costs to farmers associated with participating in more efficient, high-volume supply chain pathways may outweigh potential gains due to contracting requirements and other transaction costs. As one example, the United States Department of Agriculture Economic Research Service (USDA ERS) reported concerns on the part of fresh produce shippers that retailers had used their consolidated market power to demand more than their fair share of the retail dollar in the form of fees and special services (Calvin et al., 2001).

Increasingly, consumers are becoming aware of the implications of their food purchasing decisions. A regional research committee, Agriculture of the Middle, formed over two decades ago with a mission to compile research, case studies, and policy recommendations related to "values-based food supply chains" (*Agriculture of the Middle*, 2020). Agriculture of the Middle focuses on sustaining mid-sized farms and ranches because they provide social and environmental benefits, or externalities, apart from the marketable goods they produce (*Agriculture of the Middle*, 2020). Consolidation of agricultural and food systems business activities into larger, more concentrated enterprises likely implies that economic benefits to those businesses will be distributed to shareholders and not to people who live in the communities where the agricultural and food processing work is accomplished (Sexton, 2013). These enterprises often become publicly traded companies, thereby losing the economic development benefits of local ownership that previous studies have documented (Fleming & Goetz, 2011). The literature suggests that increased efficiency and commoditization of agricultural supply chains, frequently accompanied by oligopsony relationships, may be associated with less bargaining power for producers in the marketing of their products. If, as a society, we value farmers' ability to have equitable market interactions, then this situation may be seen as sub-optimal provision of a positive externality. Yet, there may be other externalities associated food production and marketing as well.

**Positive Externalities of Agriculture**

Agriculture and food systems activity can produce positive and negative externalities at a variety of points along the supply chain, as noted above in the discussion of the Agriculture of the Middle group's work (Fig. 2). Some positive externalities produced by agriculture are landscape values, such as biodiversity, soil and water health, and climate change mitigation; food related aspects, such as food security; and cultural values, such as farmer bargaining power and economic or social activities intrinsic to rural areas (Cooper et al., 2009; Jones et al., 2015; Romstad, 2000; Schmid et al., 2012; Unnevehr, 2004). Negative externalities include nutrient runoff, pollution, erosion, and loss of ecosystem services produced by non-agricultural land (Blanc et al., 2018; Lewis et al., 2008; Pretty et al., 2001; Romstad, 2000). Both traditional, commodity supply chains and shortened, localized supply chains can produce positive and negative externalities, and it seems likely that the levels and types of externalities produced depend on the supply chain, as well as community factors.

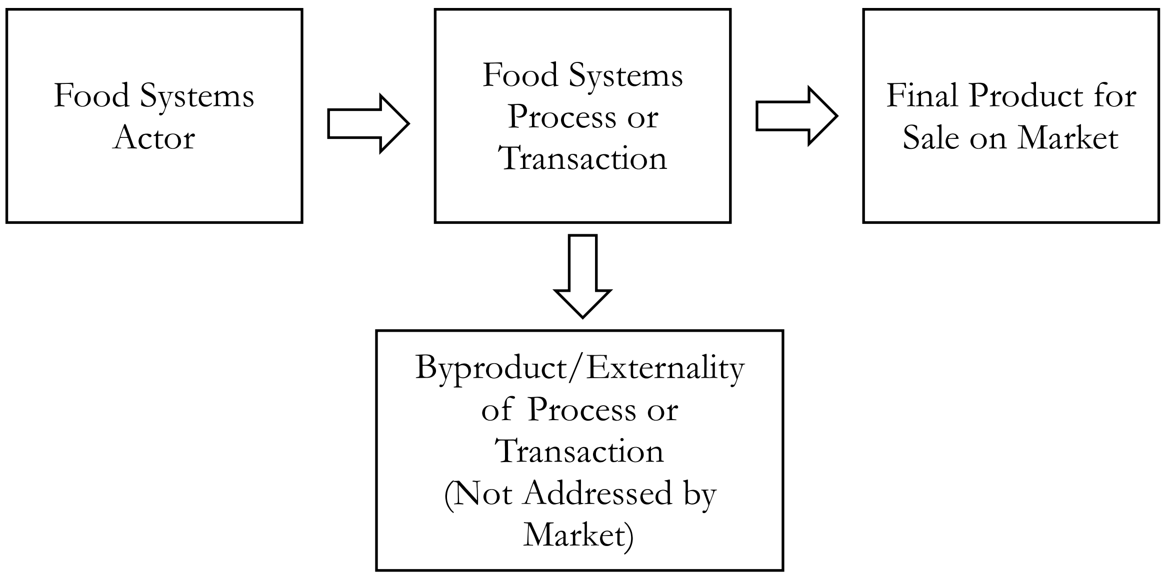


Figure 2. Conceptual model showing externality as a byproduct of a food systems process or transaction

How to achieve the optimal level of a positive externality is a topic of debate. Social welfare theory tells us that government intervention may be appropriate when there are market failures, such as barriers to activities that have positive externalities or imperfect competition due to market power concentration (Fig. 3). The market generally underprovides goods that produce positive externalities, resulting in deadweight loss (Fig. 3). Acknowledging that the marginal social benefit may be higher than the marginal private benefit motivates policy interventions that increase the quantity of good produced.

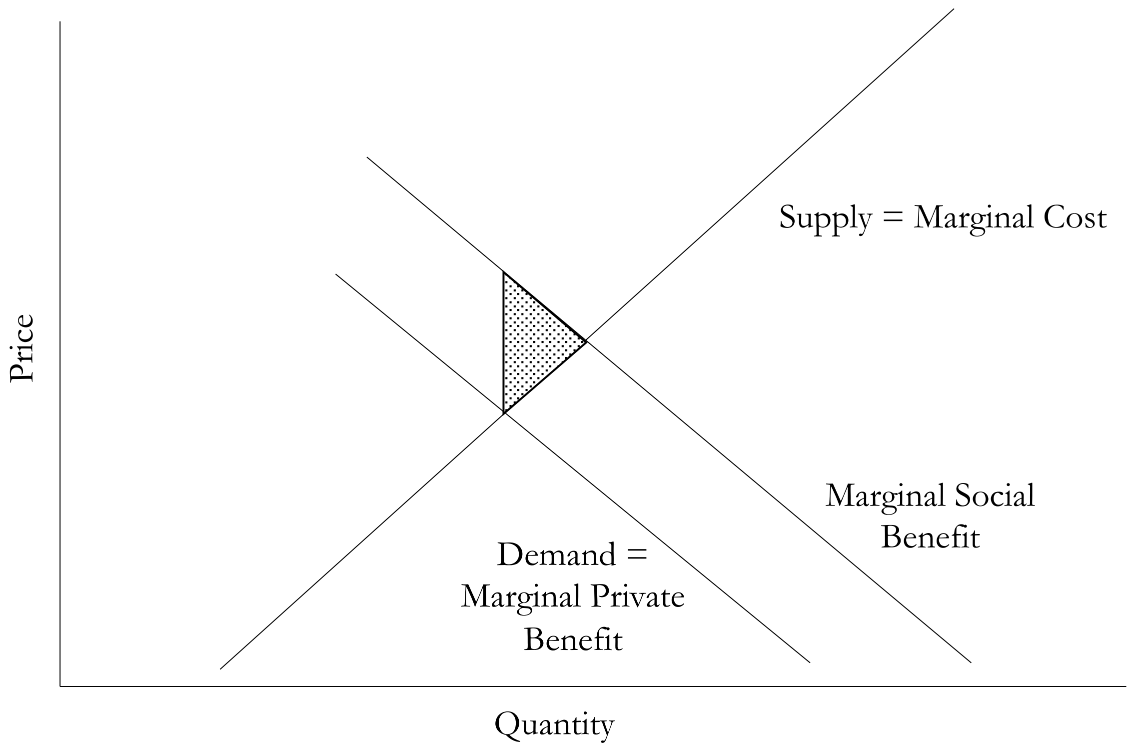


Figure 3. Goods producing positive externalities are generally underproduced, resulting in deadweight (dotted area) loss, due to the marginal social benefit exceeding the marginal private benefit

We draw from the theory of public goods, which are specific non-rival and non-excludable instances of externalities, and apply those lessons to a more general positive externality context to discuss policy levers (Randall, 1983; Samuelson, 1954). Belletti et al. (2017) build on earlier work to expand the classic definition of a public good beyond finished product characteristics to acknowledge varying degrees of "publicness" in the decision-making and distribution of benefits which are part of the production process of public goods (Kaul & Mendoza, 2004; Ostrom, 1990; Vanni, 2013). This new procedural definition of a public good provides the theoretical underpinning for our focus on local economic development associated with agriculture and food systems in rural areas as a positive externality.

Historically, a combination of market forces and policy support have been the appropriate prescription for an under-provided good with a positive externality. For example, collective action, in the form or rewards and sanctions exchanged between actors along the supply chain, could be a policy-driven measure to achieve a certain efficiency-externality balance (Sefton et al., 2007). However, recent work advocates a systems perspective when designing policy to reach the optimal point in the Efficiency-Externality Tradeoff (Nigmann et al., 2018). Nigmann et al.'s (2018) study suggests that social, cultural, and institutional drivers of positive externalities must be addressed to achieve optimality, and each of these drivers may be unique to rural areas where much of agricultural production occurs.

**Agriculture and Rural Economic Development**

Congress has charged the United States Department of Agriculture (USDA) with the implementation of many rural development policies. USDA programs related to agriculture as a mechanism for rural economic development include the Consolidated Farm and Rural Development Act of 1972; Rural Development Policy Act of 1980; Rural Development Act of 1990; Federal Crop Insurance Reform and Department of Agriculture Reorganization Act of 1994; Federal Agriculture Improvement and reform Act of 1996; Farm Security and Rural Investment Act of 2002; Food, Conservation, and Energy Act of 2008; and Agricultural Act of 2014 (Cowan, 2016). The USDA also houses many rural development programs that are not related to agriculture. As a country, the U.S. has often chosen to link rural and agricultural policy mechanisms and outcomes.

On an international scale, the Food and Agriculture Organization (FAO) touts investment in agro-industries in rural areas as a development strategy, especially for areas that are well connected to urban zones with growing consumer bases (United Nations Food and Agriculture Organization, 2017). As rural areas and small towns consider a range of approaches for revitalizing their economies and improving quality of life for their citizens, many are asking how they can leverage their participation in the food system to achieve their development goals (Jensen, 2010). It is important to acknowledge the different kinds of wealth that communities can be endowed with or invest in to understand food systems' full potential to impact a local economy. Pender et al. (2012) enumerate these types of wealth as financial, social, political, physical/built, natural, human/individual, intellectual, and cultural, while emphasizing the differences between stocks and flows of all types of wealth.

The role of agriculture in rural economic development is a widely studied topic, and many studies have found that agriculture is a vital part of rural economies (Aubry & Kebir, 2013; Marsden, Banks, et al., 2000; Marsden, Flynn, et al., 2000; Renting et al., 2003). Ashley and Maxwell (2002) compile a list of the ways farming contributes to rural economic development, including increased jobs and incomes due to farm activity, induced effects due to spending by farm laborers, tax revenues, and development of other sectors linked to agri-supply chains. Farmers' innovation and responsiveness to changing consumer tastes can increase their incomes and strengthen rural economies (Knickel et al., 2009). Drabenstott (2000) finds that changing structure in agriculture will lead to geographic concentration of agri-supply chains, and with it, distinct local economic impacts. Therefore, the regional dimensions of supply chains are important to consider, motivating the focus this thesis will place on analyzing the state-specific dynamics of the potato market.

The literature is not homogenous in its conclusions that farming always makes a substantial positive contribution to rural economies. Many studies have documented a negative relationship between agriculture and rural development outcomes (Anríquez & Stamoulis, 2007; Ashley & Maxwell, 2002; Browne et al., 1991). Farming is not without financial challenges, and Ashley and Maxwell (2002) state that current pricing and margin structure for most agricultural sectors is a substantial barrier to farm viability. They also emphasize the growing role of non-farm economic activity in rural development. Anríquez and Stamoulis (2007) evaluate agriculture as the centerpiece of rural development policy and conclude that it has mixed success depending on characteristics of communities, policies, and the availability of other options. In their book *Sacred Cows and Hot Potatoes: Agrarian Myths in Agricultural Policy*, Browne et al. (1991) debunk the national myth that small family farms in rural America are an unequivocal force in favor of wholesome moral values, rural wealth, and environmental sustainability. They also warn against the mistake of assuming that farming is the only, or even the most important, engine of economic development in rural America. Since *Sacred Cows and Hot Potatoes'* publication, a lively debate about the role of agriculture in rural development policy has developed. Drawing inspiration from Browne et al.'s book, we revisit several "hot potato" issues of agri-supply chains in this study, namely price transmission, market power, and a more current strategy commonly framed as a "hot potato": local food systems.

Taken together, the evidence suggests that farming and related food systems activities can be an important part of rural economic development, although their success depends on specific community contexts, and it is important to acknowledge other tenets of rural development. The link between food systems activities and economic development in rural areas is strong enough to distinguish local economic development as a positive externality associated with agriculture and food systems activity, justifying our Efficiency-Externality Tradeoff analysis for agri-supply chains.

## Essay I: The Efficiency-Externality Tradeoff in the Colorado Potato Supply Chain

### Background

Many small towns and rural areas have experienced economic decline in recent decades (Cromartie, 2017). One in five rural communities are economically dependent on farming, so targeting farm profitability as a rural economic development strategy makes sense (Willingham & Green, 2019). Communities with more family farms, in particular, tend to have higher wages, lower levels of income inequality, and more vibrant social interactions (Willingham & Green, 2019). One can conclude that prioritizing the financial health of family farms and their contribution to the vitality of rural America is one approach to rural development policy.

The San Luis Valley, a six-county region in southern Colorado, is an example of a rural area where the economic lifeblood is agriculture. Crop production, chiefly potatoes, and adjacent activities are a primary occupation there (San Luis Valley Development Resources Group, 2013). San Luis Valley farmers generally sell their products through a commodified supply chain, but they are still largely independent in terms of farm management, meaning that financial returns from agriculture are cycled back into the San Luis Valley community. Adapting Fig. 1 for use in this context, we frame potato production and marketing as the primary supply chain activity of interest and farmer bargaining power and low downside-risk in product pricing as positive externalities with local economic development implications (Fig. 4). Researcher proximity to the San Luis Valley region allowed for interviews, site visits, and integration of industry insider knowledge into this analysis, further justifying this choice of supply chain.

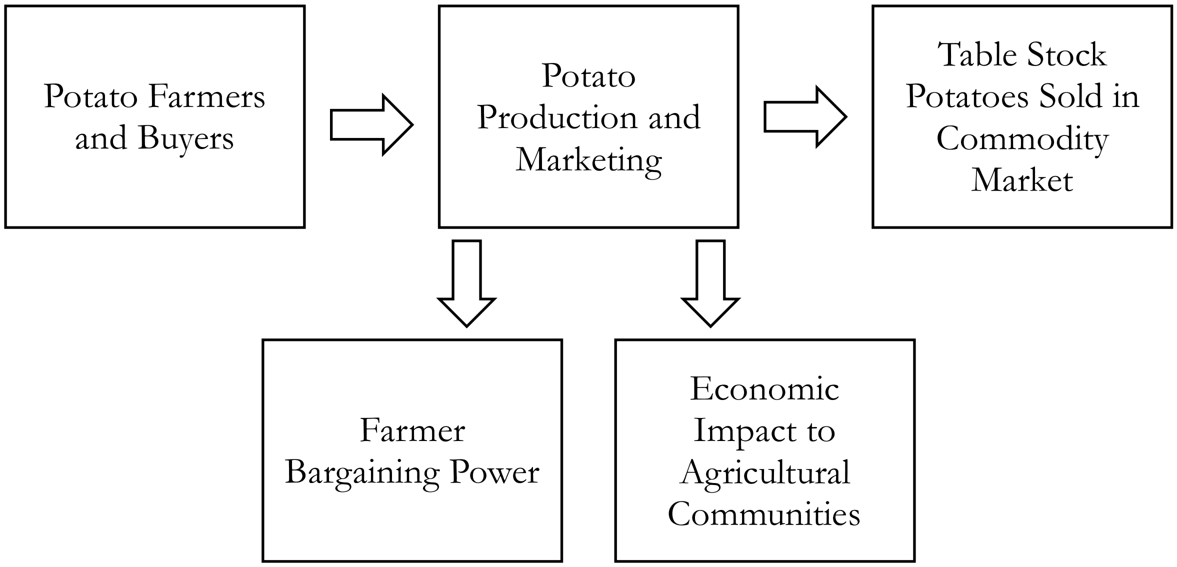


Figure 4. Farmer bargaining power and low downside-risk, particularly in pricing, is a potential positive externality of a potato supply chain

Laying out background information on potato markets is helpful before delving into econometric analysis of price dynamics. Below we provide context on U.S. and Colorado potato production, consumption, supply chain structure, and seasonal price fluctuations. Then we proceed to answer our research questions: Do the pricing dynamics for a key potato variety at different levels of the national potato supply chain suggest there are shortcomings from a singular focus on efficiency in commodity markets? If so, are other less efficient marketing channels worth exploring to diversify revenue streams for Colorado potato farmers? We aim to answer these questions by examining Granger causality and price asymmetry relationships amongst potato price time-series datasets.

*Potatoes: U.S. and Colorado Context*

In the 2018 crop year, the United States produced 450 million hundredweight (CWT) of potatoes on 1,023,300 acres at a total value of $3.75 billion (National Potato Council, 2019; USDA NASS, 2019a). The crop year for potatoes is defined as the start of harvest, generally in September, through August of the following year (USDA NASS, 2019a). About 23.7% of total production went to fresh table stock, 64.3% went to processed foods, and the remaining 12% went to other outlets and purposes, such as animal feed, seed, or shrinkage loss (USDA NASS, 2019a). In terms of U.S. production, Colorado ranked sixth overall and second for fresh or table stock production, making its producers more attentive to perishability, fresh product demand and movements, and active distribution through shipping points, terminal markets, and through brokers and retailers selling to end buyers (Table 2; Ehrlich, 2019; National Potato Council, 2019; USDA NASS, 2019). Colorado sold 14,379,391 CWT of potatoes as fresh table stock during the 2018-19 crop year, which amounted to 13.5% of all table stock in the U.S. (Colorado Potato Administrative Committee, 2020; USDA NASS, 2019a). The Colorado Potato Administrative Committee (CPAC) marketing order standardizes and codifies the expectations of potato growers in the state of Colorado regarding their production and marketing practices (Marketing order regulating the handling of potatoes grown in the state of Colorado, 2003).

Idaho was the largest potato producing state by volume in the 2018 crop year (Table 1). Together, Idaho and Washington comprised over 50% of the national market share by volume, much of which went to processed potato products. These states typically receive lower average prices for their crops, likely due to price differences between fresh table stock potatoes and potatoes destined for processing (National Potato Council, 2019). Idaho alone represented almost a third of total U.S. market share by volume, while Colorado's market share was 4.8% by comparison. Idaho is the only state that produced more fresh table stock than Colorado in 2018, and given its large market share, we hypothesize that Idaho may have some influence over Colorado fresh potato prices (Ehrlich, 2019). The CPAC annual report for the 2019-2020 crop year states, "Prices received by growers of potatoes are influenced by a competitive relationship with other growing areas, and to some extent, by U.S. economic trends. Current and potential supply levels, quality of supplies, time of harvest, consumer demand, and shipments of processed potatoes influence the price for fresh potatoes." (Colorado Potato Administrative Committee, 2020). We aim to examine price data econometrically for evidence of price influence (one indicator of potential concentrated market structure) from other growing areas, particularly Idaho, due to its status as the industry leader in potato production.

Table 1. Top 10 potato producing states based on 2018 production (National Potato Council, 2019; USDA ERS, 2019)

| State | Total Production (1,000 CWT) | % of Total Market Share | Price per CWT ($) | Value of Crop ($1,000) |
|---|---|---|---|---|
| **Idaho** | 141,750 | 31.5% | 6.85 | 960,199 |
| **Washington** | 100,800 | 22.4% | 6.52 | 688,512 |
| **Wisconsin** | 27,135 | 6.0% | 12.00 | 340,800 |
| **Oregon** | 27,000 | 6.0% | 7.49 | 210,169 |
| **North Dakota** | 23,725 | 5.3% | 9.70 | 226,592 |
| **Colorado** | 21,722 | 4.8% | 9.69 | 210,486 |
| **Minnesota** | 18,705 | 4.2% | 9.27 | 173,395 |
| **Michigan** | 18,240 | 4.1% | 10.00 | 182,400 |
| **California** | 15,457 | 3.4% | 14.50 | 224,497 |
| **Maine** | 15,035 | 3.3% | 10.20 | 156,519 |

In 2017, 69% of the potato acreage planted in the United States went to Russets, 21% to other white varieties, 7% to red and blue varieties, and 3% to yellow varieties (National Potato Council, 2019). In Colorado, an even higher 80% of acreage went to Russets, 10% to yellow varieties, 7% to red varieties, and 3% to other white varieties. Russets also constitute the largest category in terms of volume sold at 66.08% of all potatoes (Karst, 2018). As russets are the dominant variety in terms of acres planted and volume sold, we focus our econometric analysis on that variety to capture market dynamics at play in this predominant product category.

Per capita potato consumption in the U.S. has fluctuated between 110 and 145 lbs. per person annually since 1970, with people generally consuming fewer potatoes in recent years (Fig. 5; National Potato Council, 2019). In the past five years, total per capita potato consumption in the U.S. has remained in the range of 110-115 lbs. per person annually (Table 2a). Recent consumption is down from historical highs in the mid-late 1990s, when consumption was approximately 145 lbs. per person per year. This trend could be due to perceptions about the unhealthfulness of carbohydrates that have gained popularity since the early 2000s (Willett & Liu, 2019).

The primary forms potatoes are consumed in are frozen, fresh, chips, dehydrated, and canned. Approximately 80% of consumption is processed potatoes, with fresh consumption down about 2% over the 2014-18 time period (Table 2b). The frozen subcategory has seen a 3.8% increase, while the chip subcategory has seen a 2.2% decrease (Table 2b). It appears that more people are replacing fresh and chip potatoes with frozen potatoes in their diets. If health concerns are a major driver of consumption patterns, then it is ironic that most of the potatoes consumed are processed, meaning they are often classified as high-fat or -sodium foods, versus fresh (Furrer et al., 2018). A shift from processed to fresh consumption would address some of the health concerns about potatoes (Furrer et al., 2018). Moreover, such a shift would be encouraging to a state such as Colorado, which focuses on growing high-quality fresh table stock. It would also require a shorter supply chain, since fewer processing steps would be involved, thereby decreasing the number of points along the supply chain at which farmer returns could be disrupted or distorted.

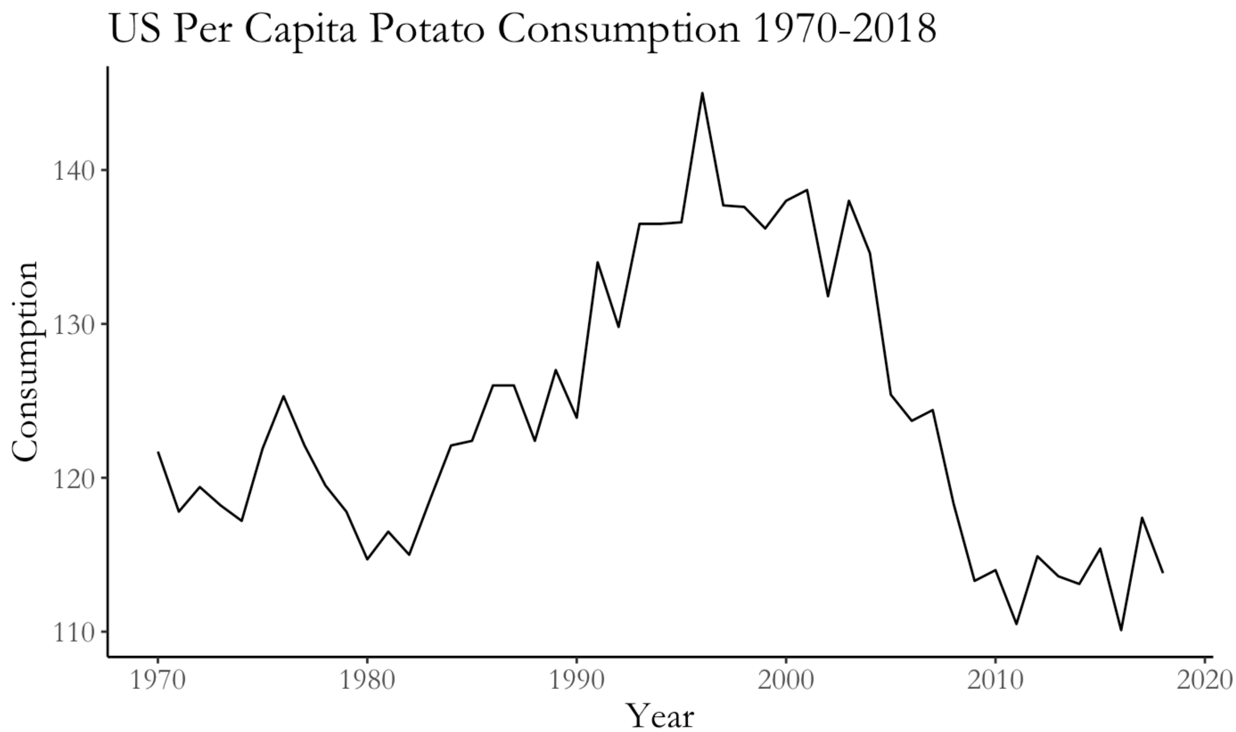


Figure 5. Total U.S. Per Capita Potato Consumption 1970-2018 in lbs./person/year (National Potato Council, 2019)

Table 2a. U.S. per capita potato consumption by type 2014-2018 (lbs. per person per year) (National Potato Council, 2019)

| Year | Fresh | Frozen | Chips | Dehydrated | Canned | Total Processed | Total |
|---|---|---|---|---|---|---|---|
| **2014** | 33.6 | 47.1 | 20 | 12.1 | 0.3 | 79.5 | 113.1 |
| **2015** | 34.2 | 49.7 | 19.6 | 11.6 | 0.4 | 81.2 | 115.4 |
| **2016** | 33.7 | 47.4 | 16.9 | 12 | 0.4 | 76.5 | 110.1 |
| **2017** | 33.4 | 51.9 | 17.8 | 12.9 | 0.5 | 83 | 117.4 |
| **2018** | 31.1 | 51.7 | 17.8 | 12.3 | 0.4 | 82.7 | 113.8 |

Table 2b. Relative percentages of U.S. per capital potato consumption by type 2014-2018 (National Potato Council, 2019)

| Year | Fresh | Frozen | Chips | Dehydrated | Canned | Total Processed | Total |
|---|---|---|---|---|---|---|---|
| **2014** | 29.7% | 41.6% | 17.7% | 10.7% | 0.3% | 70.3% | 100.0% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2015** | 29.6% | 43.1% | 17.0% | 10.1% | 0.3% | 70.4% | 100.0% |
| **2016** | 30.6% | 43.1% | 15.3% | 10.9% | 0.4% | 69.5% | 100.0% |
| **2017** | 28.4% | 44.2% | 15.2% | 11.0% | 0.4% | 70.7% | 100.0% |
| **2018** | 27.3% | 45.4% | 15.6% | 10.8% | 0.4% | 72.7% | 100.0% |

*Potato Supply Chain Structure*

We compiled time-series datasets of three price points from the USDA Agricultural Marketing Service (AMS) historical price database: shipping point, terminal market, and retail. The Specialty Crops Market News unit of the USDA AMS collects and distributes data on market conditions, including price, volume, and product characteristics, for many agricultural commodities (USDA AMS, 2020c). Specialty Crops Market News has contacts with agents along supply chains, including shippers, brokers, sellers, and buyers, and it organizes and validates information collected from these sources. Basic knowledge of supply chain structure is helpful for understanding how USDA AMS price points map to specific points on the Colorado and national potato supply chains.

Information on supply chain structure was compiled from conversations with CPAC affiliates, both producers and shippers. There are two primary pathways by which potatoes travel from producer to consumer from the San Luis Valley (Fig. 6). The first pathway, handling about 65% of all potatoes produced in San Luis Valley, is the warehouse/shipper route. Four or five farmers co-own or sell potatoes to a packing warehouse owned by one of them. The private warehouse then fills orders based on contracts set up by a brokering entity, such as Farm Fresh Direct, Mountain King, Potandin, Wada Potato, or RPE. Alternatively, farmers sell directly to a shipper. Potatoes are cleaned and packaged at either a grower-owned or broker-owned warehouse in the valley before being shipped out to their final destinations. The remaining 35% of potatoes coming out of the valley are "repacked," meaning a company with a washing and packing facility elsewhere in the country purchases unwashed, unpacked potatoes in bulk from the farm or warehouse by the truckload for shipping to their own facility.

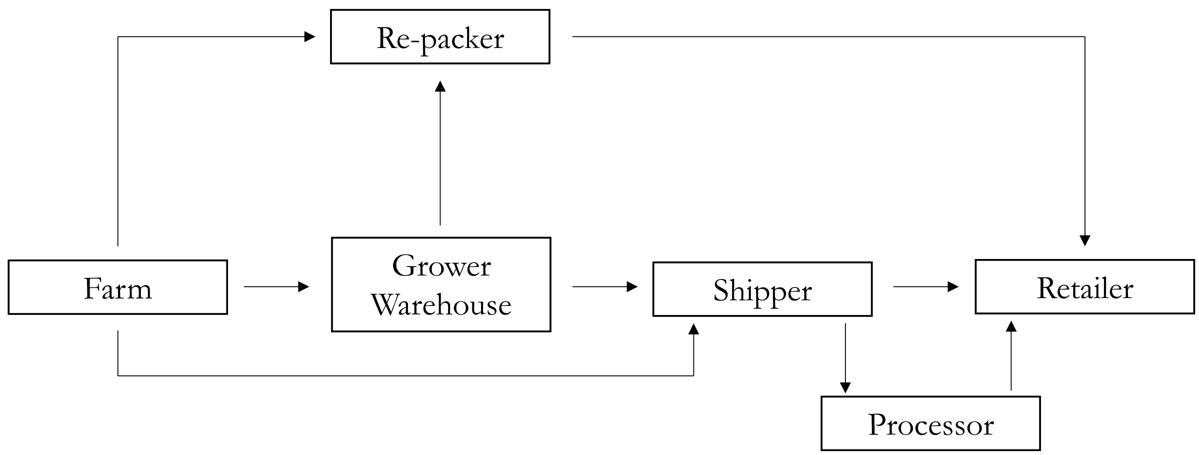


Figure 6. Common Colorado potato supply chains

The contracts set up by brokers are most commonly an agreement with large retailers or food service companies, such as Walmart, Kroger, Safeway, U.S. Foods, or Sysco. Contracts with large retailers and food service companies generally last six months in the harvest season (September through February) and then adjust based on remaining inventory for the rest of the crop year (Tonso, 2020). This arrangement means that growers generally know the price they will get for the majority of their crop by harvest time. Prices for fresh potatoes reflect the supply available nationally. Due to the considerable market power of large retail buyers, which constitute the majority of buyers of San Luis Valley products (Tonso, 2020), and the fact that many farmers sell through a broker, farmers do not have much bargaining power in the price setting process in this consolidated commodity supply chain. Existing potato supply chains have developed to efficiently connect production-heavy areas, such as the San Luis Valley, with consumers across the country. Yet, these longer, national supply chains are more likely to reflect price dynamics that do not allow growers in a particular area to fully capture any positive market shocks. Therefore, we suspect that commodified supply chains are associated with fewer positive externalities in the form of farmer bargaining power and low price risk.

*Price Patterns: Seasonality and Supply*

A key concern of this research is to understand how prices are transmitted through the supply chain. One example of price transmission back through the supply chain to the shipping point, or farm gate, is seasonal fluctuations in prices based on inventory levels. The substantial seasonal fluctuation in farmgate prices is partially due to harvest and storage patterns and conventions. The majority of the crop is harvested in the fall and then stored over the winter and through the following summer until the next harvesting season begins. Prices tend to be lower during harvest season, when potatoes are abundant, and as expected, they rise once stocks go into storage during the off-season (Table 3). If we examine monthly farmgate prices for table stock potatoes, we observe that prices tend to rise from February through August and then drop substantially in September once the harvest begins. Seasonality is not the focus of this study, so we do not formally test for the presence of seasonality. But seasonal price fluctuations are a preliminary indicator that sometimes price changes do travel along the supply chain back to growers. Learning more about when and how price changes are transmitted will inform our understanding of whether farmers are able to capture gains from market fluctuations, which would have implications for farm financial health and rural economic development.

Table 3. National farmgate prices for table stock potatoes by month 2014-2018 ($ per CWT) (National Potato Council, 2019)

| Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Avg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2014** | 9.86 | 10.08 | 10.6 | 12.17 | 11.53 | 12.98 | 9.92 | 11.47 | 9.84 | 8.97 | 9.24 | 9.4 | 10.16 |
| **2015** | 9.68 | 9.66 | 9.58 | 9.75 | 11.98 | 10.47 | 9.7 | 10.73 | 8.95 | 8.78 | 8.96 | 8.64 | 9.85 |
| **2016** | 9.05 | 8.94 | 9.29 | 9.39 | 12.99 | 13.5 | 11.77 | 12.8 | 10.48 | 9.59 | 9.91 | 9.59 | 10.6 |
| **2017** | 8.27 | 8.42 | 8.65 | 8.4 | 9.4 | 10.25 | 10.79 | 14.61 | 13.86 | 11.33 | 11.22 | 11.39 | 11.95 |
| **2018** | 11.3 | 11.2 | 11.1 | 11.2 | 11.4 | 11.8 | 11.5 | 11.2 | 9.44 | 8.65 | 9.22 | 9.37 | – |

**Data**

Analyzing price influence and price asymmetry patterns requires time-series price data for several points along the supply chain and in our case, geographic areas, since we were interested in price influence by other states producing the same products (Fig. 7a). Due to the proprietary nature of price data at intermediary points along the supply chain, we did not have access to data for every step of the typical Colorado potato supply chain (Fig. 7a). Instead we used publicly accessible USDA AMS data on three price points along the supply chain: shipping point price (a proxy for farm gate price), terminal market price (a proxy for wholesale price), and retail price (Fig. 7b). This dataset served to capture geographic price variation, since we collected shipping point prices for both Colorado and Idaho, as well as variation in prices as potatoes traveled from farms along the supply chain to consumers. We examined the supply chain dynamics, such as price influence and asymmetry, for Colorado and Idaho potatoes—Idaho being Colorado's primary fresh market competitor—in order to draw inferences about potential competition, market power, and implications for farmer bargaining power.

The AMS provides reports for shipping point, terminal market, and retail price averages (USDA AMS, 2019). These reports can be customized to a select commodity and location at a frequency of weekly, monthly, quarterly, or yearly. We selected the crop ("potatoes"), time period (variable), region (variable), and unit of aggregation ("weekly"). We used the "refine" function to select certain potato characteristics for the dataset, such as variety ("Russet"), type of production ("non-organic"), field conditions (all), size ("70"), and package type ("50-lb. carton" or "10 5-lb. bags").

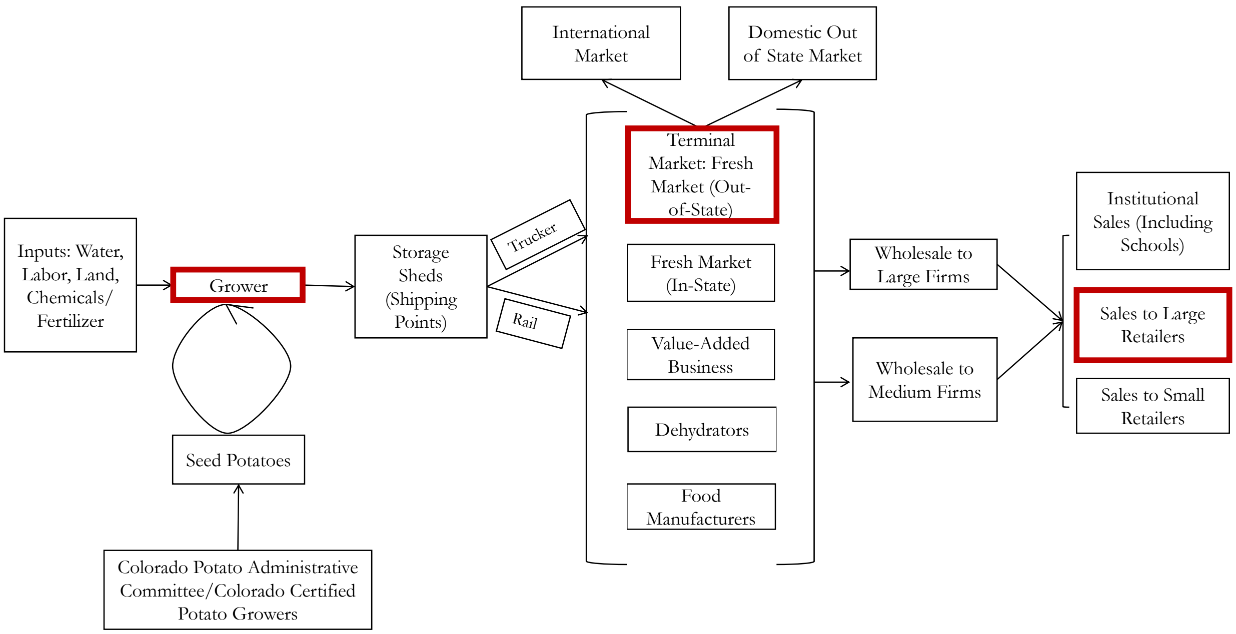


Figure 7a. Colorado potato supply chain with publicly accessible price data points used in analysis highlighted in red (Jablonski et al., 2019)

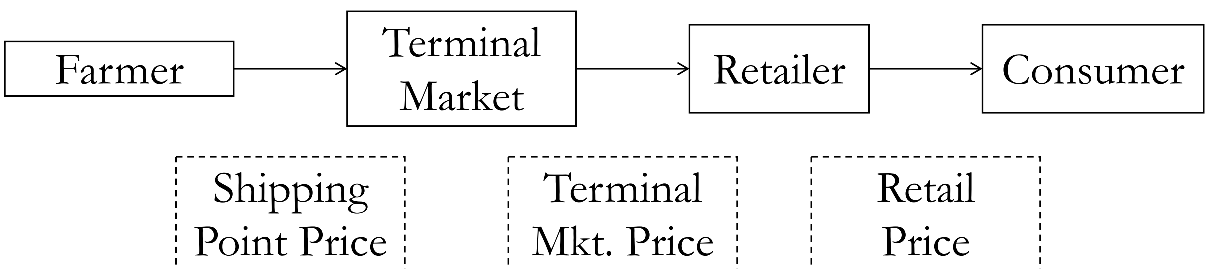


Figure 7b. Simplified potato supply chain showing only relationships for which AMS price data are available

We tested non-organic Russet potatoes in 50-lb. cartons (size 70) and 10 5-lb. bags (film bag, mesh film bag, mesh bag, and sacks). AMS collects data weekly, and to minimize the potential bias from missing data points, we collapsed the data to a monthly average of the available weekly prices. The final collapsed data had no more than four missing monthly observations out of 257 total per variable (Table 4). Retail variables only had 140 possible observations due to a later starting date for available data points, and we collapsed the data to a monthly unit of observation to match the other variables. We adjusted the monthly prices for inflation using the Consumer Price Index (CPI) with May 2019 as the reference month.

Shipping point and terminal market data began in January 1998 and went through May 2019. Retail data began in October 2007, later than the other price points were available, but this point in the supply chain was added to augment our analysis once it became available. For shipping point prices, we selected data for Colorado, specifically the San Luis Valley and Northeastern Colorado regions (including "Northeast Colorado" and "Points North and East in Colorado"). The date range was January 10, 1998 to May 25, 2019. For terminal market prices, we selected data for all terminal market locations containing potato products that originated from Colorado. The date range was January 10, 1998 to May 25, 2019 for all terminal market prices. For retail market prices, the U.S. is broken up into nine regions. Since Colorado potatoes are sold all over the country, we selected national average retail prices, as well as prices for the South Central Region, where Colorado is located. The date range was October 5, 2007 (first available date for retail prices) to May 25, 2019. 50-lb. cartons were not a unit size option, so we selected data collected on a common wholesale unit: 5-lb. bags.

For all data sets, prices were converted to a per pound price. For the shipping point prices this meant dividing by 100 since the standardized unit of measurement is a CWT, and for the terminal market prices this meant dividing by the appropriate package size. Because the units sometimes changed throughout the period of the dataset, we verified the per lb. prices that we calculated from AMS data against the potato price data available from the National Agricultural Statistics Service (USDA NASS, 2019b). The NASS data fell between the 50-lb. carton per lb. price and the 10 5-lb. bag per lb. price, and since our data tracked these numbers closely, we were satisfied that the unit conversions were accurate.

The final set of variables was: Colorado 50-lb. carton shipping point or farmgate price (CO Shipping 50 Price), Colorado 10 5-lb. bag shipping point or farmgate price (CO Shipping 10_5 Price), Idaho 50-lb. carton shipping point or farmgate price (ID Shipping 50 Price), Idaho 10 5-lb. bag shipping point or farmgate price (ID Shipping 10_5 Price), 50-lb. carton terminal market price for markets containing Colorado-originated produce (Terminal 50 Price), 10 5-lb. bag terminal market price for markets containing Colorado-originated produce (Terminal 10_5 Price), 5-lb. bag national retail price (Natl Retail Price), and 5-lb. bag South Central region retail price (SC Retail Price). Summary statistics are available below (Table 4).

Table 4. Summary statistics of price variables

| Variable | Observations | Mean | St. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| **CO Shipping 50 Price** | 253 | $0.118 | $0.038 | $0.048 | $0.257 |
| **CO Shipping 10_5 Price** | 253 | $0.080 | $0.022 | $0.044 | $0.160 |
| **Terminal 50 Price** | 257 | $0.358 | $0.087 | $0.197 | $0.697 |
| **Terminal 10_5 Price** | 255 | $0.281 | $0.052 | $0.184 | $0.470 |
| **Natl. Retail Price** | 140 | $0.524 | $0.056 | $0.413 | $0.696 |
| **SC Retail Price** | 140 | $0.448 | $0.073 | $0.307 | $0.705 |
| **ID Shipping 50 Price** | 257 | $0.128 | $0.045 | $0.051 | $0.272 |
| **ID Shipping 10_5 Price** | 257 | $0.072 | $0.021 | $0.040 | $0.161 |

**Initial Data Exploration**

To address potential outliers, and assess easily recognizable patterns visually, we plotted the data. We plotted the three supply chain links for 50-lb. cartons originating in Colorado (Fig. 8a), 10 5-lb. bags originating in Colorado (Fig. 8b), a comparison of Colorado shipping point prices for 50-lb. cartons and 5-lb. bags (Fig. 8c), and a comparison of Idaho and Colorado shipping point prices for 50-lb. cartons and 5-lb. bags (Figs. 8d-e). We observed some especially high- or low-price values, but they were in line with the NASS values from those months, so they were likely due to production and weather issues rather than reporting errors in the dataset.

We made several observations about the data plots of potato prices for Colorado and Idaho (Figs. 8a-e). First, we saw, unsurprisingly, that actors along the supply chain collect margins because retail prices were higher than terminal market prices, which were higher than farmgate prices, with very few exceptions (Figs. 8a-b). This makes sense because we would expect that later links in the supply chain have to charge more than they paid for the product to cover their costs of doing business and still capture a profit. Interestingly, we noted that 50-lb. carton shipping point prices were much more volatile than 5-lb. bag shipping point prices (Fig. 8c). Shipping point prices for 50-lb. cartons also appeared to be slightly higher than those for 5-lb. bags based on visual inspection of the graphs (Fig. 8c). We consulted summary statistics to confirm that the mean of Colorado 50-lb. carton shipping point prices was $0.118/lb. versus $0.080/lb. for 5-lb. bags (Table 4). Conversations with potato farmers indicated that 5-lb. bags are sometimes used as an inventory control mechanism for smaller potatoes, which explains the price difference in different package types (Ehrlich, 2019).

Turning to the plots of Idaho and Colorado shipping point prices, we observed that the shipping point prices for both states tracked each other closely, particularly for the 50-lb. cartons (Figs. 8d-e). This observation aligns with our knowledge that potatoes are subject to national fluctuations in price patterns. After inspecting the data visually and identifying patterns of interest, we conducted econometric analysis to further explore dynamics.

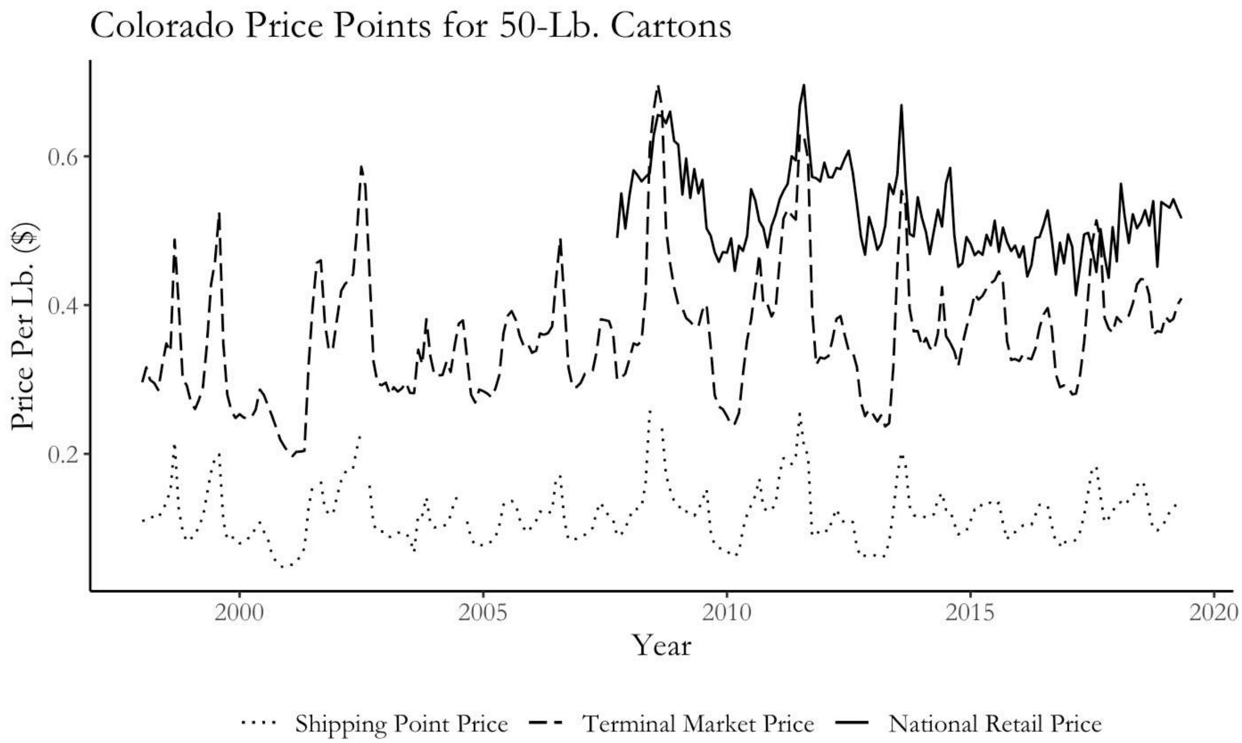


Figure 8a. Colorado 50-lb. carton prices

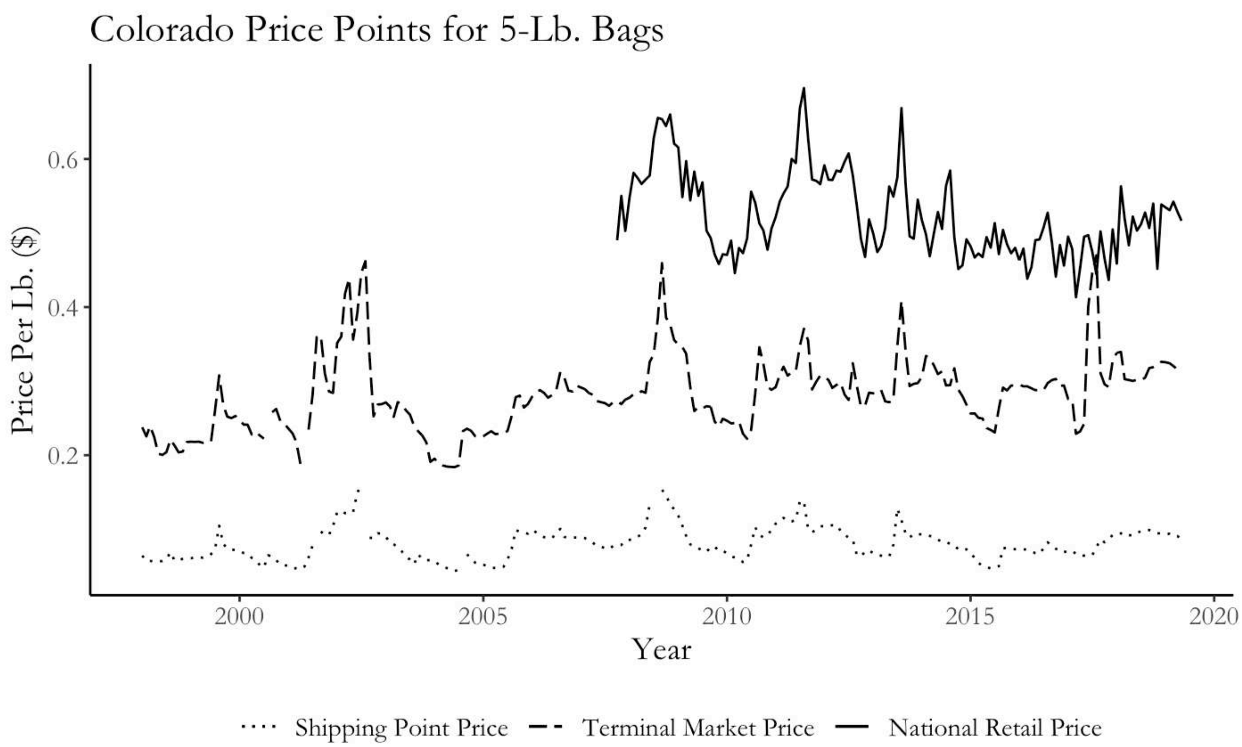


Figure 8b. Colorado 5-lb. bag prices

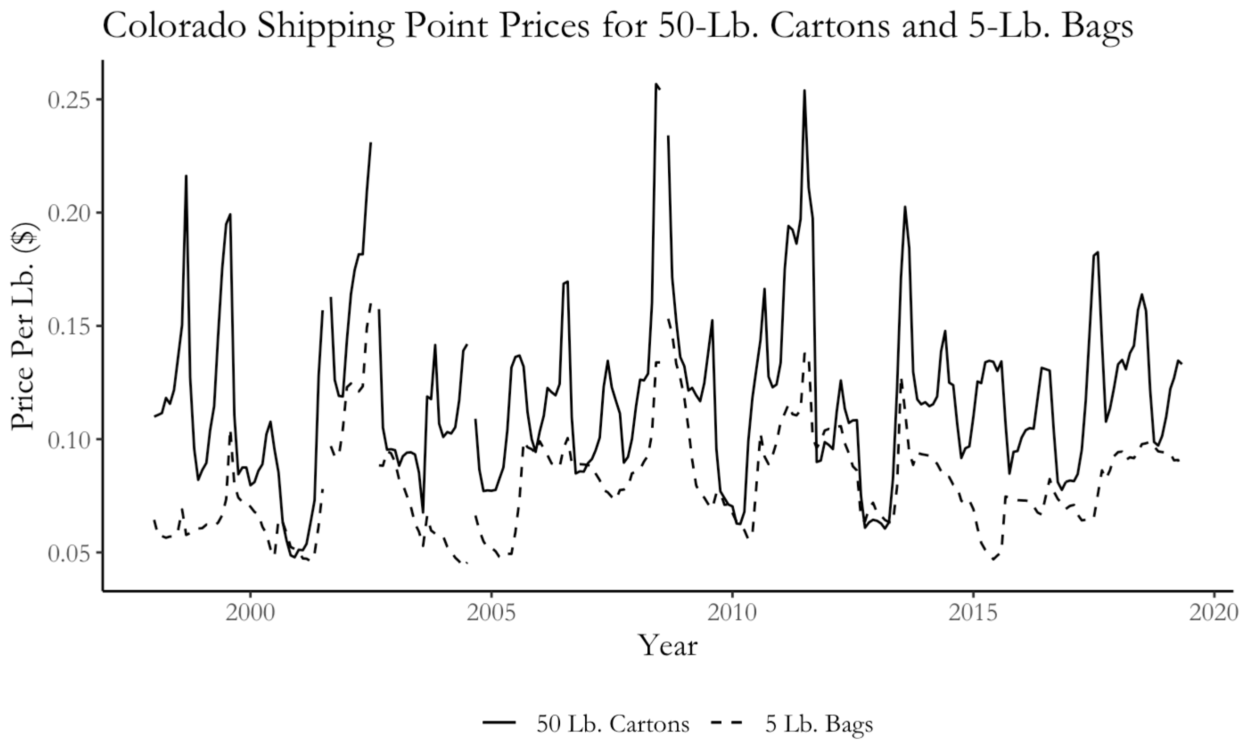


Figure 8c. Colorado shipping point prices

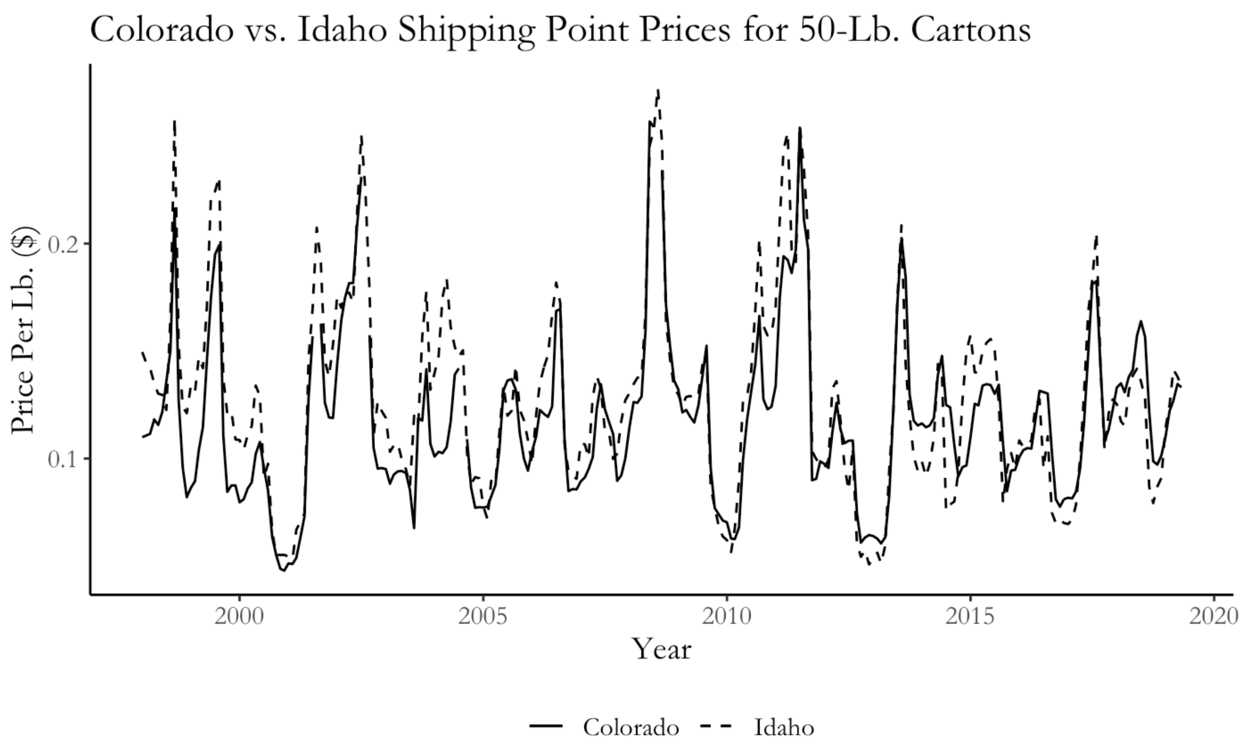


Figure 8d. Colorado vs. Idaho 50-lb. carton prices

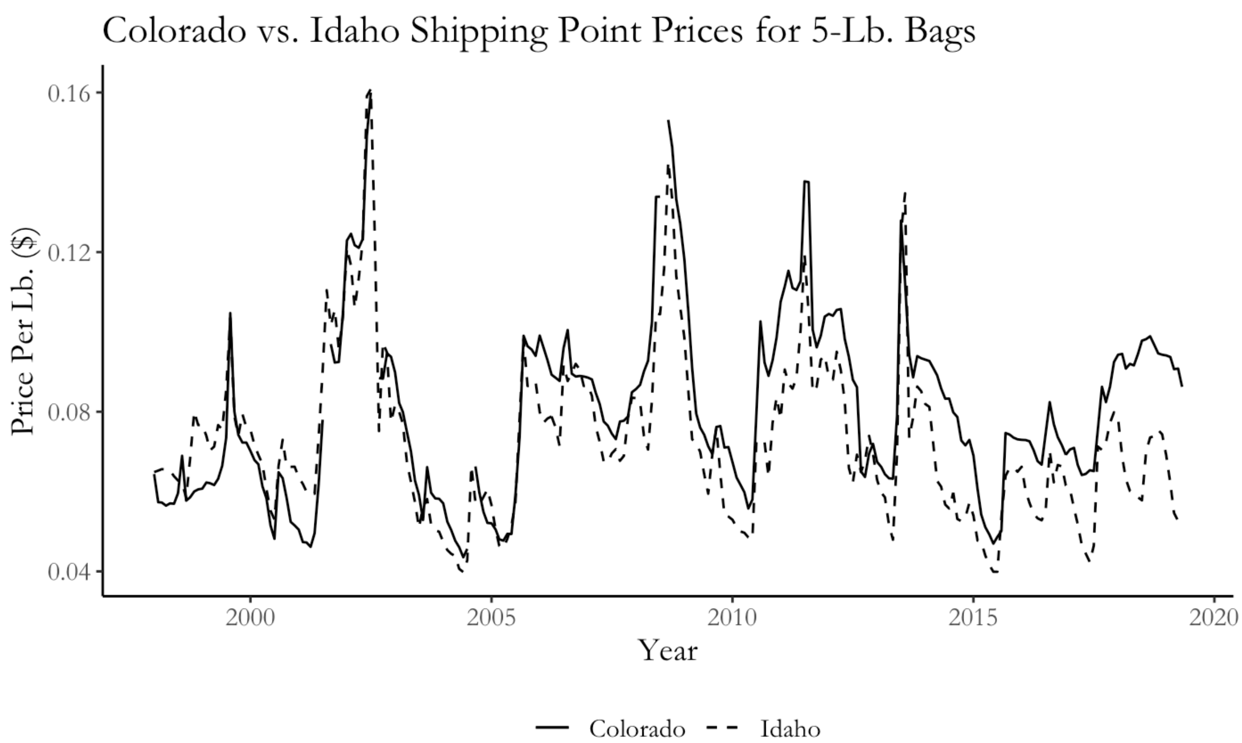


Figure 8e. Colorado vs. Idaho 5-lb. bag prices

**Fundamental Analysis**

Since we worked with time-series data for this analysis, we made a few initial considerations before proceeding with more detailed empirical work. Once data were cleaned and adjusted for inflation, we conducted fundamental time series analysis to test for stationarity and appropriate lag length for each variable. The empirical tests we performed rely on the principle of stationarity in the data, meaning the mean and variance of the data are constant over time (Gujarati & Porter, 2009, p. 740). In other words, the data do not exhibit any trends over time that make behavior of prices fundamentally different at different points in time. Determining appropriate lag length is important because in the distributed lag model which we employed, omitting a lag that has a statistically significant effect subjects the model to omitted variable bias, invalidating the results of hypothesis testing (Gujarati & Porter, 2009, p. 618-623).

We used an Augmented Dickey-Fuller Test for Stationarity in all eight variables (Gujarati & Porter, 2009, p. 757-759). We plotted the data for each variable against time to determine if we should include a trend variable and intercept. Based on data plots, we determined that we should include trend and intercept variables in Dickey-Fuller methods for every variable. Without including any lags, we could not reject the null hypothesis for the Colorado 50-lb. carton shipping point price, Colorado 10 5-lb. bag shipping point price, and Idaho 10 5-lb. bag shipping point price. We could reject the null hypothesis and conclude that the data were stationary for the rest of the variables. Once we included the appropriate number of lags, identified through testing as two lags for all variables, we could reject the null hypothesis of the Augmented Dickey-Fuller Test for all eight variables. Rejecting the null with two lags resulted in a series with stationarity for all eight variables, since we included two lags in every model.

We chose to address the lag specification issue by determining appropriate lag length using the ad hoc sequential estimation or "testing up" method described by Gujarati and Porter (2009, p. 623-624). To test for the appropriate number of lags, we regressed the contemporaneous variable on lagged values of itself and continued adding additional lags until the last lag value either became statistically insignificant at the 5% level or changed sign. Based on the "testing up" method of determining lag length, the appropriate number of lags for all eight variables was determined to be two (Gujarati & Porter, 2009, p. 623-624).

**Analytical Methods**

We performed t-tests on select pairs of shipping point prices of interest to see if they were significantly different. We compared different package sizes from Colorado, as well as Idaho and Colorado prices for different package sizes.

The next step was to perform a Granger Causality test among all links of the supply chain. The Granger Causality test consists of two "opposite" regressions, F-tests on the variables of interest in each regression, and a subsequent comparison of the resulting p-values. For example, if we want to examine the relationship between two prices, price X and price Y, we would run the following regressions if the appropriate lag number is two:

$$\text{Eq. 1: } y_t = \alpha + \beta_1 x_{t-1} + \beta_2 x_{t-2} + \beta_3 y_{t-1} + \beta_4 y_{t-2} + e$$

$$\text{Eq. 2: } x_t = \gamma + \delta_1 y_{t-1} + \delta_2 y_{t-2} + \delta_3 x_{t-1} + \delta_4 x_{t-2} + e$$

Note that the contemporaneous independent variable of interest is excluded. The contemporaneous control variable is the dependent variable, so it is limited to the left side of the regression. There are three possible outcomes of the Granger Causality Test: unidirectional causality, bidirectional causality, or independence. If the p-value of one F-test is statistically significant and the other one is not, we conclude unidirectional causality, meaning one variable Granger-causes the other at the 5% significance level. If the p-values of both F-tests are statistically significant, we conclude bidirectional causality, meaning both variables Granger-cause each other at the 5% significance level. If the p-values of neither F-test are significant, we conclude independence, meaning that statistical tests do not detect a significant Granger-causal relationship at the 5% level.

We used the dynamic Houck Method as presented by Capps and Sherwell (2005) to examine the data for price asymmetry (Eq. 3). To perform this test, we generated the following variables for each price series: positive first-differenced, negative first-differenced, positive lagged first-differenced, negative lagged first-differenced, positive lagged-twice first-differenced, and negative lagged-twice first-differenced.

$$\text{Eq. 3: } \Delta P_{rt} = \alpha_0 + \sum_{i=0}^{M_1} \alpha_{1i} \Delta P^{+}_{ft-i} + \sum_{i=0}^{M_2} \alpha_{2i} \Delta P^{-}_{ft-i} + v_t \text{, where:}$$

$\Delta P_{rt}$=First-differenced retail prices

$$\sum_{i=0}^{M_1} \alpha_{1i}\Delta P^{+}_{ft-i} = \text{Sum of positive lagged first-differenced farmgate price variables}$$

$$\sum_{i=0}^{M_2} \alpha_{2i}\Delta P^{-}_{ft-i} = \text{Sum of negative lagged first-differenced farmgate price variables}$$

$$H_0: \sum_{i=0}^{M_1} \alpha_{1i}\Delta P^{+}_{ft-i} = \sum_{i=0}^{M_2} \alpha_{2i}\Delta P^{-}_{ft-i}$$

We tested several pairs of variables for price "stickiness" or rigidity using the directionality established by the Granger Causality test: Colorado shipping point and terminal market prices, Colorado terminal market and national retail prices, Colorado shipping point and national retail prices, and Idaho shipping point and Colorado shipping point prices. All relationships were tested for both 50-lb. cartons and 5-lb. bags.

The price asymmetry test informs us about the speed with which prices return to "normal" levels if they are shocked by the market. If certain parts of the supply chain take longer to return to "normalcy," those prices are considered "sticky" or asymmetric. Price asymmetry is an important characteristic, and we can consider two situations when price stickiness would be detrimental to Colorado producers. If prices are asymmetric between Idaho and Colorado producers, and if the market experiences a downturn and prices are low, the Colorado producers' prices may be depressed for longer than would be the case under well-functioning markets. Second if the market experiences higher than average prices because there is a demand shift, lack of price transmission due to price asymmetry means that producers would not be able to capture gains from strong markets as quickly as other parts of the supply chain, thereby causing them to lose money because of the market dynamics of the supply chain.

**Results**

T-test results are summarized below (Table 5). Colorado shipping point prices were statistically significantly different at the 1% level for 50-lb. and 5-lb. bags. Colorado and Idaho prices were also significantly different at the 1% level for both 50-lb. bags and 5-lb. bags. Statistically significant differences between Idaho and Colorado shipping point prices indicated that price influence may be present, justifying the focus of the next time-series analysis on prices.

Table 5. T-test results for different package sizes and for Idaho versus Colorado shipping point prices

| Variables | T-Statistic | P-Value | Mean Difference |
|---|---|---|---|
| **CO Shipping Point 50-lb. Cartons vs. 5-lb. Bags** | 13.5028 | <0.0001 | 0.0376762 |
| **CO vs. ID Shipping Point for 50-lb. Cartons** | -2.7024 | 0.0071 | -0.0100084 |
| **CO vs. ID Shipping Point for 5-lb. Bags** | 4.0936 | <0.0001 | 0.0077876 |

We present the results of the Granger Causality test visually for the 50-lb. carton and 5-lb. bag prices (Figs. 9a-b). We note that, in general, the direction of causality flowed "downstream" from points of production in the supply chain to points of consumption. A key result was that with both package types, Idaho farmgate prices Granger-caused Colorado farmgate prices, as well as national retail prices. In the case of 5-lb. bags, the Idaho-national retail Granger causality result was bi-directional (Fig. 9b). Econometric results support anecdotal evidence from Colorado potato farmers that Idaho produces such a high volume of potatoes that they have captured some market influence and may catalyze pricing changes for fresh potatoes.

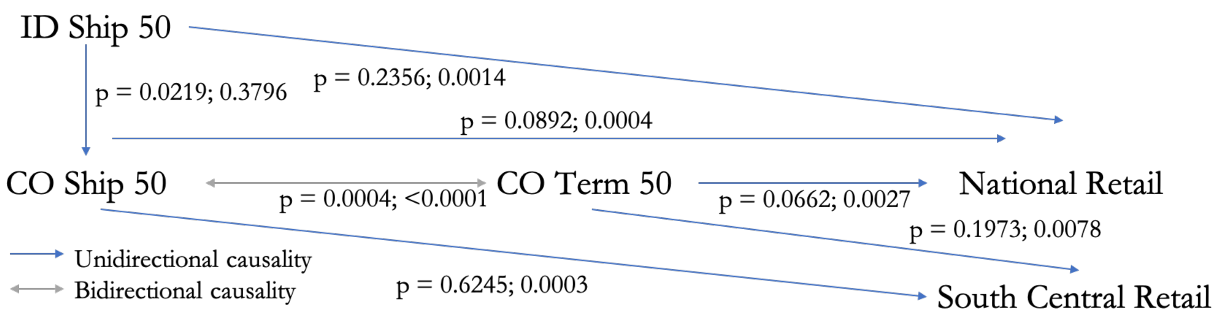


Figure 9a. Granger Causality results for 50-lb. cartons; p-values of F-tests indicated

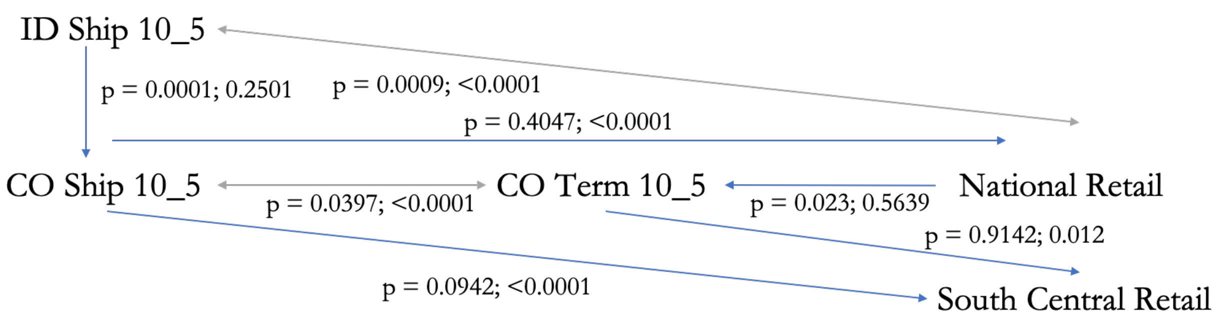


Figure 9b. Granger Causality results for 5-lb. bags; p-values of F-tests indicated

The results of the price asymmetry test indicate that there was price asymmetry between Idaho and Colorado farmgate prices at the 5% level for 5-lb. bags and at the 1% level for 50-lb. cartons (Fig. 10). There was also asymmetry at the 1% level between the Colorado shipping and terminal markets for 50-lb. cartons and asymmetry at the 5% level between Colorado terminal markets for 5-lb. bags and national retail prices.

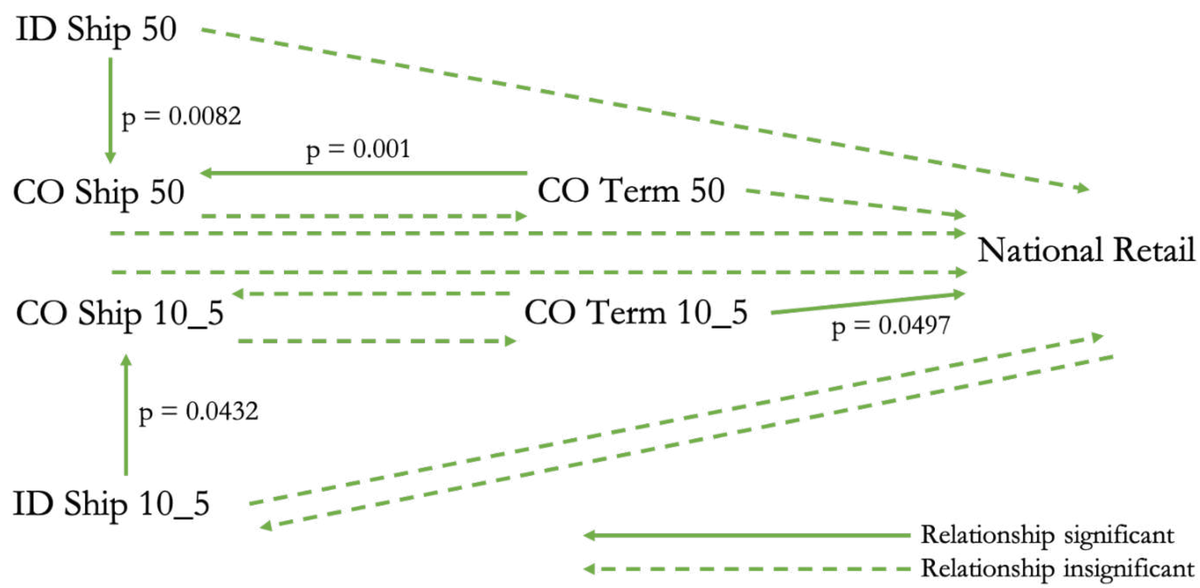


Figure 10. Results of price asymmetry tests between select links of the supply chain

**Discussion and Policy Implications**

The goal of this analysis was to examine price transmission, influence, and asymmetry patterns in the Colorado and national potato supply chain, with a special emphasis on prices received by farmers for their products. We wanted to compile evidence about whether shipping point prices move with changes in downstream supply chain links in commodified potato markets. We conclude that within the Colorado supply chain, points farther "up" the supply chain, that are closer to production, tend to Granger-cause price points further "down" the supply chain, closer to the consumer. Spatially, we observe that Idaho potato prices do influence Colorado potato prices at the farmgate supply chain link for both 50-lb. cartons and 5-lb. bags according to the Granger Causality test. We also observe price stickiness between Idaho farmgate prices and Colorado farmgate prices, as well as between some upstream and downstream links of the national potato supply chain.

Collectively these results indicate that prices are driven by the supply-side of the value chain, which aligns with anecdotal evidence provided by farmers and shippers in San Luis Valley that prices depend heavily on the volume of potatoes grown collectively by several competing regions. Granger Causality results show Colorado farmgate prices are dependent on Idaho farmgate prices, and price asymmetry results show downstream actors reap disproportionate benefits when retail prices are high (Colorado Potato Administrative Committee, 2020). Shortening and localizing supply chains is one way to improve price transmission back along the supply chain to the producer and increase the chances that Colorado producers see price and profit gains when they invest in quality improvements or product differentiation, or when consumer demand increases (Happe et al., 2008; LeRoux et al., 2010; Saitone & Sexton, 2017).

Colorado potato producers have invested in genetic and breeding improvements, equipment upgrades, and growing practice developments (San Luis Valley Research Center, 2020). They may also be able to create some value by investing in the promotion of a geographic indicator of quality for Colorado potatoes (Belletti et al., 2017; Molnar & Glenn, 2016). While participating in the national commodity market for potatoes allows farmers to sell large volumes of product, they may trade some of their power over how profits along the supply chain are distributed for their access to this national commodity market. The current market dynamics of price influence from Idaho and the national market, as well as price stickiness, indicate that producers may not be capturing profits proportionate to their efforts to enhance quality. Shortening supply chains to lower the chances of distorted price transmission would improve their chances of seeing higher prices for any of these investments.

Turning our attention to current events, the Colorado potato market situation in the face of COVID-19 developments is instructive about price dynamics faced by farmers. During March 2020, the global COVID-19 pandemic forced a halting of economic activity in the U.S. as some state and local governments adopted shelter-in-place and stay-at-home orders in an attempt to slow the spread of the virus. As consumers shopped for groceries with the goal of staying in their homes for long periods of time, they stocked up on food staples, cleaning supplies, and other household essentials (Parker-Pope, 2020). Potatoes were a popular item in those market conditions because potatoes are seen as a shelf stable pantry staple (Fig. 11). Recent analysis of U.S. produce markets has shown that the volume of potatoes purchased by consumers in March 2020 was 41% higher than it was in March 2019 (Pieterse, 2020). Fresh potato sales increased 19.2% in dollars and 15% in volume in quarter 3 of marketing year 2020 (Potatoes USA, 2020b, 2020a).

We observe that retail prices for potatoes dropped drastically in late March and subsequently recovered throughout April, returning to approximately the same level by the end of the month (Fig. 12). During that same time period, prices at the farmgate steadily decreased, indicating that the major sales gains seen by retailers perhaps did not contribute to increased farm revenues (Fig. 12). This lag in price transmission and slow return back to "normal" price levels at the farmgate once other links of the supply chain have returned to "normal" price levels is an example of price asymmetry. The fact that farmers do not appear to be capturing more revenues when prices have changed "downstream" in the supply chain indicates that there may be imperfect information flows or competitive conditions in the potato supply chain that make it challenging for producers to capture a higher price in conjunction with their retailer counterparts. It seems that in commodity supply chains the gains farmers receive when prices are unexpectedly high are disproportionate to the losses they suffer when prices are unexpectedly low, indicating that they pay for taking the risks inherent in agriculture but less frequently see the benefits. In short, policy interventions may be appropriate in cases of price asymmetry and imperfect competition, and events related to COVID-19 may draw attention to where supply chains exhibit such shortcomings.

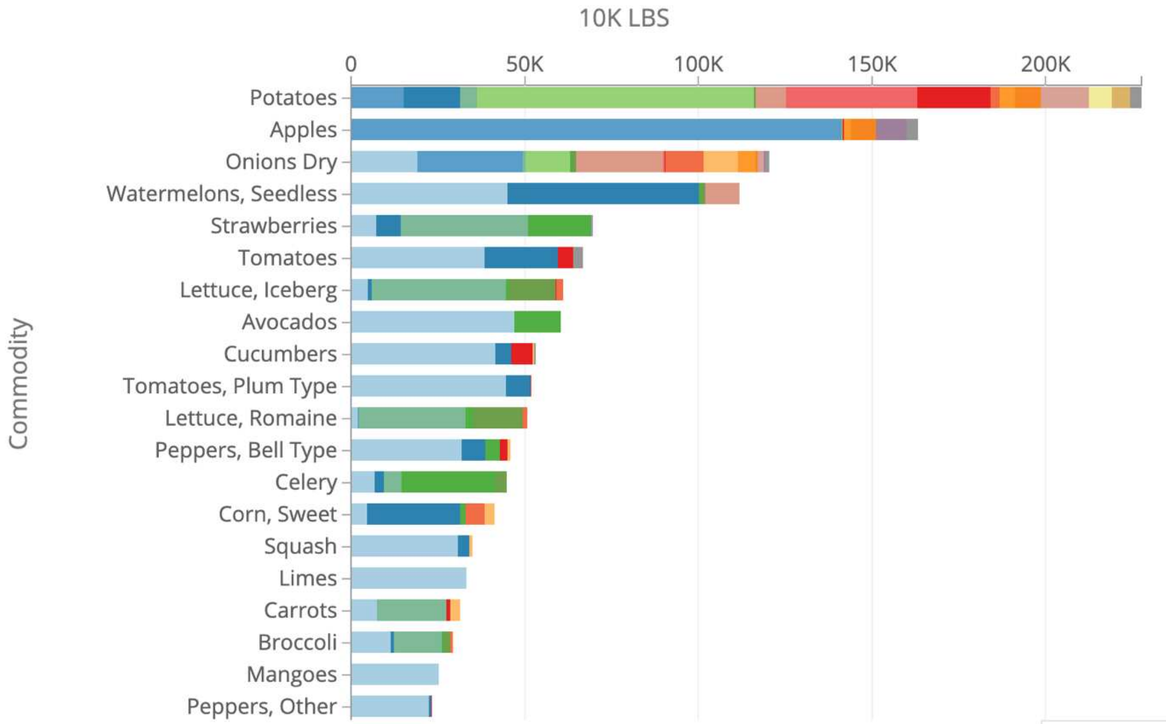


Figure 11. Volume of produce shipped March 1-May 31 by state and commodity. Idaho (light green) sold the most potatoes, followed by Colorado (bright pink) (USDA AMS, 2020b)

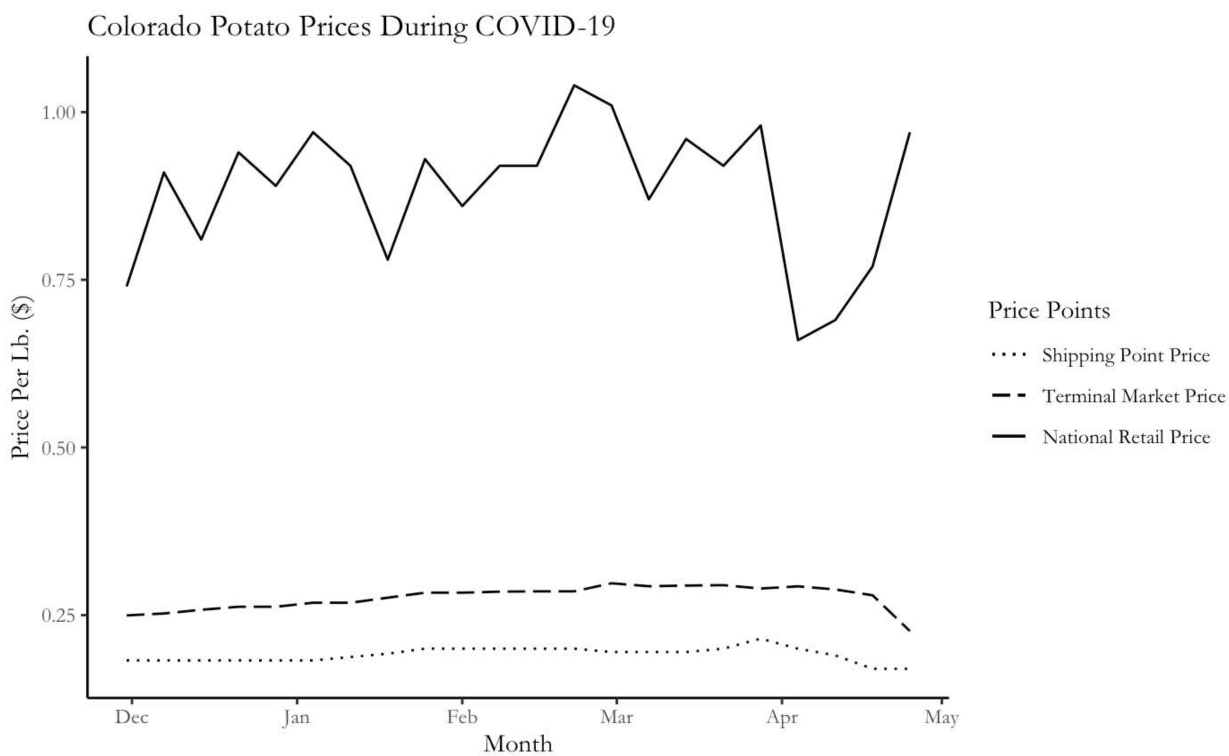


Figure 12. Farmgate, terminal market, and retail prices for potatoes Dec. 2019-April 2020 (USDA AMS, 2019)

Policy interventions to improve price transmission include government-funded efforts to strengthen relationships and communication between producers and institutional buyers in Colorado, such as public schools and city offices. These efforts are underway not only with potato producers, but with farmers in other commodity sectors, such as peaches, wheat, and beef (Jablonski et al., 2019). The Denver Food Vision, adopted by the City of Denver in October 2017, includes a 2030 "Winnable Goal" that 25% of all food purchased by public institutions in Denver will come from Colorado (Denver food vision, 2017). Local and state policies, such as the Denver Food Vision, that prioritize shortened and localized supply chains in institutional food procurement policies may allow producers to capture more of the proportion of the food dollar that they added value to by investing in quality improvements.

Similar national efforts are underway. Scaling up, the Good Food Purchasing Program (GFPP) is a nationwide certification program that aims to re-orient agri-supply chains towards local and regional purchasing behavior (Center for Good Food Purchasing, 2020). One specific pillar of their program is local economies. Recent work has found that urban food policies impact rural producers and the economic development of their communities, and this analysis contributes evidence of a specific mechanism (i.e., price transmission along supply chains) that policymakers can focus on to improve outcomes in rural and agricultural communities (Harrison et al., 2019; Jablonski et al., 2019). To explore how the market dynamics found here may inform analysis of such programs intended to support producers and their local economies, next we shift our attention to modeling the demand-side dynamics of Farm-to-School procurement.

# ESSAY II: FARM-TO-SCHOOL PROCUREMENT OPTIMIZATION

## Background

Community investment in local food systems produces economic (Andree, 2009; Blay-Palmer & Donald, 2006; Brown & Miller, 2008; Meter, 2008), social (Brown & Miller, 2008; Marsden, Flynn, et al., 2000), and environmental (Pretty et al., 2001; Pretty et al., 2005) benefits. King et al. (2010) find that local communities retain larger shares of wages, income, and farm revenues when farmers sell products through local supply chains versus mainstream channels. If schools purchase food from farmers or local businesses, such as food hubs, with strong economic ties to their local communities, a larger share of their food dollars are cycled back into their local economies relative to purchases made from large food distribution companies that may have a significant share of their employees, shareholders, and corporate offices (all of which capture some of the economic activity) in distant locales (Christensen et al., 2019; Gunter & Thilmany, 2012; Kluson, 2012; O'Hara & Pirog, 2013; Roche et al., 2015; Shideler et al., 2018; Tuck et al., 2010).

In this analysis we focus our attention on the economic benefits to local communities in which school districts are located. Work related to shortening and localizing food supply chains has shown that restructuring supply chains, such as through Farm-to-School programs, can increase the share of the food dollar that goes to the farmer or local food distribution business, thereby contributing to rural economic development (Hardesty et al., 2014; King et al., 2010; Low et al., 2015). We frame these community benefits due to local food purchases as a positive externality because their social benefits are not entirely reflected in their market cost, so they are generally under-provided (Fig. 13).

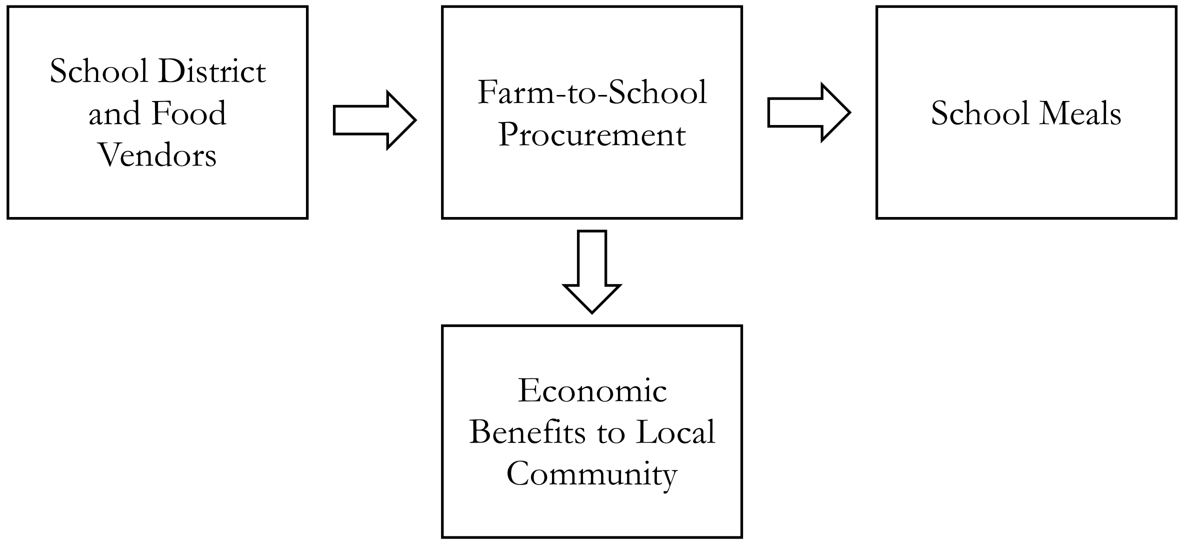


Figure 13. Local economic development is a potential positive externality of a Farm-to-School supply chain

To increase the buying dollars and potential impact of local and regional food marketing efforts, there has been increasing attention on large institutional buyers of local food, such as schools, hospitals, and municipal offices, as opposed to individual consumers. Schools provide 4.8 billion lunches annually to U.S. students (USDA FNS, 2020). Of the $6,859,584,955 that schools participating in Farm-to-School programs spent on all types of food during the 2013-14 school year, $302,469,758 (approximately 4%) was spent on local products (USDA FNS, 2015a). School nutrition programs are a reasonable proxy for institutional food procurement in general. The constraints that schools face in food purchasing are likely similar to those faced by hospitals, cities, and other large buyers who collectively have substantial purchasing power.

Programs such as the Good Food Purchasing Program (GFPP) aim to harness collective purchasing power and leverage it to make food and agriculture practices along the supply chain more ethical (Center for Good Food Purchasing, 2020). GFPP focuses on five tenets of ethical food production: local economies, nutrition, valued workforce, environmental sustainability, and animal welfare (Center for Good Food Purchasing, 2020). Programs such as GFPP can help institutions evaluate their current purchasing behavior according to a set of standards and set goals for future food procurement. As institutional procurement programs, such as GFPP, gain traction nationally, it is instructive to examine tradeoffs in purchasing decisions using Farm-to-School programs as a proxy for general institutional buying.

Farm-to-School was first funded at the federal level in 2010, with the Healthy Hunger-Free Kids Act, and includes three pillars of activities: local food procurement, agriculture or food education, and school gardens (Christensen et al., 2017; Ralston et al., 2017). The 2015 Farm-to-School Census, which surveyed school districts about their Farm-to-School activities during the 2013-14 school year, reported that 42% of all districts surveyed participate in Farm-to-School (Long, 2019; USDA FNS, 2015b). Of schools who participated, 77% participated in the procurement activity (Long, 2019; USDA FNS, 2015b); accordingly, procurement is the focus of this essay.

State and national policies geared toward supporting procurement formalize the goal of using federal National School Lunch Program (NSLP) dollars for the dual purpose of feeding children nutritious meals and supporting U.S. farmers and ranchers through new market opportunities (Feenstra & Ohmart, 2012; Low et al., 2015; Martinez, 2016). Conner et al. (2012); Izumi, Wright, and Hamm (2010); and Joshi et al. (2008) point out that sales to schools constitute a small portion of overall sales that farms make, indicating that other supply chain channels tend to be more lucrative for farmers. Conner et al. (2012) and Izumi, Wright, and Hamm (2010) agree that most farmers who participate in Farm-to-School are doing so for the risk mitigation through diversification, market opportunities for "seconds" or lower-grade produce, and community impact benefits, rather than purely for profit motives.

Challenges associated with Farm-to-School procurement have been documented (Table 6) and include availability, price and budget constraints, communication barriers, lack of supply chain infrastructure, and concerns about food safety (Long, 2019). We address price and budget, communication barriers, and lack of supply chain infrastructure in the optimization model of school food procurement below. After experimenting with availability constraints, we found that other factors were more limiting to Farm-to-School procurement, so we omitted availability constraints from the final version of the model. We do not address food safety concerns.

Table 6. Sources documenting Farm-to-School procurement barriers (Long, 2019)

| Barrier | Sources Documenting Barrier |
|---|---|
| **Availability** | (Boys & Fraser, 2019; David S. Conner et al., 2012; Gregoire & Strohbehn, 2002; Harris et al., 2012; Izumi et al., 2010; Motta & Sharma, 2016; Stokes, 2014; Thornburg, 2013) |
| **Price and budget constraints** | (Bateman et al., 2014; Conner et al., 2012; Harris et al., 2012; Izumi et al., 2010; Motta & Sharma, 2016) |
| **Communication barriers between Farm-to-School managers and producers** | (Harris et al., 2012) |
| **Lack of regional supply chain infrastructure** | (Bateman et al., 2014; Conner et al., 2012; Feenstra & Ohmart, 2012; Harris et al., 2012; Nurse et al., 2011; Stokes, 2014; Thornburg, 2013; Vogt & Kaiser, 2008) |
| **Concerns regarding local producers' food safety practices** | (Harris et al., 2012; Motta & Sharma, 2016; Thompson et al., 2017) |

Most state policies have focused on alleviating the price barrier to local food procurement, as local food is generally perceived to be more expensive than its traditionally sourced counterpart, and school food programs must pay careful attention to their costs (Donaher & Lynes, 2017; Fox & Gearan, 2019). But some advocates of local food procurement have turned their attention to the other structural, supply chain, and communication challenges of Farm-to-School. Recent work in Colorado has focused on the potential redistribution impacts of urban food policies on rural producers, since incomes and other economic indicators tend to be better in urban areas than in rural areas (Jablonski et al., 2019; Pender et al., 2019; United States Census Bureau, 2019).

In 2017 and 2018 twenty-three states passed legislation to encourage Farm-to-School procurement (National Farm to School Network & Center for Agriculture and Food Systems, 2019). Many state-level policies provide reimbursements to school districts if they participate in certain local purchasing behaviors. Colorado House Bill (CO HB) 19-1132, passed in May 2019, aims to increase returns to the state's farmers, strengthen local supply chains, and improve the quality of school lunches by authorizing a $500,000-capped reimbursement program for school district spending on Colorado-grown or -processed foods (CO HB 19-1132: School incentives to use Colorado food and producers, 2019). It effectively reduces the costs of Colorado-grown or -processed products for eligible school districts by providing a $0.05 per meal incentive. Policymakers intend for this bill to reduce cost barriers to school districts serving Colorado food products in their cafeterias.

As summarized previously, the Agriculture of the Middle policy group classified supply chain routes into three major categories: direct markets, intermediated markets, and commodity markets (Fig. 14). The categories can be distinguished by sales volume and value per unit of sales (Angelo et al., 2016). Direct markets are characterized by low volume and high value added, intermediated local markets are characterized by higher volume and high value added, and commodity markets are characterized by high volume and low value added. Our analysis is focused on wholesale volume business models on the right side of the classification scheme: farm direct wholesale to institutions, food hubs, or non-traditional distributors of local food, and traditional distributors. These categories echo the supply chain groups defined in Christensen et al. (2019). Different supply chain routes and community factors produce different types of externalities, and we draw from the local food literature to parameterize our optimization model to capture these differences.

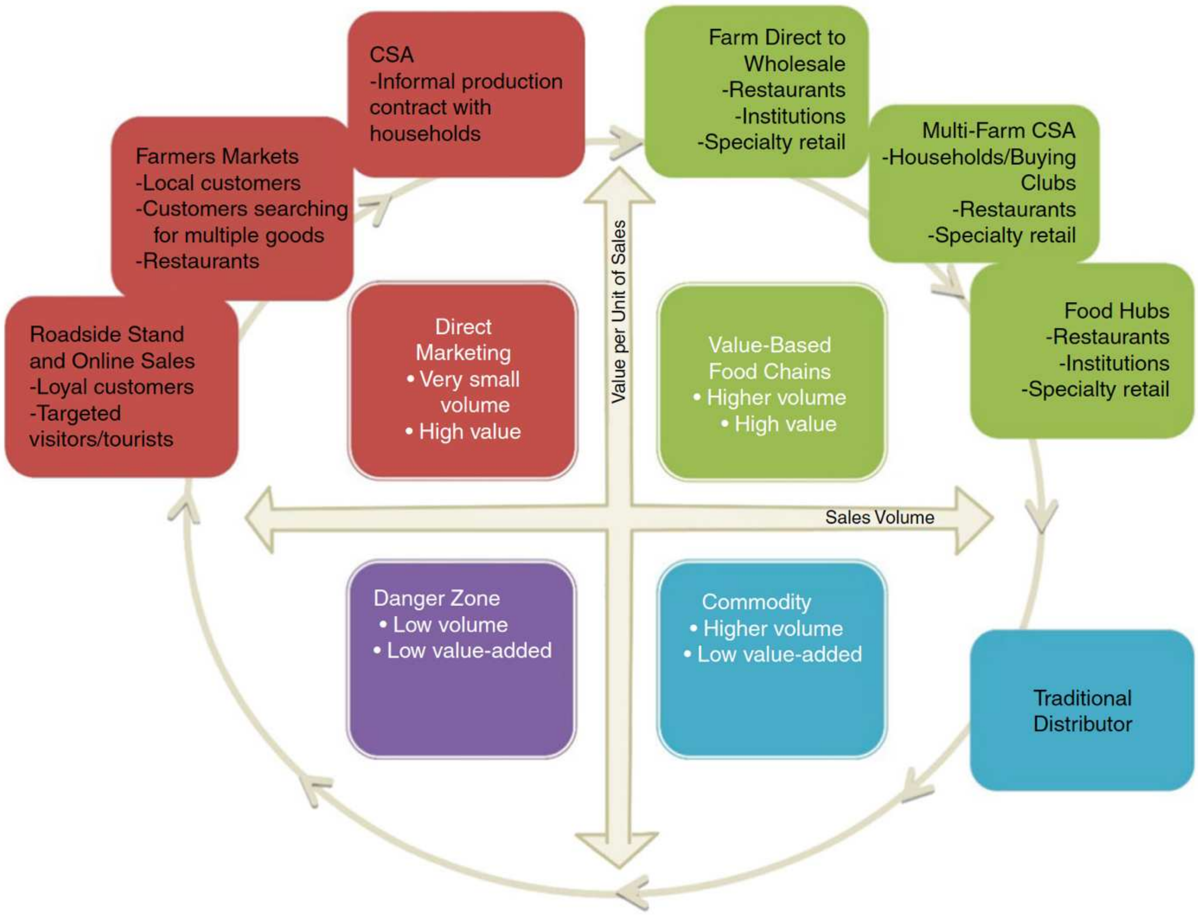


Figure 14. Local food business models (Angelo et al., 2016)

Formally, our research question is: what tradeoffs among food prices, other costs associated with Farm-to-School procurement, and the contribution to local economic development might school districts consider when optimizing their choice of food procurement supply chain routes? The primary contribution of this study is the development of an innovative conceptual optimization model that allows for a customizable, data-driven characterization of Farm-to-School procurement decisions, with a focus on supply chain route, that is informed by primary data and recent literature from various local food supply chain studies. As there are a number of economic and other factors that vary greatly across the different supply chain options that now exist, this study paid particular attention to integrating the best available empirical data from the literature, case studies, and primary data analysis to represent tradeoffs among factors that may drive school decisions (e.g., price, labor needs, social outcomes). Practitioners can re-parameterize and customize the model to reflect the conditions in their local school districts and run various scenarios that reflect potential policy impacts on school food purchasing behavior.

**Data**

The optimization model explores the Efficiency-Externality Tradeoff by characterizing heterogeneity amongst four common supply chain pathways in terms of positive externalities and efficiency in the form of cost savings. We structured the choice variables of the model based on conceptual models of supply chain routes laid out by Angelo et al. (2016) and Christensen et al. (2019). We compiled data to populate the model in a number of ways because of the diverse array of parameters and measures needed to characterize the factors integrated into the optimization model. We used total annual food expenditures by school districts and meal counts, obtained from the 2015 United States Department of Agriculture Food and Nutrition Service (USDA FNS) Farm-to-School Census and school district budgets. The Farm-to-School Census is an online survey completed by school food service directors, who self-reported data on their programs (USDA FNS, 2015b). Questions primarily addressed procurement with a secondary focus on educational activities. We also obtained data from published and industry sources on Farm-to-School procurement, supply chain pathways, food marketing and product variety, and local versus conventional food price premia. We used an annual Sysco shareholder report (Sysco, 2014), results of the Wallace Center and Michigan State University's Food Hub Benchmarking Survey (Colasanti et al., 2018), and Colorado State University Food Systems Team Market Channel Assessments (Jablonski et al., 2017) to compile information on supply chain cost structure, which allowed us to calculate objective function parameters (Colasanti et al., 2018; Jablonski et al., 2017; Sysco, 2014). To estimate a local price premium, the USDA AMS Custom Average Pricing Tool, which tracks farmgate price averages by commodities and product characteristics over specified time periods, and Iowa Farm-to-School records were used as reference points (Iowa Department of Education, 2020; USDA AMS, 2020a). We quantified relationships in the model constraints by consulting relevant studies from a wide variety of fields, which we introduce in greater detail in the next section.

## Empirical Model and Methods

We first introduce the complete optimization model and subsequently explain how we structured the model and arrived at parameter values for the objective function and constraints.

*School District Food Cost Minimization Model*

The formal statement of the optimization problem is:

$$\text{Minimize} \sum 2.52z_1+2.70z_2+2.09z_3+2.03z_4$$

w.r.t. z, s.t.

$$1z_1+1z_2+1z_3+1z_4 \geq 1{,}840{,}596 \text{ (Quantity)}$$

$$.16z_1+.16z_2+.14z_3+.14z_4 \leq .16*(1z_1+1z_2+1z_3+1z_4) \text{ (Labor: Food Prep)}$$

$$52.94z_1+30.73z_2+101.89z_3+101.89z_4 \geq 60*(1z_1+1z_2+1z_3+1z_4)$$
(Assortment Breadth)

$$4.75z_1+4.36z_2+4.00z_3+4.00z_4 \geq 4.0*(1z_1+1z_2+1z_3+1z_4) \text{ (Assortment Depth)}$$

$$1z_1+1z_2+1z_3 \geq .25*(1z_1+1z_2+1z_3+1z_4) \text{ (Intensity of Local)}$$

$$(1.6251*2.52)z_1+(1.6640*2.70)z_2+(1.4872*2.09)z_3+(1.4872*2.03)z_4 \geq 4.25*(1z_1+1z_2+1z_3+1z_4)$$
(Economic Impact)

$$.038z_1+.0418z_2+.087z_3+.087z_4 \leq .05*(1z_1+1z_2+1z_3+1z_4) \text{ (Price Risk)}$$

Once we linearized all constraints and simplified terms, we derived the following model, programmed in R and solved using the nonlinear optimizer "lpSolve," employing the simplex method. Next we walk through our process for structuring and parameterizing the model, paying particular detail to how the coefficients were arrived at using past literature, a variety of data sources, and extrapolation methods. The linearized model is:

$$\text{Minimize} \sum 2.52z_1+2.70z_2+2.09z_3+2.03z_4$$

w.r.t. z, s.t.

$$1z_1+ 1z_2+1z_3+1z_4\geq 1{,}840{,}596 \text{ (Quantity)}$$

$$-.02z_3-.02z_4\leq 0 \text{ (Labor: Food Prep)}$$

$$-7.06z_1- 29.27z_2+41.89z_3+41.89z_4\geq 0 \text{ (Assortment Breadth)}$$

$$.75z_1+ .36z_2\geq 0 \text{ (Assortment Depth)}$$

$$.75z_1+ .75z_2+.75z_3- .25z_4\geq 0 \text{ (Intensity of Local)}$$

$$-0.15z_1+0.17z_2 - 1.14z_3-1.23z_4\geq 0 \text{ (Economic Impact)}$$

$$-.012z_1- .0082z_2+.037z_3+.037z_4\leq 0 \text{ (Price Risk)}$$

*Objective Function Setup and Parameterization*

The school district's generic cost minimization objective function is:

$$\text{Minimize} \sum c_x z_x \quad \text{w.r.t. } z.$$

C is the cost per meal of purchasing from a supply chain pathway x, and z is the number of meals purchased through a supply chain pathway x. The choice variables are the supply chain pathways: Direct Local ($z_1$), Non-Traditional Local ($z_2$), Traditional Local ($z_3$), and Traditional Non-Local ($z_4$) (Fig. 15; Table 7). Choice variable pathways contain more specific vendor types as defined in the 2015 Farm-to-School Census. We defined the choice variable vendor groups to match the methodology of Christensen et al. (2019). The Direct Local category includes food purchased from food producers, farmers' markets, or CSAs. The Non-Traditional Local category includes purchases indirectly made from local farms and ranches by distribution relationships managed through food hubs, producer co-operatives, food buying co-operatives, and State Farm-to-School program offices.

The Traditional Local category includes purchases indirectly made from local farms and ranches through relationships managed by mainline distributors, processors/manufacturers, Department of Defense Program vendors, USDA Foods, and food service management companies. The Traditional Non-Local category includes the same group of vendors as the Traditional Local grouping, but this category of variables represents their non-local product offerings. These groups also loosely correspond to the Agriculture of the Middle policy group's classification scheme for local food business models (Fig. 14-15).

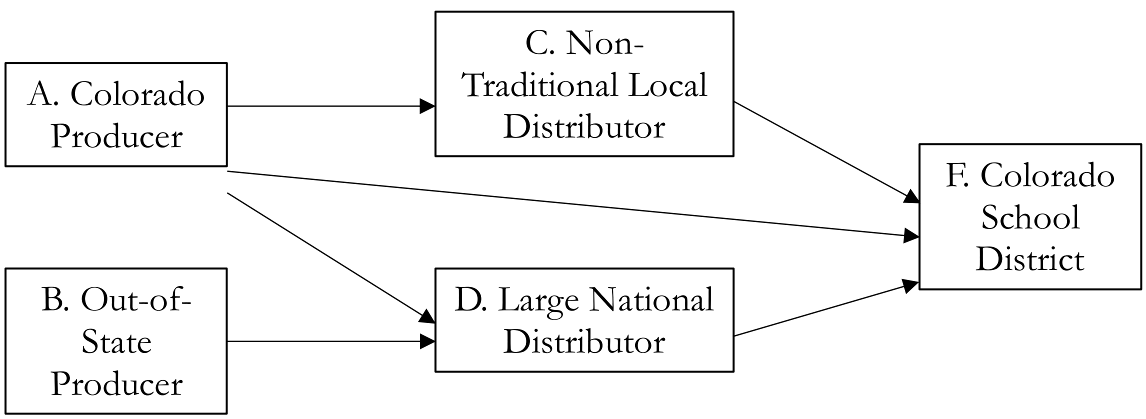


Figure 15. Choice variable supply chains for products purchased by Colorado school districts

Table 7. Supply chain pathways on choice variables

| **Choice Variable (Number of Meals)** | **Pathway Name** | **Supply Chain Pathway (From Fig. 15)** |
|---|---|---|
| $\mathbf{z_1}$ | Direct Local | A → F |
| $\mathbf{z_2}$ | Non-Traditional Local | A → C → F |
| $\mathbf{z_3}$ | Traditional Local | A → D → F |
| $\mathbf{z_4}$ | Traditional Non-Local | B → D → F |

The price that a school pays for food reflects several costs: a) the cost of the food product itself; b) transaction costs on the part of the producer related to marketing; c) food preparation; and

d) administrative labor/transaction costs on the part of the school related to procurement (Fox & Gearan, 2019; Motta & Sharma, 2016). We take costs a) and b) into account in objective function parameters for different supply chain routes as described below. We attempt to capture c) and d) with delineated labor constraints.

To begin we calculate a baseline average per meal spent on food costs by school districts that do not procure locally, essentially representing the "lowest common denominator" for school meals. We consulted the 2015 Farm-to-School Census to find names of schools that did not participate in any Farm-to-School activity in the 2013-14 school year. To capture some variety amongst Colorado's 178 school districts (Colorado Department of Education, 2020a), we chose the first five Colorado school districts alphabetically that did not participate in Farm-to-School activities: Agate 300, Aguilar Reorganized 6, Akron R-1, Archuleta Co. 50 JT, and Ault-Highland RE-9 (USDA FNS, 2015b). These school districts tended to be smaller and more rural than many other districts in Colorado, so they are not representative of the state's districts as a whole.

We consulted publicly available school budgets and Colorado Department of Education meal count records to calculate an average food cost per meal for each of the five districts (Table 8; Agate School District, 2016; Aguilar Reorganized 6 School District, 2017; Akron R-1 School District, 2018; Archuleta Co. 50 JT School District, 2016; Ault-Highland RE-9 School District, 2015; Colorado Department of Education, 2020b). Different budget years were available from school websites, so we chose the fiscal year closest to the 2013-14 school year, since that is the data year for the Farm-to-School Census that was used to estimate other factors in the model. We carefully matched meal count records with the year we pulled school food expenditures from budgets. We saw that school districts likely benefit from economies of scale in lunch production costs because school districts with more students tended to have lower average meal costs. We chose the median value of the five average meal costs we calculated (from Aguilar Reorganized 6) to be our baseline meal cost: \$2.03. We used this number to parameterize the Traditional Non-Local ($z_4$) supply chain route in the objective function.

Since the five sample districts we chose tended to be smaller and more rural, and we observed a trend of smaller districts having higher average meal costs, the actual baseline price for all Colorado school districts is likely lower than \$2.03 per meal. The literature also suggests that the \$2.03 baseline value may be slightly high, as that value is slightly higher than the range of \$1.17 to \$1.38 calculated by Newman (2012) in her documentation of an ERS analysis of 2005 meal cost data from 400 schools nationally. Practitioners using the model could parameterize the objective function with a baseline meal price number that is more tailored to the school district or group of districts of interest to them.

Table 8. Data used in cost per meal calculations for five Colorado school districts (Agate School District, 2016; Aguilar Reorganized 6 School District, 2017; Akron R-1 School District, 2018; Archuleta Co. 50 JT School District, 2016; Ault-Highland RE-9 School District, 2015; Colorado Department of Education, 2020b)

| District | Data Year | School Food Expenditures | Meal Count | Cost per Meal |
|---|---|---|---|---|
| **Agate 300** | 2015-16 | \$6,055 | 1355 | \$4.47 |
| **Aguilar Reorganized 6** | 2016-17 | \$41,000 | 20,200 | \$2.03 |
| **Akron R-1** | 2017-18 | \$112,291 | 49,976 | \$2.25 |
| **Archuleta Co. 50 JT** | 2015-16 | \$268,420 | 154,105 | \$1.74 |
| **Ault-Highland RE-9** | 2014-15 | \$188,668 | 115,107 | \$1.64 |

A few reasons for this difference in cost could be regional price variation, meal counting practices (more meals may be prepared and paid for than are "counted" as being served), inclusion of "other food service supplies" in the school food budget line, and low economies of scale in the subsample of Colorado school districts we chose. The meal count number reflects only the actual meals served to students and does not reflect extra meals prepared by the school that were never consumed due to absences or lower meal program participation rates than expected. Likely, the "real" cost per meal is slightly lower than $2.03 because districts cannot "count" all the meals they prepare, so the meals they do count absorb the cost of the "extra" meals. School districts only receive federal meal reimbursements for meals served to students, so it is in the best interest of schools to minimize the number of "extra" meals prepared. Another reason the cost per meal we calculated might be higher than Newman's (2012) values is that the school budgets we consulted often lumped "other food service supplies" in with food costs. "Other food service supplies" may include cooking and eating utensils and appliances used in food service, as well as cafeteria and kitchen cleaning supplies. Even if the average meal cost in our model is slightly higher than average, the absolute value of the baseline meal matters less when we consider that the other supply chain route parameters were based on relative levels above this baseline. Future researchers could adapt the model to different baseline meal prices and carry that change through to the other objective function parameters.

Using $2.03 as a baseline cost for meals procured from the Traditional Non-Local supply chain route, we altered this figure for each choice variable based on information compiled about profit margins of supply chain routes from a variety of sources (Table 11). Ideally, we would have information about three categories of finances that constitute total sales for each supply chain route: cost of goods, operating expenses, and profit. However, in reports we consulted, the profit and operating expenses figures were aggregated (Colasanti et al., 2018; Jablonski et al., 2017; Sysco, 2014). Therefore, we aggregated those two categories in our parameter calculations. While information availability on different supply chain routes limited our ability to precisely estimate parameters, we still provide approximations of relative meal costs based on information that was available. We found it encouraging that several sources corroborated the calculations on margins for various supply chain routes that we performed, which we describe next (Draganska & Jain, 2005; Hansen, 2003; Plakias et al., 2020).

More than 15,000 companies are involved in foodservice distribution in the U.S. (Sysco, 2014). Sysco is a publicly traded company that served approximately 17.4% of the foodservice market in the U.S. and Canada in 2013, making it one of the largest broadline food distribution companies in the country. In its Annual Shareholders' Report from fiscal year 2014, Sysco emphasized a business strategy of supply chain consolidation and centralization. It pointed to customer relationships, product variety, prices, reliability, and punctuality as the most important factors for successful food distribution. These features of its business model make it a good proxy for a broadline distributor participating in the Traditional Non-Local ($z_4$) and, since its customers have demanded more local products, Traditional Local ($z_3$) supply chain routes. We used information from the Shareholders' Report to parameterize the traditional supply chain routes ($z_3$ and $z_4$) in our optimization model. We consulted the fiscal year 2014 report, so the data would be from the same year as the 2015 Farm-to-School Census data. We broke the baseline price of $2.03 down into the profit/operating expenses and cost of goods categories for the Traditional Non-Local supply chain route ($z_4$). Sysco's total sales in that year were $46,516,712, the cost of those goods was $38,335,677, and the gross profit (including operating expenses) was $8,181,035. Eighty-three percent of total sales was paid by Sysco to acquire the product, leaving 17% to cover profit and operating expenses, a number which we used as a proxy for marketing and distribution costs.

We calculated a 33% premium for local food versus conventionally procured food using the Iowa Farm-to-School report (Appendix A). When parameterizing the model, we chose Colorado data when available and, otherwise, national data or data from another state. For the local food premium data, we chose Iowa because their Farm-to-School program archives detailed purchasing reports, including volume and price data, online and because they serve a variety of local products in different meal component categories (Iowa Department of Education, 2020). Because Iowa school districts used a food hub to procure their local food (Thilmany, 2020), the 33% premium we calculated represents the $0.67 difference in cost between the Traditional Non-Local route ($z_4$) at $2.03 per meal and the Non-Traditional Local route ($z_2$), which includes food hubs as distributors, at $2.70 per meal (Fig. 16).

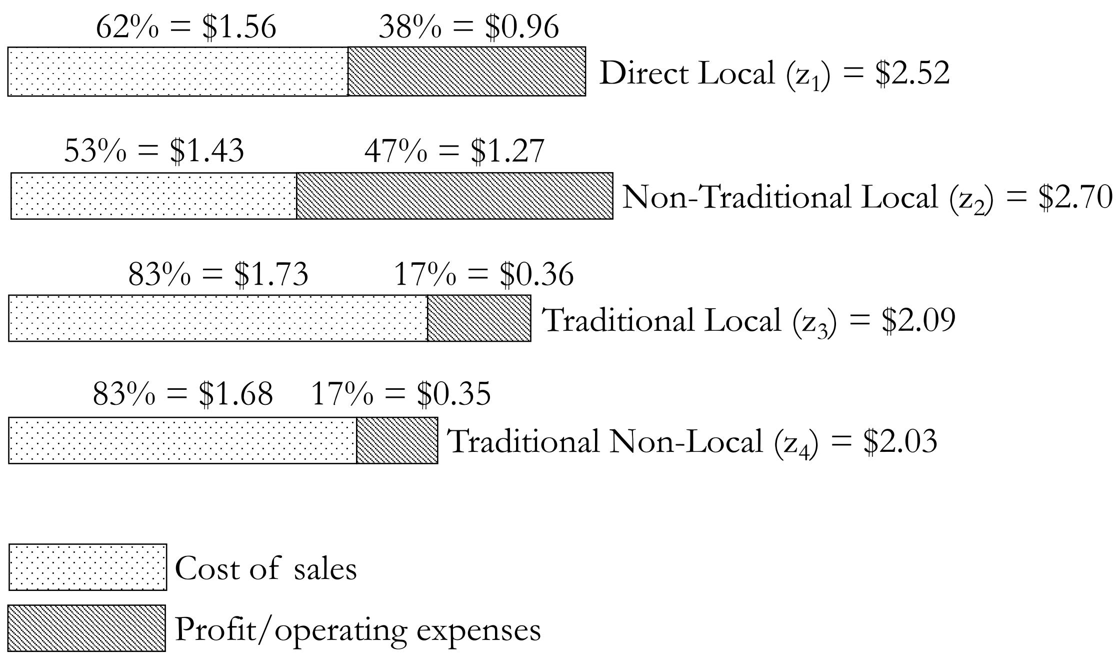


Figure 16. Cost structure breakdown for each supply chain route with baseline objective function parameter values

We assumed that 33% premium was partially due to increase in the cost of the product paid by the distributor to the farmer and partially due to increased profit/operating expenses. Choosing how to distribute the 33% percent premium into profit/operating expenses and cost of goods was an important step to appropriately estimate the meal costs for the remaining supply chain routes ($z_1$ and $z_3$). Food hubs attribute approximately 47% of their total sales to profit and operating expenses, compared to 17% for large traditional distributors (Fig. 16; Colasanti et al., 2018). The difference of 30% represents a portion of the 33% premium difference between these two supply chain routes.

The remaining 3% of the 33% premium (remaining after the estimated profit/operating expenses difference was subtracted), was attributed to the difference in cost of goods, meaning the difference in the price paid to the farmer for the local product over the conventional product. If we calculated the proportion of the $0.67 premium that goes to each type of expense, we observed that $0.61 goes to operating expenses/profit (which is relatively higher than mainline distributors by our estimate) and $0.06 goes to the cost of goods, or a premium on the farmgate price (thereby providing some of the potential local benefit to the community).

To calculate the meal cost for the Traditional Local supply chain route ($z_3$), we assumed the farmer expects the same absolute price premium per meal for a local product as if they were selling through a food hub ($0.06), but that the traditional supplier is able to market and distribute more efficiently, eliminating the portion of the price difference between $z_2$ and $z_4$ that went to operating expenses/profit. Summing the baseline Traditional Non-Local meal cost of $2.03 and the local farmgate premium of $0.06 gave the traditional local meal cost of $2.09. While we would ideally have information on the breakdown of profits versus operating expenses, we did not have this level of granularity in our data for all supply chain routes, but past studies and industry data allowed for realistic estimates to inform the model.

The final meal cost parameter we needed to calculate related to the Direct Local supply chain route ($z_1$). In previous research sponsored by the USDA AMS, the Market Channel Assessment Study conducted by the Colorado State University Food Systems Team found that, for farmers selling to "other" types of institutions (which includes schools), approximately 62% of the cost of the food goes to costs of production up through harvest, while the remaining 38% constitutes marketing, distribution, and operating expenses, as well as profits (Jablonski et al., 2017). This figure is within the range of 13-62% for marketing costs of farms selling direct to consumers documented by King et al. (2010) in the 15 case studies that formed the basis for their supply chain report. We performed the same calculation that we did for the Non-Traditional Local supply chain route, subtracting the 17% profit/operating costs margin of the large national distributor from the 38% margin for the local producer selling directly. That 21% difference was added to the local product farmgate price premium of 3% for a total of a 24% premium captured by the farmer using this supply chain route. Using the Traditional Non-Local distributor baseline price of $2.03, we added the 24% premium for a final meal price of $2.52 for the Direct Local supply chain route ($z_1$). A summary of the objective function parameters can be found below (Table 9).

Table 9. Objective function parameters

| Choice Variable | Pathway Name | Objective Function Cost Parameter |
|---|---|---|
| $z_1$ | Direct Local | $2.52 |
| $z_2$ | Non-Traditional Local | $2.70 |
| $z_3$ | Traditional Local | $2.09 |
| $z_4$ | Non-Local | $2.03 |

*Constraint Setup and Parameterization*

Once we established estimates for costs to schools of meals purchased through various supply chain routes, we turned our attention to constraining the objective function appropriately to answer our research question. Based on a literature review of factors school districts consider when procuring food, we chose to incorporate the following constraints into our model: quantity, labor, assortment breadth, assortment depth, intensity of local procurement, economic impact, and price risk (Carpenter & Moore, 2006; Chiang & Wilcox, 1997; D. Conner et al., 2012; Feenstra & Ohmart, 2012; Gordon et al., 2007; Denver food vision, 2017; Izumi et al., 2010; Meyer & Conklin, 1998; Motta & Sharma, 2016; Newman, 2012; Woodward-Lopez et al., 2014). We classified the quantity, labor, assortment breadth, and assortment depth as baseline constraints. We classified the intensity of local procurement, economic impact, and price risk as policy constraints. With the exception of the quantity constraint, we chose right-hand side constraining values so the baseline constraints would not bind. We did this for two reasons. First, we wanted to clearly see the impact of every policy constraint when we turned it on. Second, reliable numbers for right-hand side constraint bounds were difficult to find, so we did not want to place too much emphasis on them when interpreting model output. We detail theoretical underpinning and parameterization of each constraint below.

There are some factors we did not explicitly include in the model with individual constraints whose importance we still want to acknowledge: budget, assortment cost, seasonality, kitchen equipment, food quality, and communication along the supply chain. We consider each of these factors and explain why we omitted them when we discuss model limitations below.

The quantity constraint forces the school district in the model to purchase a minimum number of meals. Because the model is cost minimizing, a quantity-unconstrained model would purchase zero meals. Schools participating in the National School Lunch and Breakfast Programs must maintain daily meal count records to claim a reimbursement from the federal government. We used this meal count number, aggregated to the annual level, to parameterize the quantity constraint. The annual meal count for any school district could be used to minimally constrain the total number of meals sourced from all four supply chain routes. We chose to use the nearby Poudre Valley School District's meal count for the 2013-14 school year in our sample model: 1,840,596 meals (Colorado Department of Education, 2020b; USDA FNS, 2015b). The final quantity constraint is:

$$1z_1 + 1z_2 + 1z_3 + 1z_4 \geq 1{,}840{,}596.$$

The labor constraint captures the differences in preparation time among supply chain routes. To a lesser degree, it could also be a proxy for administrative labor, or transaction costs, associated with local procurement. Preparing raw ingredients requires more staff time than warming pre-processed batches of food does. Most farms and some statewide food distributors of local products sell raw ingredients that need additional labor and equipment inputs in order to meet meal pattern requirements. Woodward-Lopez et al. (2014) used regression analysis to find the relationship between scratch cooking and labor costs in a school food context. The authors used a convenience sample of ten California school districts and included 146 meals from October 2010 in their analysis, gleaning data from school food service records and interviews with staff. They varied levels of scratch cooking, geographic location, and student body sociodemographic factors within their sample. They classified cooking into four categories: convenience, minimal, almost scratch, and scratch. Only the scratch category was statistically significantly different from the reference category of convenience cooking for labor costs. The authors found that on average scratch cooking cost $0.02 per meal more than the base labor cost of $0.14 per meal for the convenience cooking category, all else constant (p-value = .035). Based on this study, we assumed that the two more specialized local routes ($z_1$ and $z_2$) cost $0.02 more in labor costs than the two traditional supply chain routes ($z_3$ and $z_4$). The labor constraint is:

$$0.16z_1 + 0.16z_2 + 0.14z_3 + 0.14z_4 \leq 0.16 * (1z_1 + 1z_2 + 1z_3 + 1z_4).$$

Linearized, it becomes:

$$-0.02z_3 - 0.02z_4 \leq 0.$$

School meals must include five meal components: vegetable, fruit, grain, meat/meat alternative, and milk (USDA FNS, 2020). Students are more satisfied with lunch service when meals are palatable, culturally appropriate, and contain a variety of ingredients (Meyer, 2000; Meyer & Conklin, 1998). If participation rates are high, then schools can achieve economies of scale and reduce their per meal cost of production. It is thus in the financial interest of school districts to procure a large assortment of ingredients to keep students interested in their menus (Conner et al., 2012; Ralston et al., 2017). The assortment breadth constraint captures the costs to schools associated with product variety available from different distributor types. Larger broadline distributors generally carry a larger set of product lines than small distributors, and schools have fewer transaction costs by procuring from a distributor who can provide all the ingredients they need for their menu. It is also more expensive for distributors to carry such large product varieties, and we assumed that these additional costs are already reflected in the costs charged to schools.

To capture assortment breadth Chiang and Wilcox (1997) used regression analysis to establish a relationship between profit margin and product assortment in a food retail context: product variety = 141.52 – 233.1% * profit margin. Indianapolis-based grocery retailer Marsh Supermarkets provided number of SKUs carried and retail margin data on 231 categories of common grocery items (Chiang & Wilcox, 1997). We used the Chiang and Wilcox (1997) regression to calculate product variety for the supply chain routes in our model based on their gross profit margins, which we had already calculated while parameterizing the objective function. The final assortment breadth constraint is:

$$52.94z_1 + 30.73z_2 + 101.89z_3 + 101.89z_4 \geq 60 * (1z_1 + 1z_2 + 1z_3 + 1z_4).$$

Linearized, it becomes:

$$-7.06z_1 - 29.27z_2 + 41.89z_3 + 41.89z_4 \geq 0.$$

Although not a common term used in local and direct produce marketing, we integrated an assortment depth constraint to capture the availability of differentiated or niche products that specialized distributors, such as food hubs or farmers, sell and that are not otherwise available from mainline distributors. These products might have special properties, such as being produced locally, that are inherent to geography or production processes (Belletti et al., 2017). The right-hand side of the constraint could be changed to reflect a school district's higher or lower preferences for specialty or local products that are only available from certain types of distributors.

Carpenter and Moore (2006) found in a survey of 454 grocery consumers, randomly selected at the national level, that they ranked the importance of "product selection" as 4.00 (out of 5) for supermarkets and 4.36 for specialty food stores. The higher ranking for specialty stores indicates that those stores carry products that garner special attention from consumers, which is a primary reason for shopping there. Certain institutional buyers, such as schools, may also seek out products with certain characteristics (such as being produced locally) that can only be purchased from certain distributors. We used the Carpenter and Moore study to approximate the relative ability of different distributors to provide products with special characteristics. We used the 9% difference in the ranking of the product assortment characteristic between supermarkets and specialty food stores as the basis for the assortment depth constraint parameter for the $z_2$, $z_3$, and $z_4$ supply chain routes. We added an additional 9% of assortment depth to the $z_1$ parameter. The final assortment depth constraint is:

$$4.75z_1 + 4.36z_2 + 4.00z_3 + 4.00z_4 \geq 4.0 * (1z_1 + 1z_2 + 1z_3 + 1z_4).$$

Linearized, it becomes:

$$0.75z_1 + 0.36z_2 \geq 0.$$

The intensity of local procurement activity constraint is meant to represent a policy lever whereby school districts commit to purchasing a certain portion of their food from local sources. As an example, in its Food Vision, the City of Denver committed to a goal of 25% local food procurement by the year 2030 (Denver food vision, 2017). We based the intensity of local constraint parameter on this policy, although the constraint could be tailored to any percent local procurement policy under consideration. The intensity of local procurement activity constraint is:

$$1z_1 + 1z_2 + 1z_3 \geq 0.25 * (1z_1 + 1z_2 + 1z_3 + 1z_4).$$

Linearized, it becomes:

$$0.75z_1 + 0.75z_2 + 0.75z_3 - 0.25z_4 \geq 0.$$

The economic impact constraint consists of economic impact multipliers for different supply chain routes. These multipliers capture economic impacts to local economies from the local food sector versus the traditional wholesale sector. The Direct Local and Non-Traditional Local parameters came from customized local food sector multiplier calculations created using IMPLAN data and customized to reflect local food sector activity using USDA Agricultural Resource Management Survey data from 2013-16 (Table 10; Thilmany & Watson, 2019). The multi-county designation was the appropriate geographical scope to use for these multipliers because Farm-to-School transactions often take place across county lines. The "both direct and intermediated" multiplier is most appropriate among the categories (that also included "direct only" or "intermediated only") for the Direct Local supply chain route because farmers who sell to institutions, such as schools, are likely to have large and complex enough operations to sell both through both direct and intermediated market channels. The "intermediated" multiplier is most appropriate for the Non-Traditional Local supply chain route because farmers are selling their products through another entity (e.g., food hub, co-op) in this marketing channel.

The Traditional Local and Non-Local parameters came from 2016 IMPLAN data for the San Luis Valley, CO wholesale trade sector, which was the NAICS sector that most closely aligned with a large food distributor's economic activities. Saguache, Alamosa, Rio Grande, Conejos, Costilla, and Mineral Counties were included in the multi-county San Luis Valley region. The custom local food multipliers and IMPLAN multipliers are all calculated based on multi-county regions in rural and rural-adjacent areas, so there is some parallelism to the regions represented in this constraint. We multiplied each supply chain route's impact multiplier by the cost per meal for that route, which gave us 4.10 for $z_1$, 4.42 for $z_2$, 3.11 for $z_3$, and 3.02 for $z_4$. We constrained the model to a minimum average economic impact per meal of 4.25, although this is a policy lever that could be shifted to align with the values of the institutional buyer. The economic impact constraint is:

$$(1.6251*2.52)z_1+(1.6640*2.70)z_2+(1.4872*2.09)z_3+(1.4872*2.03)z_4 \geq 4.25 * (1z_1+1z_2+1z_3+1z_4).$$

Linearized, it becomes:

$$-0.15z_1+0.17z_2 - 1.14z_3-1.23z_4 \geq 0.$$

Table 10. Customized local food sector economic impact multipliers (Thilmany & Watson, 2019)

| Region | Direct to Consumer | Intermediated | Both |
|---|---|---|---|
| **Multi-State Region** | 1.916768825 | 1.949214039 | 1.961292487 |
| **California** | 2.18370675 | 2.05918918 | 2.064115674 |
| **Other State** | 1.704166853 | 1.728002754 | 1.707632 |
| **Multi-County Region** | 1.618976018 | **1.663989417** | **1.625148312** |
| **Urban County** | 1.55036016 | 1.603028403 | 1.581933873 |
| **Medium County** | 1.527742248 | 1.603711792 | 1.585209978 |
| **Rural County** | 1.416288912 | 1.494052366 | 1.476183282 |

Note: *Multipliers used in the optimization model are bolded.*

The price risk constraint captures differences in price volatility faced by producers among different supply chain routes. We pulled standard deviations of farm gate and terminal market shipping point prices from the analysis of potato markets in essay I to more generally represent price risk at different levels of the supply chain (with shorter, local chains being exposed to less risk). If farmers sell through a more price-volatile market channel, the prices they receive at the farmgate are likely less reliable and their risk increases; and similarly, school districts would face the same price volatility as buyers in these markets. The farm gate price standard deviation was 0.038, which corresponds to the $z_1$ route, and the terminal market price standard deviation was 0.087, which corresponds to the $z_3$ and $z_4$ routes. We added an additional 10% price risk to $z_2$ as compared to $z_1$ to represent that due to the bidding and contract nature of schools' relationships with individual producers, farmers would likely face less price risk through that route than they would if selling through an intermediary. We set the right-hand side constraint value to be 0.05, although this could be shifted. The price risk constraint is:

$$0.038z_1 + 0.0418z_2 + 0.087z_3 + 0.087z_4 \leq 0.05*(1z_1 + 1z_2 + 1z_3 + 1z_4).$$

Linearized, it becomes:

$$-0.012z_1 - 0.0082z_2 + 0.037z_3 + 0.037z_4 \leq 0.$$

The final parameters are summarized below (Table 11). Ge et al. (Ge et al., 2015, 2016) used a similar methodology of compiling relevant conceptual framing and parameters from the literature, calculating, and assuming parameters for optimization models. We followed their example of compiling values, information about methodology, and data sources for all parameters for the reader (Table 11).

Table 11. Parameter names, values, data sources, and methodology

| **Parameter Variable** | **Value *(z1; z2; z3; z4; constraint)*** | **Methodology** | **Data Source** | **Geographic Area of Data** |
|---|---|---|---|---|
| **Objective Function Cost** | 2.52; 2.70; 2.09; 2.03 | Calculated from literature | (Colasanti et al., 2018; Iowa Department of Education, 2020; Jablonski et al., 2017; Sysco, 2014; USDA AMS, 2019) | National; Iowa; Colorado, National, National |
| **Quantity** | 1; 1; 1; 1; 1,840,596 | Assumed from literature | (Colorado Department of Education, 2020b) | Poudre Valley School District |
| **Labor** | -0.02; -0.02; 0; 0; 0 | Assumed from literature | (Woodward-Lopez et al., 2014) | California school districts |
| **Assortment Breadth** | -7.06; -29.27; 41.89; 41.89; 0 | Calculated from literature | (Chiang & Wilcox, 1997) | Indianapolis-based retailer |
| **Assortment Depth** | 0.75; 0.46; 0; 0; 0 | Calculated from literature | (Carpenter & Moore, 2006) | National |
| **Local Intensity** | 0.75; 0.75; 0.75; -0.25; 0 | Assumed from policy | (Denver food vision, 2017) | Denver, Colorado |
| **Economic Impact** | -0.15; 0.17; -1.14; -1.23; 0 | Calculated for Local Food Impact Calculator from USDA ARMS and IMPLAN data | (Thilmany & Watson, 2019) | Colorado multi-county; Colorado multi-county; National; National |

| | | | | |
|---|---|---|---|---|
| **Price risk** | -0.012; -0.0082; 0.037; 0.037; 0 | Calculated | (USDA AMS, 2019) | Colorado |

We ran the model under several scenarios to see how various policy levers would impact Farm-to-School procurement behavior. Most of the scenarios consisted of turning on various policy lever constraints (Table 12). For the first scenario, Business as Usual (BAU), we included no policy constraints. In the second, CO HB 19-1132, we modeled purchasing behavior under a $0.05 per meal reimbursement for local purchasing behavior, such as that authorized in a recent policy instituted in Colorado in May 2019, CO HB 19-1132. Under this scenario we lowered the objective parameters by $0.05 per meal for $z_1$, $z_2$, and $z_3$. We based the third scenario, 25% Local, on the Denver Food Vision 2030 winnable goal, in which at least 25% of all meals purchased had to come from $z_1$, $z_2$, or $z_3$. For this scenario, we returned the objective function parameters to their original values and turned on the intensity of local constraints. For the fourth scenario, High Economic Impact, we turned off the intensity of local constraint and turned on the economic impact constraint. In the Low-Price Risk scenario, we turned off the intensity of local and economic impact constraints and turned on the price risk constraint. For the final Combo scenario, we combined all seven constraints, four baseline constraints and the three policy level constraints, along with the original objective function parameters the see the impact of a bundle of policies on school purchasing.

Table 12. Constraint combinations for various scenarios

| Scenario | Quantity | Labor | Assortment Breadth | Assortment Depth | Local Intensity | Economic Impact | Price Risk |
|---|---|---|---|---|---|---|---|
| **BAU** | On | On | On | On | Off | Off | Off |
| **CO HB 19-1132** | On | On | On | On | Off | Off | Off |
| **25% Local** | On | On | On | On | On | Off | Off |
| **High Econ. Imp.** | On | On | On | On | Off | On | Off |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Low Price Risk** | On | On | On | On | Off | Off | On |
| **Combo** | On | On | On | On | On | On | On |

Note: *The scenarios are Business as Usual (baseline objective function parameter values, no policy constraints), CO HB 19-1132 (objective function parameter values lowered by $0.05 each, no policy constraints), 25% Local (baseline objective function parameter values, policy constraint: school districts are required to purchase 25% of their meals from a local source), High Economic Impact (baseline objective function parameter values, policy constraint: school districts are required to achieve an average per meal level of economic impact), Low Price Risk (baseline objective function parameter values, policy constraint: school districts are required to purchase in a way that achieves a per meal level of price volatility for farmers), and Combo (baseline objective function parameter values, all policy constraints from previous three scenarios are in effect).*

*Sensitivity Analysis*

We conducted a sensitivity analysis on the objective function parameters because there was some uncertainty about their parameterization. We varied the objective function parameters one at a time from 50% of their baseline values to 50% in excess of their baseline values. Notably, we also had to change the appropriate economic impact constraint parameter when that policy was enacted during a scenario because the constraint was partially based on the price per meal. We then observed changes in model solution and duals and reported the range of choice variable, constraint dual, and activity dual values for each scenario.

**Results**

Results are summarized below (Tables 13-15). Under the BAU scenario, the school district purchased all of its meals through the most cost-effective Traditional Non-Local route (Table 13). It is interesting to note that the $0.05 per meal credit was not enough to change its purchasing behavior in the CO HB 19-1132 scenario, and it still purchased all its meals through the Traditional Non-Local route. Under the 25% Local scenario, the district purchased 25% of its meals through the most cost-effective local route, the Traditional Local route, and the remaining 75% of its meals through the Traditional Non-Local route. Under the High Economic Impact scenario, the school district purchased 47% of its meals through the Non-Traditional Local route, which has the highest economic impact per meal. It purchased the remaining 53% through the Direct Local route, which has a slightly lower economic impact per meal and also a lower cost. Under the Low-Price Risk scenario, the school district purchased 76% of its meals through the Direct Local route, which was the most cost-effective route of the two routes that had a lower price risk, Direct Local and Non-Traditional Local. It purchased the remaining 24% of its meals through the Traditional Non-Local route. The Combo scenario showed that the most binding constraint was the economic impact constraint. The school district's purchasing behavior in the Combo scenario was identical to that under the High Economic Impact scenario. It is worth noting that all three policy levers pushed the school district to purchase through a different combination of local supply chain routes. So, policy levers can make a difference, but we can also consider the implicit "cost" of such choices.

Table 13. Supply chain route purchasing decisions under various scenarios

| Scenario | $z_1$ Meals Purchased (% of Total) | $z_2$ Meals Purchased (% of Total) | $z_3$ Meals Purchased (% of Total) | $z_4$ Meals Purchased (% of Total) |
|---|---|---|---|---|
| **BAU** | 0 (0%) | 0 (0%) | 0 (0%) | 1,840,596 (100%) |
| **CO HB 19-1132** | 0 (0%) | 0 (0%) | 0 (0%) | 1,840,596 (100%) |
| **25% Local** | 0 (0%) | 0 (0%) | 460,149 (25%) | 1,380,447 (75%) |
| **High Econ. Imp.** | 977,816.6 (53%) | 862,779.4 (47%) | 0 (0%) | 0 (0%) |
| **Low Price Risk** | 1,389,837.8 (76%) | 0 (0%) | 0 (0%) | 450,758.2 (24%) |
| **Combo** | 977,816.6 (53%) | 862,779.4 (47%) | 0 (0%) | 0 (0%) |

Note: *The scenarios are Business as Usual (baseline objective function parameter values, no policy constraints), CO HB 19-1132 (objective function parameter values lowered by $0.05 each, no policy constraints), 25% Local (baseline objective function parameter values, policy constraint: school districts are required to purchase 25% of their meals from a local source), High Economic Impact (baseline objective function parameter values, policy constraint: school districts are required to achieve an average per meal level of economic impact), Low Price Risk (baseline objective function parameter values, policy constraint: school districts are required to purchase in a way that achieves a per meal level of price volatility for farmers), and Combo (baseline objective function parameter values, all policy constraints from previous three scenarios are in effect).*

The shadow values of constraints represent the cost to school districts of participating in certain optimization-constraining behaviors, such as procurement policies (Table 14). Technically, the shadow value shows the change in value of the objective function if the right-hand side constraint value is increased by one. The way we have set up the constraints, a one-unit increase in the constraint value does not necessarily correspond to a one-unit increase or decrease in meals served, so it is difficult to interpret shadow values in terms of marginal effects of a single meal. But the shadow values do show us the relative expenses of certain policy measures: 25% Local was the most affordable, followed by Low Price Risk, and High Economic Impact.

Table 14. Shadow values ($) for constraints under various scenarios

| Scenario | Quantity | Labor | Assortment Breadth | Assortment Depth | Local Intensity | Economic Impact | Price Risk |
|---|---|---|---|---|---|---|---|
| **BAU** | 2.03 | 0 | 0 | 0 | n/a | n/a | n/a |
| **CO HB 19-1132** | 2.03 | 0 | 0 | 0 | n/a | n/a | n/a |
| **25% Local** | 2.045 | 0 | 0 | 0 | 0.060 | n/a | n/a |
| **High Econ. Imp.** | 2.60 | 0 | 0 | 0 | n/a | 0.56 | n/a |
| **Low Price Risk** | 2.40 | 0 | 0 | 0 | n/a | n/a | -10.00 |
| **Combo** | 2.60 | 0 | 0 | 0 | 0 | 0.56 | 0 |

Note: *The scenarios are Business as Usual (baseline objective function parameter values, no policy constraints), CO HB 19-1132 (objective function parameter values lowered by $0.05 each, no policy constraints), 25% Local (baseline objective function parameter values, policy constraint: school districts are required to purchase 25% of their meals from a local source), High Economic Impact (baseline objective function parameter values, policy constraint: school districts are required to achieve an average per meal level of economic impact), Low Price Risk (baseline objective function parameter values, policy constraint: school districts are required to purchase in a way that achieves a per meal level of price volatility for farmers), and Combo (baseline objective function parameter values, all policy constraints from previous three scenarios are in effect).*

Activity duals show the effect on the objective function of forcing the school to purchase a meal through one of the non-optimal supply chain routes instead of the optimal routes chosen by the model (Table 15). Essentially, the activity duals tell us how expensive it would be (on the margin) for the school district to make an alternative purchasing decision under a certain policy scenario. This is helpful information for policy makers deciding how much they need to subsidize school districts if they want to encourage them to procure food from certain routes under certain policies.

Table 15. Activity duals ($) under various scenarios

| Scenario | $z_1$ Dual | $z_2$ Dual | $z_3$ Dual | $z_4$ Dual |
|---|---|---|---|---|
| **BAU** | 0.49 | 0.67 | 0.06 | 0 |
| **CO HB 19-1132** | 0.44 | 0.62 | 0.01 | 0 |

| | | | | |
|---|---|---|---|---|
| **25% Local** | 0.43 | 0.61 | 0 | 0 |
| **High Econ. Imp.** | 0.05 | 0 | 0.01 | 0.16 |
| **Low Price Risk** | 0 | 0.22 | 0.06 | 0 |
| **Combo** | 0 | 0 | 0.13 | 0.12 |

Note: *The scenarios are Business as Usual (baseline objective function parameter values, no policy constraints), CO HB 19-1132 (objective function parameter values lowered by $0.05 each, no policy constraints), 25% Local (baseline objective function parameter values, policy constraint: school districts are required to purchase 25% of their meals from a local source), High Economic Impact (baseline objective function parameter values, policy constraint: school districts are required to achieve an average per meal level of economic impact), Low Price Risk (baseline objective function parameter values, policy constraint: school districts are required to purchase in a way that achieves a per meal level of price volatility for farmers), and Combo (baseline objective function parameter values, all policy constraints from previous three scenarios are in effect).*

*Sensitivity Analysis*

As we varied the objective function parameters from 50% of their baseline value to 50% above their baseline value, we saw wide fluctuations in school district purchasing behavior (Table 16). Because the objective function baseline values were clustered fairly close together, a 50% change was enough to make the parameter being altered either the most or least expensive option, which explains the wide ranges in choice variable values. Generally, when meals from a certain supply chain route were cheaper, the school district purchased more of them, and when they were more expensive, the school district purchased fewer of them. The model was unsolvable when the Non-Traditional Local parameter value was lowered to 50% of its baseline value in the High Economic Impact and Combo scenarios. We hypothesize that the new, lower cost of the Non-Traditional Local meal in this step of the sensitivity analysis decreased the total dollar amount the school spent through this supply chain route, which lowered the expenditure to which the economic impact multiplier was applied. The lower price tag decreased the overall economic impact to a point where the minimum per meal level of economic impact laid out in the corresponding constraint could not be achieved.

Even with fluctuation in meal purchasing behavior, we observe that certain patterns hold. School districts tend to purchase fewer meals through the Direct Local and Non-Traditional Local supply chain routes under the Business as Usual scenario. The school district purchases a maximum of 75% of its meals through the Traditional Non-Local route in the 25% Local scenario. The school district always purchases at least some of its meals through the Non-Traditional Local route, which has the highest economic impact multiplier, in the High Economic Impact scenario. The district purchases fewer meals through the broadline distributor and more meals directly or through a local distributor in the Low Price Risk scenario. The Combo results are the same as the scenario with the most binding constraint: High Economic Impact.

Table 16. Sensitivity analysis results for choice variables (meals purchased)

| **Scenario** | **$z_1$ Meals Purchased (% of Total)** | **$z_2$ Meals Purchased (% of Total)** | **$z_3$ Meals Purchased (% of Total)** | **$z_4$ Meals Purchased (% of Total)** |
|---|---|---|---|---|
| **BAU** | 0-1,575,129 (0-86%) | 0-1,083,509.9 (0-59%) | 0-1,840,596 (0-100%) | 0-1,840,596 (0-100%) |
| **CO HB 19-1132** | 0-1,840,596 (0-100%) | 0-1,840,596 (0-100%) | 0-1,840,596 (0-100%) | 0-1,840,596 (0-100%) |
| **25% Local** | 0-1,840,596 (0-100%) | 0-1,840,596 (0-100%) | 0-1,840,596 (0-100%) | 0-1,380,447 (0-75%) |
| **High Econ. Imp.** | 0-1,735,985 (0-94%) | 104,611-1,733,088 (6-94%) | 0-109,182 (0-6%) | 0-223,501 (0-12%) |
| **Low Price Risk** | 0-1,840,596 (0-100%) | 0-1,840,596 (0-100%) | 0-450,758 (0-24%) | 0-450,758 (0-24%) |
| **Combo** | 0-1,735,985 (0-94%) | 104,611-1,733,088 (6-94%) | 0-109,182 (0-6%) | 0-223,501 (0-12%) |

Note: *The scenarios are Business as Usual (baseline objective function parameter values, no policy constraints), CO HB 19-1132 (objective function parameter values lowered by $0.05 each, no policy constraints), 25% Local (baseline objective function parameter values, policy constraint: school districts are required to purchase 25% of their meals from a local source), High Economic Impact (baseline objective function parameter values, policy constraint: school districts are required to achieve an average per meal level of economic impact), Low Price Risk (baseline objective function parameter values, policy constraint: school districts are required to purchase in a way that achieves a per meal level of price volatility for farmers), and Combo (baseline objective function parameter values, all policy constraints from previous three scenarios are in effect).*

In terms of relative cost of different policies, CO HB 19-1132 still has the lowest range, followed by 25% Local, Low Price Risk, and High Economic Impact (Table 17). But there is some overlap in the ranges, so if one parameter value changed and others held constant, the affordability ranking might change.

Table 17. Sensitivity analysis results for shadow values ($)

| Scenario | Quantity | Labor | Assortment Breadth | Assortment Depth | Local Intensity | Economic Impact | Price Risk |
|---|---|---|---|---|---|---|---|
| **BAU** | 0.43-2.09 | 0 | 0-0.02 | 0 | n/a | n/a | n/a |
| **CO HB 19-1132** | 1.02-2.04 | 0 | 0 | 0 | n/a | n/a | n/a |
| **25% Local** | 1.045-2.15 | 0 | 0 | 0 | 0-1.08 | n/a | n/a |
| **High Econ. Imp.** | 2.60-2.62 | 0 | 0 | 0 | n/a | 0.48-0.61 | n/a |
| **Low Price Risk** | 1.35-2.58 | 0 | 0 | 0 | n/a | n/a | -30.71-0 |
| **Combo** | 2.60-2.62 | 0 | 0 | 0 | 0 | 0.48-0.61 | 0 |

Note: *The scenarios are Business as Usual (baseline objective function parameter values, no policy constraints), CO HB 19-1132 (objective function parameter values lowered by $0.05 each, no policy constraints), 25% Local (baseline objective function parameter values, policy constraint: school districts are required to purchase 25% of their meals from a local source), High Economic Impact (baseline objective function parameter values, policy constraint: school districts are required to achieve an average per meal level of economic impact), Low Price Risk (baseline objective function parameter values, policy constraint: school districts are required to purchase in a way that achieves a per meal level of price volatility for farmers), and Combo (baseline objective function parameter values, all policy constraints from previous three scenarios are in effect).*

The activity duals show the financial incentive the school district would require to be indifferent between their current purchasing decision and purchasing additional meals from sub-optimal supply chain routes (Table 18). These dollar values can be thought of as the range within which policymakers would have to subsidize school lunch programs on a per meal basis if they wanted school districts to purchase from a certain supply chain route. All of these ranges have zero as a lower bound because the school would require no additional financial incentive if meals through a certain supply chain route were priced 50% lower than their current assumed value.

Table 18. Sensitivity analysis results for activity duals ($)

| Scenario | $z_1$ Dual | $z_2$ Dual | $z_3$ Dual | $z_4$ Dual |
|---|---|---|---|---|
| **BAU** | 0-1.75 | 0-2.02 | 0-1.11 | 0-0.99 |
| **CO HB 19-1132** | 0-1.68 | 0-1.95 | 0-1.03 | 0-1.01 |

| | | | | |
|---|---|---|---|---|
| **25% Local** | 0-1.69 | 0-1.96 | 0-0.83 | 0-0.99 |
| **High Econ. Imp.** | 0-0.26 | 0 | 0-0.30 | 0-0.28 |
| **Low Price Risk** | 0-1.17 | 0-1.57 | 0-1.11 | 0-0.99 |
| **Combo** | 0-0.26 | 0 | 0-0.30 | 0-0.28 |

Note: *The scenarios are Business as Usual (baseline objective function parameter values, no policy constraints), CO HB 19-1132 (objective function parameter values lowered by $0.05 each, no policy constraints), 25% Local (baseline objective function parameter values, policy constraint: school districts are required to purchase 25% of their meals from a local source), High Economic Impact (baseline objective function parameter values, policy constraint: school districts are required to achieve an average per meal level of economic impact), Low Price Risk (baseline objective function parameter values, policy constraint: school districts are required to purchase in a way that achieves a per meal level of price volatility for farmers), and Combo (baseline objective function parameter values, all policy constraints from previous three scenarios are in effect).*

**Discussion and Policy Implications**

We set out to examine the tradeoffs faced by school districts when deciding how to procure food, particularly local food, with an emphasis on the positive externality of local economic development that is associated with Farm-to-School activity. Not surprisingly, we discovered that price is a primary motivating factor for school districts when deciding how to make procurement decisions, but literature has built a compelling case for us to assume the cost competitiveness of some supply chains is due to incomplete consideration of externalities of such systems.

As discussed in the introduction, there are positive externalities associated with less efficient supply chains, such as local purchasing options. In the absence of policies that internalize the benefits of positive externalities of Farm-to-School activity, schools are likely to purchase food through the cost-effective Traditional Non-Local supply chain route. Convenience, labor, and food cost all play a role in this decision. The Traditional Non-Local supply chain route is the most technically efficient route. If a policymaker wanted to shift the school district's purchasing to a local supply chain route so the community could benefit from those positive externalities, it would have to offer $0.06 per meal to make the school district indifferent between the Traditional Non-Local and Traditional Local routes. While our model may not reflect the exact price premia for various supply chain routes faced by Colorado school districts, the $0.06 per meal reimbursement level it suggests is only $0.01 higher than the reimbursement offered by CO HB 19-1132 to eligible school districts who purchase food locally, indicating that this amount may be enough to change school purchasing behavior from non-local to local within the offerings of their mainline distributor. However, the dual on Direct Local activity is $0.49, and the dual on Non-Traditional Local activity is $0.67, indicating that a $0.06 per meal reimbursement may be too low to incentivize schools to purchase from local distributors or directly from producers. Both of these routes have a higher economic impact per meal than the Traditional Local and Non-Local routes.

We saw that certain policy levers shift school purchasing to different alternative supply chain routes, so policymakers should consider what their goals are with local procurement policy. Do they want to encourage local procurement generally, no matter who the intermediary vendor is that sells directly to the school? That goal aligns with the 25% Local policy. Do they want to have the greatest level of economic impact? That goal aligns with the High Economic Impact policy, which costs the school districts substantially more than the 25% Local policy. To justify the expense, policymakers would need to believe that the intermediary Non-Traditional Local distributors produce enough positive externalities for the community, in the form of benefits from higher employment and infrastructure, that supporting those businesses justifies the extra cost. Do they want to protect producers from price changes? While this is not a widespread concern among Farm-to-School advocates, this goal aligns with the Low Price Risk policy scenario and our findings from essay I. If policymakers wanted to support Direct Local procurement, price risk is a potential mechanism by which they could encourage schools to purchase through that route.

Limitations of the model presented here include accuracy of price premia assumptions for different supply chain routes, as most price data along the supply chain are proprietary, and it is difficult to make price generalizations for a wide range of products. Parameter values are assumed or calculated from literature values, which are generalized for a wide variety of school districts. If policymakers want results that are most accurate for their local areas, they would likely benefit from customizing the model to reflect local conditions. Another limitation is that the model is linear, so the original constraints are all assumed to be linear, which is not likely the case.

As we alluded to while discussing model setup, we did not explicitly model several factors that are thought to be important in the Farm-to-School literature: budget, assortment cost, seasonality, equipment, food quality, food safety, and communication along the supply chain. We opted to leave an explicit budget constraint out of the model, because the model is already minimizing costs, and we wanted to observe how total spending would change in various scenarios without limiting the model's behavior in this way. We assumed the cost to firms of providing a large or specialized assortment of items was implicit in the price it charges for its products; in short, such differentials were already part of the objective function cost parameters. We initially included a seasonality constraint in the model and then realized that other constraints were more likely to be binding, so we removed it for simplicity.

Infrastructure may also matter. School districts with the equipment to do raw ingredient preparation are more likely than districts that do not to participate in Farm-to-School. Additionally, the type of kitchen equipment that schools have access to can make them more or less efficient at preparing food. While equipment is an important consideration for Farm-to-School procurement, we focused our efforts on constructing a model that assumed the school district of interest did have the equipment capabilities to participate in Farm-to-School procurement if other supply chain conditions were suitable. We could not find reliable estimates of food quality and communication differentiated by supply chain route in the literature to include these constraints in the model in a compelling way, so we leave that task for future research. The literature suggests that more localized and specialized supply chain routes require more or different communication than traditional routes, so the labor constraint could reflect some of the differences in administrative labor in addition to the food preparation labor that it was specifically parameterized to represent.

Making parameter values more robust is a potential future research direction. Another would be to build a non-linear version of the model, or at least incorporate some non-linear constraints of interest, such as one for transaction costs associated with administrative labor of procuring through different supply chain routes. A final potential research direction would be to clarify the mechanisms by which local procurement produces positive externalities and quantify the magnitude and distribution of those effects in a welfare context. Although the model structure is simple, it provides a functional policy assessment framework on which to build as more information becomes available.

# CONCLUSION

The goal of this study was to analyze the Efficiency-Externality Tradeoff of agri-supply chains in two contexts: Colorado potato supply chain price dynamics and policy levers used to influence Farm-to-School supply chains. We used econometric methods to test for Granger causality and price asymmetry in the first essay. We developed an optimization model of Farm-to-School purchasing behavior and ran it under several policy scenarios in the second essay. We compiled evidence in support of the case that commodified supply chains generally are associated with fewer positive externalities, which took the form of farmer bargaining power, lower price risk, and enhanced local economic development in the examples we chose.

In the first essay we saw evidence that commodity potato supply chains experience imperfect price transmission, which may contribute to low farmer bargaining power and relatively higher downside price risk. The literature suggests that less efficient supply chains may contribute higher levels of both of these positive externalities. In the second essay we saw evidence that schools generally purchase through commodity supply chains due to price considerations, unless policy levers incentivize them to purchase food locally. The literature documents higher local economic development associated with local food procurement than conventional procurement, so we conclude that traditional school food supply chains have fewer positive externalities than supply chains in which school districts are "nudged" by Farm-to-School policy to procure some share of their foods through more localized channels. In short, efficient commodity supply chains have developed over many years to feed people conveniently and efficiently. Yet, if a community or state wants to enhance positive externalities and contribute to broader economic development goals, it appears some policy levers or business strategies can be effective in influencing participation in alternative supply chains.

Substantial changes to supply chain structure or agent motivations, built on policy interventions, are likely required to shift buying and purchasing transactions away from efficiently operated and price effective commodity supply chains and re-capture the benefits of alternative supply chains. Shifting behavior is not easy, since the current market structure and supply chain network relationships have developed over many years to move food products across the country and the world in a competitive marketplace. Perhaps some motivation for changing supply chain behavior could come from the goal to build resilient economies, which is crucial in a world of unexpected changes. The world has watched one such change unfold dramatically this spring: the COVID-19 pandemic. As Oregon farmer Cory Carman summarized the benefits of local food supply chains during the pandemic, "Everything that made us a little less efficient, a little less competitive before is making us more resilient, more secure, and more responsive now." (Curry, 2020). In other words, there are notable tradeoffs between highly efficient commodity agri-supply chains and shorter chains that support farmer bargaining power, a favorable risk portfolio, and local economic development.

Policy implications vary widely depending on context. For our supply-side example of the Colorado potato supply chain, perhaps the Colorado Potato Administrative Committee could explore balancing their mix of market channels to include shorter supply chains with the intention of securing better returns to farmers when they invest in product improvements or when the market is favorable. This might require considering channels that represent less volume, and the transaction costs of selling through these lower-volume channels is a reality with which producers and shippers will have to contend. Alternatively, producers and shippers could approach mainline distributors with a proposal to negotiate on behalf of famers for higher returns in exchange for increased business volume with participating distributors. This analysis provides motivation for trade organizations or marketing orders, such as the Colorado Potato Administrative Committee, to negotiate on behalf of producers as buyers and public policymakers signal their interest in supporting supply chains with fairer terms.

Sliding down the supply chain to the demand-side example of school food procurement, policy implications for this supply chain include a need to address costs faced by schools in the form of food, labor, transaction costs, and equipment required to participate in different supply chain routes. Using the optimization model tool will help school food service and policymaking practitioners understand the economic tradeoffs of different supply chain routes as suppliers of school food. We saw that the choice of policy lever impacts the type of local supply chain route from which the school chooses to purchase. Therefore, Farm-to-School policy advocates should consider not only what they are disincentivizing schools to do (i.e., procure conventionally) but also the specific local purchasing behaviors they want to encourage and what outcomes they expect. Aligning institutional food procurement policies with a community's goals is crucial is food systems are to play a central role in economic development.

Limitations of the study include the specificity of price transmission and influence results to the potato supply chain, uncertainty about accuracy of parameters for the school food procurement model, linearity of the procurement model, and lack of specific information about transaction costs associated with certain supply chain routes. We focused on clearly explaining methodology in both essays so that if industry groups, policymakers, or researchers who work in other supply chain contexts want to explore the market dynamics of any particular supply chain, they have a flexible and well-documented tool to customize to their situation.

Several future research directions address some of the limitations listed above. Analysis of price dynamics could be conducted on commodity crops other than potatoes. More data could be collected about costs to schools associated with various supply chain routes. Incorporating non-linearity, especially within key constraints such as transaction costs, would be an important and impactful modification of the model. A final research direction would be to conduct a welfare analysis to compare the cost saving and profit maximizing benefits of commodity supply chains to the benefits of positive externalities associated with less efficient supply chains. Clearly and convincingly identifying supply chains that qualify as conventional and localized, as well as quantifying the magnitude and distribution of costs and benefits for those supply chains, would be involved in such an analysis. The more detailed information researchers and policymakers compile and the better they understand current market dynamics, the more effective the policies they craft will be at nudging markets to align with economic development goals.

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## APPENDIX A: ESTIMATING LOCAL PRICE PREMIA USING A FARM-TO-SCHOOL MEAL BUNDLE OF GOODS

We wanted the model to be generalizable at the national level, so we chose to pull local prices from a state with detailed statewide Farm-to-School reporting and a variety of local products available in different meal component categories. Iowa reports all local products purchased, including volume purchased for school year to date, price ranges for the current year, and average prices for the preceding year (Iowa Department of Education, 2020). We chose the two most commonly purchased products in each meal component category based on year-to-date purchases from January 2020 (Table A1). For fruit, the most common items are apples and watermelon, for vegetables onion and peppers, for meat/meat alternative ground beef patties and pork shoulder, for milk 1% milk. We then pulled the previous year's (2018-19 academic year) average price for each product included in the bundle. We found national average retail prices for meat and milk but not wholesale prices. The retail prices were higher enough than wholesale that we did not think they were a reasonable comparison. Instead we chose to infer wholesale conventional prices for meat and milk based on the percent difference between local fruits and vegetables and local meat and milk (Table A4).

To infer conventional wholesale meat and milk prices, we first averaged the per pound price of local watermelon, apple, onion, pepper, and potato to create a baseline local fruit and vegetable price ($0.86/lb.). We then found the percent difference between each product in the meat and milk category and this baseline price. We created a baseline conventional fruit and vegetable price by averaging the conventional prices for the same four fruit and vegetable products. We used the percent difference in local prices to infer the conventional prices for meat and milk items as related to the baseline conventional fruit and vegetable price.

Table A1. Local and conventional prices for selected Farm-to-School products

| Product | Local Price Per Lb. | Local Price Source | Conventional Price Per Lb. | Conventional Price Source | Conventional Price Notes | % Premia for Local |
|---|---|---|---|---|---|---|
| **Apple (Fruit Item 1)** | 1.59 | Iowa Farm-to-School (FTS) Local Purchase Report (LPR)* | 0.7975 | AMS Custom Avg. Pricing Tool (CAPT)** | Avg. 40-lb. carton price $31.90 | 99.37% |
| **Watermelon (Fruit Item 2)** | 0.55 | Iowa FTS LPR | 0.1465 | AMS CAPT* | Avg. 500-lb. bin price $73.24 price*** | 275.43% |
| **Onion (Vegetable Item 1)** | 0.70 | Iowa FTS LPR | 0.4404 | AMS CAPT * | Avg. 50-lb. container price $22.02 | 58.95% |
| **Pepper (Vegetable Item 2)** | 1.02 | Iowa FTS LPR | 0.9512 | AMS CAPT * | Avg. 1 1/9 bushel or 25-lb. container price $23.78 | 7.23% |
| **Russet Potato (Vegetable Item 3)** | 0.44 | Iowa FTS LPR | 0.293 | AMS CAPT * | Avg. 50-lb. carton price $14.65**** | 50.17% |
| **Whole-grain bread (Grain Item 1)** | 0.824 | Denver Public Schools (Wilson, 2019) | 1.73 | Webstaurant Online Store (Webstaurant , 2020) | -- | -52.37% |
| **Ground beef patties (Meat Item 1)** | 3.12 | Iowa FTS LPR | 1.91 | Inferred; see Table 14. | -- | 63.35% |
| **Pork shoulder (Meat Item 2)** | 1.64 | Iowa FTS LPR | 1.00 | Inferred; see Table 14. | -- | 64.00% |
| **Fluid milk (Milk Item 1)** | 0.459 | Iowa FTS LPR | 0.2807 | Inferred; see Table 14. | -- | 63.52% |

**The Iowa Farm-to-School (FTS) local purchase report records the name, amount, and price of every food purchased through participating FTS programs in Iowa.*

***Agricultural Marketing Service (AMS) Custom Average Pricing Tool for Terminal Markets. We used Chicago terminal market prices because that is the closest terminal market to Iowa (where local FTS prices are taken from). To compare prices for the same year the Iowa farm-to-school prices are from, we used the date range of August 4, 2018 to July 27, 2019.*

****A standard bin is 46x38x36 inches and holds 1000 lbs. The bins for this statistic are 24 inch, so we used 500 lb. as the unit weight.*

*****50 lb. cartons cost $16.28, and 50 lb. bales of 5 or 10 lb. bags cost $13.02. All prices were for non-organic Russets with no size restriction. We calculated that schools use about 66 lbs./week of Russet potatoes, based on the assumption that a 36-week school year was half-elapsed in January, when the Iowa Farm-to-School purchasing report was compiled, so the 50 lb. carton or bale unit seemed appropriate. We averaged the carton and bale price.*

To estimate the cost difference to schools between conventionally procured and local food, we calculated the cost of a conventional and local bundle of goods based on the Food and Nutrition Service's (FNS) Meal Pattern Requirements (Tables A1-A2). We chose to use the meal pattern requirements for grades K-5. We converted the FNS requirements, which are in cups for fruits and vegetables, ounces for meat and grain, and fluid ounces for milk, to lbs. (Table A2). We calculated an average price per lb. for each meal pattern component by averaging the price of the two products chosen for each category (Table A3). We converted the price per pound to a price per serving using the conversion rates we collected (Table A1). We summed the prices of all meal components for the conventional and local bundles and then compared the price of the bundles to estimate the local food premium (Table A3). Based on the cost per serving difference, the cost per serving for a local meal is $0.9626 and the cost per serving for a conventional meal is $0.7220, making the local premium 33.32%, rounded to 33% in our model.

Table A2. Weight of meal components (minimum required by FNS for K-5 meals)

| **Component** | **Minimum Weekly Amount** (USDA FNS, 2012) | **Average Daily Minimum Amount*** | **Daily Minimum Conversion to Pounds** | **Source** |
|---|---|---|---|---|
| **Fruit** | 2 ½ cups | ½ cup | 0.167 lb. | Farmer's Almanac (Boeckmann, 2017a) |
| **Vegetable** | 3 ¾ cups | ¾ cup | 0.214 lb. | Farmer's Almanac (Boeckmann, 2017b) |
| **Grain** | 9 oz.** | 1.8 oz. | 0.1125 lb. | Common knowledge |
| **Meat** | 10 oz. *** | 2 oz. | 0.125 lb. | Common knowledge |
| **Milk** | 5 cups. | 1 cup or 8 fl. oz. | 0.522 lb. | Common knowledge |

**The average daily minimum amount is the minimum weekly amount divided by five, since there are five days in the school week. This amount is different from the actual daily minimum amount required by FNS for the grain and meat components, but it captures the regulated weekly minimum amount that schools must meet in order to receive a federal meal program reimbursement.*
***We used the upper bound of the 8-9 oz. range given by FNS in their meal pattern requirement guidelines.*
****We used the upper bound of the 8-10 oz. range given by FNS in their meal pattern requirement guidelines.*

Table A3. Weighted average of meal pattern requirements (average of prices for two most common items from each component based on Iowa Farm-to-School budget)

| Component | Lbs./Serving* | $/Lb. (Local) | $/Lb. (Conventional) | $/Serving (Local) | $/Serving (Conventional) |
|---|---|---|---|---|---|
| **Fruit** | 0.167 | 1.07 | 0.472 | 0.1787 | 0.0788 |
| **Vegetable** | 0.214 | 0.72 | 0.5615 | 0.1541 | 0.1202 |
| **Grain** | 0.1125 | 0.824 | 1.73 | 0.0927 | 0.1946 |
| **Meat** | 0.125 | 2.38 | 1.455 | 0.2975 | 0.1819 |
| **Milk** | 0.522 | 0.459 | 0.2807 | 0.2396 | 0.1465 |
| **Total** | | | | 0.9626 | 0.7220 |

**Lbs./serving is the average daily minimum amount from Table A2.*

Table A4. Calculations for inferring conventional meat and milk wholesale prices

| Component | Item 1 Local Price ($/lb.) | Item 2 Local Price ($/lb.) | Item 3 Local Price ($/lb.) | Item 1 % Change from Baseline Fruit/Veg. Bundle | Item 2 % Change from Baseline Fruit/Veg. Bundle | Inferred Conventional Price Item 1 ($/lb.) | Inferred Conventional Price Item 2 ($/lb.) |
|---|---|---|---|---|---|---|---|
| **Fruit (Local)** | 1.59 | 0.55 | -- | | | | |
| **Vegetable (Local)** | 0.70 | 1.02 | 0.44 | | | | |
| **Meat (Local)** | 3.12 | 1.64 | -- | | | | |
| **Dairy (Local)** | 0.459 | -- | -- | | | | |
| **Fruit (Conv.)** | 0.7975 | 0.1465 | -- | | | | |
| **Vegetable (Conv.)** | 0.4404 | 0.9512 | 0.293 | | | | |
| **Meat (Conv.)** | | | | 262.79% | 90.70% | 1.91 | 1.00 |
| **Dairy (Conv.)** | | | | -46.59% | -- | .2807 | -- |
| **Avg. Fruit/Veg. (Local)** | 0.86 | | | | | | |
| **Avg. Fruit/Veg (Conv.)** | 0.5257 | | | | | | |