A BASELINE ASSESSMENT OF SCHOOL FOOD SPENDING AND LOCAL PROCUREMENT: EXPLORING THE CASE OF CO HB 19-1132 AND OTHER PUBLIC POLICIES

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ABSTRACT

Many agricultural and food system policies are enacted to support positive economic development. Yet, there may be tradeoffs associated with certain types of policies – particularly between efficiency and both positive and negative externalities. To test this, we investigate the role of local and regional supply chains in generating local economic development (an example of a positive externality). School nutrition programs are a rich context for this study because they engage with a variety of supply chain pathways, have garnered increasing attention from advocates of institutional procurement in recent years, and many of them have Farm-to-School programs, which produce local economic development benefits according to previous studies. We use an optimization model to test for what we coin the "Efficiency-Externality Tradeoff" specifically looking at how the supply chain by which agricultural products arrive to a school impact both efficiency and local economic development outcomes. We 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. This finding has implications for economic development policies, particularly those targeted at improving the quality of life in agriculturally dependent areas via institutional procurement in a school setting.

INTRODUCTION

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 (Van der Vorst 2005; Bunte et al. 1998; Boehlje 1999; Li and O'Brien 1999; Aramyan et al. 2007; Baldwin 2012; Moss and Taylor 2014). 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 resulting from consolidation 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 profits from business investments, or local economic development (Saitone and Sexton 2017; McBride and Key 2003; Calvin et al. 2001; Willingham and Green 2019). These positive externalities can contribute to wealth creation in agriculturally-dependent areas (Ashley and Maxwell 2002; Aubry and Kebir 2013; Harrison et al. 2019; Marsden, Flynn, and Harrison 2000; Pender, Marré, and Reeder 2012; Renting, Marsden, and Banks 2003; Marsden, Banks, and Bristow 2000), many of which have experienced economic decline in the past several decades (Alig, Kline, and Lichtenstein 2004; Cromartie 2017).

Community investment in local food systems produces economic (Andree 2009; Blay-Palmer and Donald 2006; Meter 2008; Brown and Miller 2008), social (Marsden, Flynn, and Harrison 2000; Brown and Miller 2008), and environmental (Pretty et al. 2005; Pretty et al. 2001) 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 food 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 larger 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 (O'Hara and Pirog 2013; Shideler et al. 2018; Tuck et al. 2010; Kluson 2012; Gunter and Thilmany 2012; Roche, Conner, and Kolodinsky 2015; Christensen, Jablonski, and O'Hara 2019; Jablonski, Schmit, and Kay 2016).

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. 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.

This article asks: what are the tradeoffs among food prices, other costs associated with Farm-to-School procurement, and the contribution to local economic development that school districts might 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 choices they are considering for school food purchasing behavior.

Farm to School

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 procurement activity (Long 2019; USDA FNS 2015b); accordingly, procurement is the focus of this article.

Challenges associated with Farm-to-School procurement have been well documented (Table 1) and include: availability, price and budget constraints, communication barriers, lack of supply chain infrastructure, and concerns about food safety (Long 2019). Most state policies have focused on alleviating the price barrier to local food procurement (National Farm to School Network and Center for Agriculture and Food Systems 2019), 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 and Lynes 2017; Fox and 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 how procurement policies can support economic development (Jablonski et al. 2019).

[Table 1 here]

In 2017 and 2018 twenty-three states passed legislation to encourage Farm-to-School procurement (National Farm to School Network and Center for Agriculture and Food Systems 2019). Many of these 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 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 (Colorado General Assembly 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. We use an optimization model to assess how this policy, along with several other policy options, may affect the supply chain route through which school districts purchase meals.

DATA, EMPIRICAL MODEL, AND METHODS

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 use total annual food expenditures by school districts and meal counts, obtained from the 2015 U.S. Department of Agriculture (USDA) Food and Nutrition Service (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). 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's Market Channel Assessments (Jablonski et al. 2017) to compile information of supply chain cost structure, which allowed us to calculate objective function parameters. To estimate a local price premium, the USDA Agricultural Marketing Service (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 (USDA AMS 2020; Iowa Department of Education 2020). 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.

School District Food Cost Minimization Model

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.

The formal statement of the optimization problem is:

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

$$\text{w.r.t. } z\text{, s.t.}$$

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

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

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

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

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

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

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

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:

$$\text{Minimize} \sum 2.52z_1+2.70z_2+2.09z_3+2.03z_4 \quad \text{w.r.t. } z$$

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. 1; Table 2). 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.

[Figure 1 and Table 2 here]

To begin we calculate a baseline average per meal spent on food 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).[1]

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 3; Akron R-1 School District 2018; Aguilar Reorganized 6 School District 2017; Archuleta Co. 50 JT School District 2016; Ault-Highland RE-9 School District 2015; Agate School District 2016;

[1] These school districts tended to be smaller and more rural than many other districts in Colorado, so it should be noted that they are not representative of the state's districts as a whole.

Colorado Department of Education 2020b).[2] 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.

[Table 3]

Previous literature suggests that the national average baseline meal price may be slightly lower than the $2.03 figure used in our model. For example, Newman (2012) documented a price range of range of $1.17 to $1.38 as part of a USDA Economic Research Service (ERS) analysis of 2005 meal cost data from 400 schools nationally. 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"[3] in the school food budget line, and low economies of scale[4] in the subsample of Colorado school districts we chose. 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.

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 6). Ideally, we would have information about three categories of finances that constitute total sales for each supply chain route:

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[2] 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 same year we compiled 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.

[3] "Other food service supplies" may include cooking and eating utensils and appliances used in food service, as well as cafeteria and kitchen cleaning supplies.

[4] We observed a trend of smaller districts having higher average meal costs, signaling that economies of scale come into play with school food costs. The five sample districts we chose tended to be smaller and more rural, which indicates that the baseline price we used in the model is perhaps slightly higher than the actual baseline price for Colorado school districts on the whole.

cost of goods, operating expenses, and profit. However, in the publicly available reports we consulted, the profit and operating expense figures were aggregated (Sysco 2014; Colasanti et al. 2018; Jablonski et al. 2017). Therefore, we aggregated those two categories (profit and operating expenses) 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 our margin calculations for various supply chain routes, which we describe next (Draganska and Jain 2005; Hansen 2003; Plakias, Klaiber, and Roe 2020).

[Table 6]

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. They 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 their customers have demanded more local options, 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 goods sold 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. 2).

We assumed that the 33% premium was partially due to the increase in the cost of the product paid by the distributor to the farmer, and partially due to increased 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. 2; 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).

[Figure 2 here]

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 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). Even though this is not an exact benchmark to compare to the Sysco numbers, it is a relevant comparator for a farm marketing directly. This figure is also 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 4).

[Table 4 here]

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[5] (Table 1; Izumi, Wright, and Hamm 2010; Conner et al. 2012; Motta and Sharma 2016; Feenstra and Ohmart 2012; Newman 2012; Gordon et al. 2007; Woodward-Lopez et al. 2014; Chiang and Wilcox 1997; Meyer and Conklin 1998; Carpenter and Moore 2006; Hancock 2017). 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.[6] We detail theoretical underpinning and parameterization of each constraint 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

[5] There are some factors included in the literature 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.

[6] With the exception of the quantity constraint, we chose right-hand side constraining values so the baseline constraints would not be binding. We did this for two reasons. First, we wanted to clearly delineate the impact of every policy constraint when turned 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.

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. 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 and Conklin 1998; Meyer 2000). 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 the number of SKUs carried and retail margin data on 231 categories of common grocery items (Chiang and 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, Marescotti, and Touzard 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 "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 (Hancock 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:

$$1z_1 + 1z_2 + 1z_3 \geq .25 * (1z_1 + 1z_2 + 1z_3 + 1z_4).$$

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 Local Direct 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 5; Thilmany & Watson, 2019).[7]

[Table 5 here]

The Traditional Local and Non-Local parameters came from 2016 IMPLAN data for the San Luis Valley, CO[8] wholesale trade sector, which was the NAICS sector that most closely aligned with a large food distributor's economic activities. The custom local food multipliers and IMPLAN multipliers are all calculated based on multi-county regions in rural and rural-adjacent areas, so there

[7] 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 (Plakias, Klaiber, and Roe 2020). The "both direct and intermediated" multiplier is most appropriate among the categories (that also included "direct only" or "intermediated only") for the Local Direct 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.

[8] Saguache, Alamosa, Rio Grande, Conejos, Costilla, and Mineral Counties were included in the multi-county San Luis Valley region.

is some parallelism to the regions represented in this constraint.[9] We multiplied each supply chain route's 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:

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

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 a separate analysis of potato markets 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 .05, although this could be shifted. The price risk constraint is:

[9] Urban areas tend to have higher economic impact multipliers than rural areas.

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

Linearized, it becomes:

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

The final parameters are summarized below (Table 6). Ge et al. (Ge, Gray, and Nolan 2015; Ge et al. 2016) used a similar methodology: compiling relevant conceptual framing and parameters from the literature, calculating, and assuming parameters for optimization models. We followed their example for all parameters to make such information easy for the reader to follow (Table 6).

[Table 6 here]

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 7). 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 three policy level constraints, along with the original objective function parameters the see the impact of a bundle of policies on school purchasing.

[Table 7 here]

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 8-10). Under the BAU scenario, the school district purchased all of its meals through the most cost-effective Traditional Non-Local route (Table 8). 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.

[Tables 8-10 here]

The shadow values of constraints represent the cost to school districts of participating in certain optimization-constraining behaviors, such as procurement policies (Table 9). 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.

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 10). 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.

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

11). 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 newer, 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.

[Table 11 here]

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.

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 12). But there is some overlap in the ranges, so if one parameter value changed and others held constant, the affordability ranking might change.

[Table 12 here]

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 13). 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 13 here]

DISCUSSION

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 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 is $0.49, and the dual on Non-Traditional Local 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.

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. As we alluded to while discussing model setup, another limitation is that 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. A final limitation is that the model is linear, so the original constraints are all assumed to be linear, which is not likely the case.

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

We saw evidence that schools generally purchase through commodity supply chains due to price considerations, unless policy triggers push 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 benefit from Farm-to-School policy support. Efficient commodity supply chains have developed over many years to feed people quickly and efficiently. Yet, they may be associated with fewer positive externalities and contribute relatively less to economic development goals.

Substantial changes to supply chain structure or agent motivations, built on policy interventions, are likely required to shift buying and purchasing transaction 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 has developed over many years, in response to increasing supply chain complexity, to quickly and cheaply move food products across the country and the world. 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 tradeoffs between highly efficient commodity agri-supply chains and shorter chains that may contribute more to local economic development.

Policy implications 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 strengths and weaknesses 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 (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 development goals is crucial if food systems are to play a central role in economic development.

FIGURES

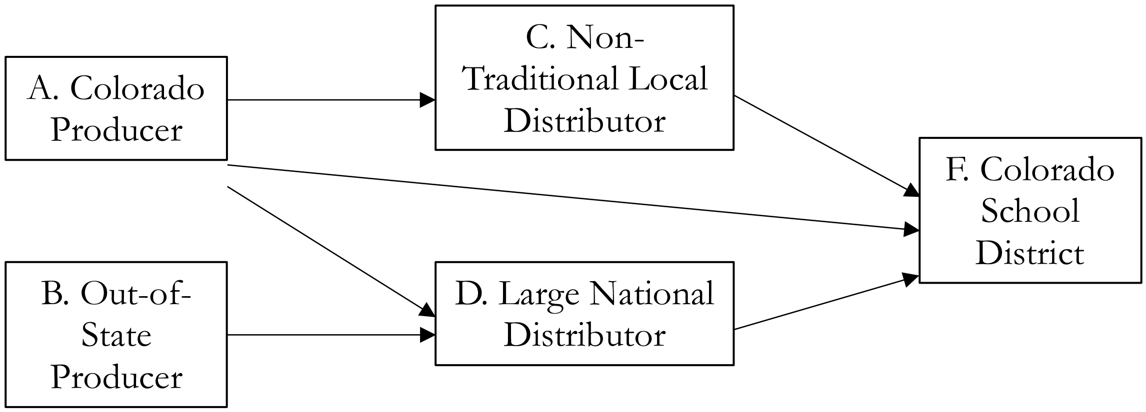

Figure 1. Choice variable supply chains for products purchased by Colorado school districts

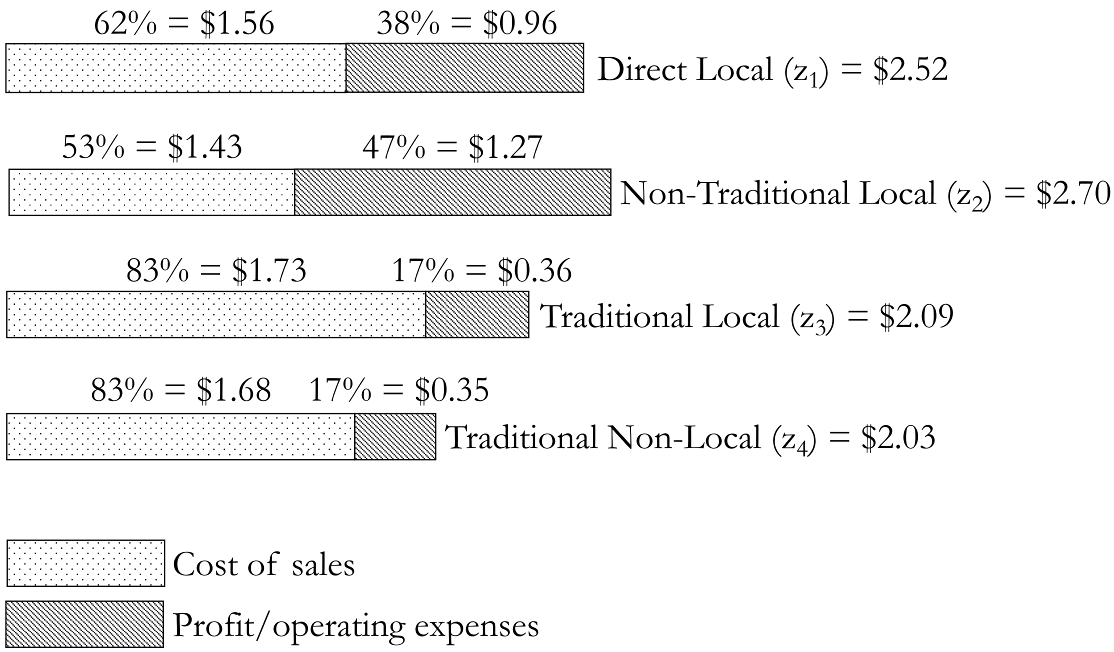

Figure 2. Cost structure breakdown for each supply chain route with baseline objective function parameter values

TABLES

Table 1. Sources Documenting Farm-to-School Procurement Barriers (Long 2019)

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

Table 2. Supply Chain Pathways on Choice Variables

Choice Variable (number of meals)	Pathway Name	Supply Chain Pathway (from Fig. 1)
z_1	Direct Local	A → F
z_2	Non-Traditional Local	A → C → F
z_3	Traditional Local	A → D → F
z_4	Traditional Non-Local	B → D → F

Table 3. Data Used in Cost Per Meal Calculations for Five Colorado School Districts (Colorado Department of Education 2020b; 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)

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

Table 4. 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

Table 5. 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.*

Table 6. 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	(Sysco 2014; Colasanti et al. 2018; Jablonski et al. 2017; USDA AMS 2019; Iowa Department of Education 2020)	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 and Wilcox 1997)	Indianapolis-based retailer
Assortment depth	0.75; 0.46; 0; 0; 0	Calculated from literature	(Carpenter and Moore 2006)	National
Intensity of local	0.75; 0.75; 0.75; -0.25; 0	Assumed from policy	(Hancock 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 and 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

Table 7. 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).*

Table 8. 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).*

Table 9. 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).*

Table 10. 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).*

Table 11. 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).*

Table 12. Sensitivity Analysis Results for Shadow Values ($)

Scenario	Quantity	Labor	Asst. Br.	Asst. Dp.	Local Int.	Ec. Imp.	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).*

Table 13. 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).*

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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/protein 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 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. 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						