Who Pays for WIC’s Formula? A Structural Analysis of the US Infant Formula Market

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March 26, 2017
Incomplete draft, please do not circulate or cite

Abstract

The US infant formula market is highly concentrated and over one-half of the total sales are through the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC). The three major manufacturers compete not only for non-WIC consumers but also to serve WIC participants exclusively by bidding a rebate on the wholesale prices. The winning rebates are about 85-90% of manufacturers’ wholesale prices.

Using data of sales and manufacturers’ rebates, we investigate how the WIC program (1) affects manufacturers’ pricing strategies and leads to the substantial gap between the wholesale prices and the after-rebate prices, and (2) distorts the prices paid by the non-WIC consumers. Our estimates show that manufacturers’ marginal costs are much higher than the prices paid by WIC program. Nevertheless, winning a WIC contract is profitable because serving WIC participants has a substantial spillover effect (increasing 30.6% of the demand from nonparticipants), and the manufacturer’s loss from WIC participants are subsidized by the increased prices for nonparticipants. We further conduct counterfactual analyses to investigate the impacts of the WIC program on non-WIC consumers and test the existence of collusion in the non-WIC market.

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1 Introduction

Government programs play prominent roles in our society. In addition to benefit the participants, programs also affect the welfare of the nonparticipants because the purchase from the programs might alter firms’ behavior and product prices in the related markets. This paper investigates the impacts of the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) on the US infant formula market. Providing infant formula to participating infants less than one year old represents a large portion of program costs, 16% in 2005, and over one-half of the infant formula sales ($3.5 billion in 2007) were through WIC.

The infant formula market is highly concentrated and the market share of three major manufacturers (Mead Johnson, Ross and Carnation with their infant formula brands being Enfamil, Similac and Gerber, respectively) is over 98% in 2008. The manufacturers compete through two channels. On the one hand, they set a national wholesale price of their product and the non-WIC participating consumers pay the retail price. On the other hand, they compete for the exclusive right to serve participants of WIC through auctions by bidding a rebate on the national wholesale price for the purchase from the program. The winning rebates have averaged about 85-90% of manufacturers’ wholesale prices.

The contribution of this paper is to explain the unreasonably high rebate and evaluate the impacts of WIC on the nonparticipants. The substantial discrepancy of wholesale prices and rebates could be due to several alternative rationales. (1) The marginal cost is sufficiently low such that the after-rebate prices for WIC are still profitable. Meanwhile, the relatively high wholesale prices are sustainable because of inelastic demand of nonparticipants or collusion of manufacturers. (2) The after-rebate prices are below the marginal costs and not profitable. Nevertheless, there is a large “spillover” effect of winning the WIC contract, i.e., whoever serves the WIC market attracts additional demand from non-WIC consumers, such that the total profit from WIC and non-WIC consumers is higher for a winner. To disentangle these alternative mechanisms, it is essential to estimate the demand of each manufacturer and recover their marginal costs. Our findings indicate that the after-rebate prices are lower than the marginal costs and the spillover effect is large enough to compensate the winner’s loss from WIC. A counterfactual analysis shows that the wholesale prices are distorted by WIC and it would be much lower without the WIC program.

To address the questions above, we first model manufacturers’ competition by a two-stage game with incomplete information. In the first stage, each manufacturer sets a national wholesale price for its product with their costs being private information. In the second stage, manufacturers participate in auctions to compete for the exclusive right to serve the WIC consumers. Specifically, upon observing the competitors’ wholesale prices, each manufacturer submits a rebate to its wholesale price and the lowest after-rebate price wins. Note that the link between the two stages is through the spillover effect, which is due to the fact that non-WIC consumers may switch to the winner’s product from other

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1We use manufacturers and their brands interchangeably in the paper.
firms because of advertising, recommendation of doctors for new-births, etc.\footnote{Huang and Perloff (2014) demonstrate that a spillover effect is likely important for manufacturers to set prices.}

We estimate manufacturers’ marginal costs using multiple data resources in two steps. First, we recover demand functions and the spillover effect from the ScanTrack sale data from Nielsen (2006-2012). The result indicates that winning the WIC contract increases the demand in regular retail market by 31%, a substantial spillover effect. The estimated own elasticity of demand is -6.88, -7.99 and -4.72 for Enfamil, Similac and Gerber, respectively. In the second step, we estimate manufacturers’ marginal costs from the WIC Infant Formula Rebates procurement data (1987-2013). We utilize the conditions implied by the equilibrium bidding strategy of the manufacturers as well as the estimated spillover effect in this step of estimation. The estimated marginal costs of the three manufacturers are over 50% of the corresponding wholesale prices, which are much higher than the after-rebate prices for WIC. We demonstrate that the manufacturers compete aggressively such that serving WIC participants only is not profitable. Nevertheless, the substantial spillover effect enables the winner to acquire extra profit from nonparticipants, and the gain exceeds the loss on WIC participants.

A possible conclusion from the evidence above is that prices for non-WIC consumers would be lower without WIC. Intuitively, the manufacturer who wins the WIC contract has to compensate its loss from WIC participants by setting a higher price for nonparticipants. To empirically test this hypothesis, we conduct a counterfactual analysis and compare the model-predicted wholesale prices with and without the WIC program. The results confirm the intuition that the wholesale prices are distorted by WIC.

This paper provides the first structural analysis of the US infant formula market. Our results suggest that the extremely low after-rebate prices are due to the large spillover effect and possible collusion of manufacturers in the non-WIC market. Furthermore, we demonstrate that nonparticipants bear much higher prices because of WIC. Infant formula pricing has long been a source of debate. Some speculated that large rebates from manufacturers are subsidized by higher prices to non-WIC consumers (GAO 1988).\footnote{In 1990, the Senate Subcommittee on Antitrust, Monopolies, and Business Rights held hearings on the manufacturers’ pricing behavior (Oliveira et al. 2004). The Federal Trade Commission also investigated pricing practices of the manufacturers in the early 1990s (Oliveira et al. 2004).} Using an event study, Oliveira et al. (2004) argue that non-WIC consumers are price insensitive, thus retailers increase the contract brand’s price. Similarly, Prell et al. (2004) also attributes the large rebate and relatively high wholesale prices to the demand elasticities of consumers by using a Cournot oligopoly model. Huang and Perloff (2014) and Oliveira et al. (2010) identify a spillover effect to be an important factor in setting prices. Davis (2011) takes into account the spillover effect and shows that manufacturers’ marginal costs are often lower than the after-rebate prices, thus WIC program has no impact on non-WIC consumers. Our paper is fundamentally different from the existing work in that (1) we model manufacturers’ pricing strategies in non-WIC and WIC markets jointly by a sequential game; (2) we utilize both sales data and manufacturers’ rebates for estimation; and (3) we rigorously investigate the impacts of the WIC program by counterfactual
analyses, especially we test the existence of potential collusion in the no-WIC market.

Another contribution of our paper is that it may help us understand other markets where government programs play important roles. Although the infant formula market is uniquely characterized by the rebate program and high concentration, our analysis and empirical results may provide useful tools and policy implications to other markets where government programs affect related markets. For example, Duggan and Morton (2006) find that government procurement rules in Medicaid program can change equilibrium price of pharmaceuticals and product proliferation in the private sector.

The outline of the paper is as follows. Section 2 provides background on the US infant formula market. Section 3 presents a structural model of manufacturers’ two-channel competition. Section 4 describes the data we use for estimation and discusses some reduced-form evidence, while Section 5 provides our estimating strategies and empirical results. Section 6 conducts counterfactual analyses. The final section concludes and discusses important directions for future work.

2 The Market and Data

2.1 The market

The US infant formula market is large ($3.5 billion sales in 2007) and it plays important roles in children’s health and development through providing formula for infants less than one year old (Weizman et al. 2005). The products in the market are milk- and soy-based, and they take three physical forms: liquid concentrate, powder, and ready-to-feed. Based on the total volume sales from the demand data discussed later in this section, milk-based powder dominates the market with a 76.4% of market share, while the share of milk-based liquid concentrate, soy-based liquid concentrate and soy-based powder is 11.77%, 4.03% and 7.80%, respectively. Three manufacturers Mead Johnson, Ross, and Carnation, produce about 98% of domestic sales (Oliveira et al. 2010). A fourth manufacturer, Wyeth, was active in the domestic market until 1996. Each manufacturer produces its infant formula in several production centers, then distributes to retailers. The production centers of Ross are in Casa Grande, AZ, Columbus, OH, Sturgis, MI, and Alta Vista, VA. Mead Johnson’s are in Evansville, IN, Zealand, MI, and Springfield, MO. The only production center of Carnation is in Eau Clair, WI.

The WIC program, established in 1972, provides a variety of services and supplemental foods for low-income women, infants, and young children. The program is administered jointly by the U.S. Department of Agriculture (USDA) Food Nutrition Service (FNS) and authorized state agencies. Funding is provided through FNS to state agencies with annual congressional appropriations. Each state’s cash grant includes a food grant and a Nutrition Services and Administration (NSA) grant. Because available funds are limited, state agencies have enacted a variety of measures to control costs attempting to ensure the efficient use of funds and the full participation for all eligible individuals.

Food benefits are typically distributed through retail outlets. Participants receive food vouchers that can be redeemed at authorized retail stores, isolating them from price
considerations when purchasing supplemental foods. Federal mandates dictate allowable quantities of supplemental foods, which are noted on food vouchers. State regulations also frequently impose further restrictions on the types of foods (brands, package sizes etc) that can be purchased, in the interest of controlling costs (Davis and Leibtag 2005). Based on redeemed vouchers, states reimburse retail outlets for the items sold to WIC participants.

In October 1988, federal law required all WIC agencies to explore implementing cost-containment methods for procuring infant formula and to begin implementing cost-containment practices if they proved to lower costs. In 1989, federal law required all state agencies to adopt a competitive bidding process or another process that provided equal or greater savings. Those States with home delivery/direct distribution or Indian State agencies with 1,000 or fewer participants are exceptional.

Manufacturers who submit sealed-bids for the WIC contract to a state agency are required to specify a rebate amount for the primary contract brand infant formula (a single iron-fortified milk-based infant formula that is suitable for routine issuance to most generally healthy, full-term infants) for each of the three forms of infant formula (liquid concentrate, powder, and ready-to-feed). The contract is awarded to the manufacturer offering the lowest net price. The rebate program is very effective at reducing federal WIC costs. The winning rebates are about 85-90% of manufacturers’ wholesale prices and the federal WIC costs are reduced about $1.5 billion annually.

2.2 Data

The data we use for our analysis are from two main sources: the WIC bid data from USDA and sales data from Nielsen ScanTrack.

The WIC bid (auction) data are a panel of each firm’s winning or losing rebate bids for all contract auctions from 1986 through 2013. Originally, there are four firms, Mead Johnson, Ross, Wyeth, and Carnation, participating in the procurement auction. We use the sample period 1998-2013 during which Wyeth has stopped participating in the WIC auctions. The data also include national wholesale prices for truckload-size shipments of infant formula, the prices that agencies use when evaluating which rebate bids will provide the lowest net prices (net price is defined as wholesale price subtracts rebate). We have 139 valid milk-based auctions for our analysis, where Carnation, Mead Johnson and Ross win 20%, 44% and 35% of them, respectively. Table 1 presents summary statistics of wholesale prices of the three brand and their rebates, both in dollar per ounce, as well as their ratio for these auctions. The manufactures’ rebates are substantial and the WIC program pays far less than the non-WIC consumers. On average, the rebate is about 81% of the national wholesale prices. The ratio of rebate over wholesale price is further illustrated in Figure 1.

We obtain the ScanTrack data from the Nielsen Company, which span the period from 2006 to 2012 for demand estimation. The dataset covers supermarkets, grocery stores, and drug stores with more than $2 million annual sales in the U.S., where the bulk of infant formula products are sold. We observe dollar sales, volume sales, and average prices
Table 1: Summary statistics of whole sale prices and rebates

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enfamil whole sale rebate</td>
<td>0.360</td>
<td>0.052</td>
<td>0.170</td>
<td>0.454</td>
</tr>
<tr>
<td>Enfamil whole sale</td>
<td>0.837</td>
<td>0.120</td>
<td>0.381</td>
<td>0.956</td>
</tr>
<tr>
<td>Gerber whole sale rebate</td>
<td>0.358</td>
<td>0.055</td>
<td>0.203</td>
<td>0.444</td>
</tr>
<tr>
<td>Gerber whole sale</td>
<td>0.855</td>
<td>0.076</td>
<td>0.613</td>
<td>0.982</td>
</tr>
<tr>
<td>Similac whole sale rebate</td>
<td>0.334</td>
<td>0.093</td>
<td>0.0003</td>
<td>0.451</td>
</tr>
<tr>
<td>Similac whole sale</td>
<td>0.762</td>
<td>0.204</td>
<td>0.0007</td>
<td>0.967</td>
</tr>
<tr>
<td>Overall whole sale rebate</td>
<td>0.348</td>
<td>0.073</td>
<td>0.0003</td>
<td>0.454</td>
</tr>
<tr>
<td>Overall whole sale</td>
<td>0.809</td>
<td>0.161</td>
<td>0.0007</td>
<td>0.982</td>
</tr>
</tbody>
</table>

Figure 1: Percentage of rebate to wholesale price

of infant formula products across 48 states in the U.S. since there are no observation on sales of Alaska and Hawaii. In addition, it also provides detailed information on product
Table 2: Summary Statistics of Sales and Prices for Infant Formula

<table>
<thead>
<tr>
<th></th>
<th>Full Sample</th>
<th>Enfamil</th>
<th>Similac</th>
<th>Gerber</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std.Dev</td>
<td>Mean</td>
<td>Std.Dev</td>
</tr>
<tr>
<td>Dollar Sales ($million)</td>
<td>2.67</td>
<td>4.58</td>
<td>2.39</td>
<td>4.81</td>
</tr>
<tr>
<td>Volume Sales (million ounces)</td>
<td>2.52</td>
<td>4.15</td>
<td>2.23</td>
<td>4.26</td>
</tr>
<tr>
<td>Unit Price ($ per ounce)</td>
<td>0.46</td>
<td>0.04</td>
<td>0.47</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Note: The retail prices are deflated to 1983 dollars.

characteristics (e.g. brand names, container sizes, package sizes, etc.), marketing (e.g. price and in-store displays), location and time of sales.

Table 2 provides summary statistics for all products across all states and years. An average annual non-WIC dollar sales for an infant formula brand in one state is $2.67 million. We calculate the percentage of WIC infant participation out of all infants born in each state in each year using data from Nielsen home scan data, which provide sales for all households, WIC and non-WIC combined. Then the non-WIC sales are approximated by Total Sales \times (1 - \text{WIC}%). The non-WIC volume sales are generated in a similar way and the average annual volume sold for a brand in one state is 2.52 million ounces. The average sales weighted retail price of a baby formula brand is $0.46 per ounce. We further provide subsample statistics for the three brands in Table 2. Similac leads the market with an average annual sales of $4.06 million in one state, followed by Enfamil and Gerber Good Start. The prices are similar for Similac and Enfamil, $0.47 and $0.47 per oz, respectively. Gerber offers a slightly lower price with $0.46 per oz.

We collect demographic factors that may affect demand for infant formula as well some cost shifters from various online sources. Table 3 presents the summary statistics. On average, there are a total of 42,020 non-WIC infants born in a state in one year and 59.2% women are working. 86% of the population have high school education and the median income in an average state in $23,969.

2.3 Reduced-form analysis

A striking pattern of the data shown in Table 1 and Figure 1 is the extremely high percentage rebate offered by the manufacturers. Intuitively, this can be due to (1) large spillover effects on the non-WIC markets of winning; (2) economies of scale in the formula industry; or (3) the sufficiently low marginal cost of formula. We investigate the first two conjectures using some reduced-form evidence and revisit the third one in our structural model.

We first check the impact of winning an auction on the sales in non-WIC markets. Our finding is that non-WIC consumers purchase the winning brand significantly more than the losing brands. This finding is robust across states and time. Figure 2 provide a visual illustration of the impact using Massachusetts as an example. The vertical dashed line in 2010 indicated the winner change in the WIC auction. From 2006 to 2009, the winner of
Table 3: Summary Statistics of Demand Shifters

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std.Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Wic Birth (in 1,000)</td>
<td>42.02</td>
<td>42.58</td>
</tr>
<tr>
<td>Women Labor Participation Rate (%)</td>
<td>59.20</td>
<td>3.76</td>
</tr>
<tr>
<td>High School Education (%)</td>
<td>86.17</td>
<td>5.47</td>
</tr>
<tr>
<td>Median Income ($1,000)</td>
<td>23.97</td>
<td>8.74</td>
</tr>
<tr>
<td>Median Age</td>
<td>37.30</td>
<td>2.92</td>
</tr>
<tr>
<td>Hispanic (%)</td>
<td>10.64</td>
<td>10.62</td>
</tr>
<tr>
<td>White (%)</td>
<td>72.72</td>
<td>13.89</td>
</tr>
<tr>
<td>African American (%)</td>
<td>10.36</td>
<td>8.95</td>
</tr>
<tr>
<td>Asian (%)</td>
<td>2.80</td>
<td>2.30</td>
</tr>
<tr>
<td>Raw Milk Price ($ per ounce)</td>
<td>0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Electricity Rate ($ per kwh)</td>
<td>0.12</td>
<td>0.01</td>
</tr>
<tr>
<td>Retail Wage ($)</td>
<td>11.74</td>
<td>0.39</td>
</tr>
</tbody>
</table>

the WIC auction in Massachusetts was Gerber. Starting 2010, Enfamil won the auction for the next three year. As shown in panel (a), Gerber dominated the non-WIC infant formula market during the period as a winner of the WIC auction. However, the volume sales of Gerber plummeted since Enfamil became the winner in the Massachusetts market. On the other hand, the volume sales of Enfamil in the non-WIC market skyrocketed immediately after winning the WIC auction. The volume sales of Similac is relatively stable during the whole time period. Panel (b) presents the percentage change in volume sales. The pattern in Massachusetts is representative.

Figure 2: Impact of Winning Auctions on Volume Sales in Non-WIC Markets: MA

To quantify the effect of winning auction on non-WIC sales, we run a simple pooled OLS regression of logarithm of volume sales on $Win$, a dummy variable that equals to 1
Table 4: Impact of Winning Auction on Sales Volume

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>-292.30</td>
<td>-289.30</td>
<td>-90.00</td>
</tr>
<tr>
<td></td>
<td>(218.90)</td>
<td>(195.20)</td>
<td>(91.75)</td>
</tr>
<tr>
<td>Win</td>
<td>11.97*</td>
<td>11.18**</td>
<td>5.38***</td>
</tr>
<tr>
<td></td>
<td>(6.81)</td>
<td>(5.72)</td>
<td>(2.68)</td>
</tr>
<tr>
<td>non-WIC birth (in 1,000)</td>
<td>0.0520*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.00479)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High school education</td>
<td>-0.0265</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0407)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median income (in $1,000)</td>
<td>-0.0292</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.107)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median age</td>
<td>0.0007</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0972)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hispanic (%)</td>
<td>0.0310</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0929)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White (%)</td>
<td>0.0349</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0809)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black (%)</td>
<td>0.0464</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0856)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women labor participation (%)</td>
<td>-0.0584</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0925)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>132.20</td>
<td>134.20</td>
<td>43.05</td>
</tr>
<tr>
<td></td>
<td>(98.11)</td>
<td>(89.85)</td>
<td>(46.59)</td>
</tr>
<tr>
<td>Year dummy</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Firm dummy</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

Standard errors in parentheses: * p < 0.10, ** p < 0.05, *** p < 0.01

if a firm win the auction in a state in a given year as well as other covariates. The results in Table 4 suggest that the demand of a firm increases significantly with winning of an auction in that state. In fact, on average 77.7% of a firm’s own sales in the non-WIC market can be attributed to the win. It is worth to notice that, the 77.7% in this analysis is not equivalent to our definition of the spillover effect in our analysis later, which will be discussed in details later.

We further examine the potential impact of the identity of rival firms winning the auction by conducting an OLS regression for each of the three firms. The results are presented in Table 5. For example, for Enfamil, we examine how Enfamil’s infant formula sales in a state would be affected if Gerber or Similac wins the auction in that year, with Enfamil’s sales when Similac wins as a basis. The coefficient of the binary variable “Gerber win” is not significant compared to “Similac win”, suggesting that the identity of the rivals winning the auction does not affect sales of Enfamil. This implies that proportion of consumers switched to the winning firm is constant, and the spillover effect
is independent of firms’ identity.

Table 5: Sales Response to the Identity of Rival Winning the Auction

<table>
<thead>
<tr>
<th></th>
<th>Enfamil</th>
<th></th>
<th>Gerber</th>
<th></th>
<th>Similac</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std.Dev</td>
<td>Mean</td>
<td>Std.Dev</td>
<td>Mean</td>
<td>Std.Dev</td>
</tr>
<tr>
<td>Enfamil Win</td>
<td>0.351***</td>
<td>0.168</td>
<td>-0.274</td>
<td>0.191</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gerber Win</td>
<td>-0.170</td>
<td>0.153</td>
<td>0.892***</td>
<td>0.174</td>
<td>0.228</td>
<td>0.143</td>
</tr>
<tr>
<td>Similac Win</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.507***</td>
<td>0.236</td>
</tr>
<tr>
<td>Constant</td>
<td>12.992***</td>
<td>0.137</td>
<td>11.424***</td>
<td>0.156</td>
<td>13.118***</td>
<td>0.309</td>
</tr>
<tr>
<td>State Dummy</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Time Dummy</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

The economies of scale might exist in producing and/or distributing infant formula. Intuitively, if marginal costs decrease in quantity, manufacturers would bid more aggressively in a state with larger demand. We conduct a linear regression of rebates on wholesale prices, market size (approximated by number of infants and WIC infants) and distance between manufacturers’ production centers to the markets. The results in Table 6 suggest that both market size and distance do not have significant effects on rebates. This could be due to the fact that the manufacturers have been in the market long enough to expand to a scale that exhausts scale economies.

3 The Model

This section develops a model for the market of infant formula where firms compete sequentially in non-WIC and WIC markets.

3.1 A model of infant formula market

Following the institutional setting, we model the competition of $J$ firms in $M$ markets by a two-stage game with incomplete information. In the first stage, firm $j$ sets a national wholesale price $p_j$ for its product with their costs being private information. In the second stage, a few markets $M_1 \subset M$ hold independent procurement auctions, where firms compete for the exclusive right to serve the WIC markets. Specifically, in the market holding the procurement auction, firm $j$ submits a price $\tilde{q}_j$ for the WIC consumers. Before the firms submit their bids, they observe the wholesale prices and update their beliefs on the cost distribution of their opponents based on their national wholesale prices.

Note that the link between the two markets or the two stages is through the spillover effect, which captures the additional benefit of winning the WIC procurement auction. This spillover effect is due to the fact that non-WIC consumers may switch to the winner’s product from other firms because of advertising, recommendation of doctors for newbirths,
Table 6: Nonexistence of economies of scale

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>wholesale price</td>
<td>0.68***</td>
<td>0.67***</td>
<td>0.68***</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(0.15)</td>
<td>(0.15)</td>
</tr>
<tr>
<td>infant (1000)</td>
<td>-0.00083</td>
<td>0.0016</td>
<td>0.0021</td>
</tr>
<tr>
<td></td>
<td>(0.0028)</td>
<td>(0.0044)</td>
<td>(0.0044)</td>
</tr>
<tr>
<td>WIC infant (1000)</td>
<td>0.0029</td>
<td>-0.0029</td>
<td>-0.0026</td>
</tr>
<tr>
<td></td>
<td>(0.0052)</td>
<td>(0.0086)</td>
<td>(0.0086)</td>
</tr>
<tr>
<td>infant × infant</td>
<td>-0.000070</td>
<td>-0.000077</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.00013)</td>
<td>(0.00013)</td>
<td></td>
</tr>
<tr>
<td>WIC infant × WIC infant</td>
<td>0.00029</td>
<td>0.00027</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.00043)</td>
<td>(0.00043)</td>
<td></td>
</tr>
<tr>
<td>distance (100 miles)</td>
<td>0.0021</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0016)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>distance × distance</td>
<td>-0.000028</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.000045)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>constant</td>
<td>0.053</td>
<td>0.059</td>
<td>0.036</td>
</tr>
<tr>
<td></td>
<td>(0.064)</td>
<td>(0.064)</td>
<td>(0.066)</td>
</tr>
</tbody>
</table>

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
etc. This spillover effect can be viewed as a mechanism to redivide the non-WIC market. To model the spillover effect, we first introduce the demand for both WIC and non-WIC markets without the auction.

Let $D_{jm}(p)$ denote firm $j$’s non-WIC demand without procurement auction in state $m$, where $p \equiv (p_1, p_2, ..., p_J)$ is a vector of firms’ national wholesale prices. Let $d_m$ denote the WIC demand in state $m$, which is price insensitive since the WIC participants do not pay the formula themselves. With the presence of the procurement auction, we model the spillover effect by a constant coefficient $\delta$ (later in the empirical analysis, we allow the spillover effect to depend on characteristics of markets), the proportion of demand that the auction winner “steals” from their opponents. In particular, firm $j$’s non-WIC demand with the presence of auction becomes the following:

\[
\text{non-WIC demand} = \begin{cases} 
D_{jm}(p) + \delta \sum_{k \neq j} D_{km}(p), & \text{if firm } j \text{ wins the auction} \\
(1 - \delta)D_{jm}(p), & \text{otherwise.} 
\end{cases}
\]

All the losing firms’ demands in the non-WIC market become $(1 - \delta)$ proportional to the original demand. This setting nests the case of no spillover effect with $\delta = 0$. Note that as long as $\delta > 0$, the benefit of winning the auction is not just the possible profit from serving in the WIC market, but also the extra market share in the non-WIC market. Thus, when a firm submits its bid, it must take into account profit from both sources. Consequently, the auction considered in this paper is not a standard auction as in the existing literature and it requires new methodology to estimate it.

The costs of firm $j \in J \equiv \{1, 2, ..., J\}$ in market $m$, $c_{jm}$, is assumed to be private information. Before determining its national wholesale price, the costs of firms in market $m$ are drawn from distribution $F(\cdot)$, which may be dependent on state and firm characteristics.

We model the competition among the infant formula manufacturers through a two-stage pricing and auction game with incomplete information. In the first stage, firms’ competition for non-WIC market by setting national wholesale prices. In the price-setting stage, all the firms set their national wholesale price by taking into account both the price competition in the non-WIC market and the spillover effects from winning the auction in the WIC market. For this purpose, we distinguish three disjoint subsets of all the $M$ markets. Specifically, the markets for firm $j$ are divided by markets with no upcoming auction $\mathcal{M}_{1j} \cap \mathcal{M}_{2j}$, where firm $j$ has lost and won in the markets $\mathcal{M}_{1j}$ and $\mathcal{M}_{2j}$, respectively, and markets with upcoming auction in the second-stage $\mathcal{M}_{3j}$, i.e., $\mathcal{M} = \mathcal{M}_{1j} \cup \mathcal{M}_{2j} \cup \mathcal{M}_{3j}$. In the wholesale pricing stage, firm $j$’s expected total profit in
all $M$ markets is,

$$
\pi_{1,j} = \int \left\{ \sum_{m \in \mathcal{M}_{j3}} \left[ (\tilde{q}_{jm} - c_{jm})d_m + (p_j - c_{jm})(\delta \sum_{k \neq j} D_{km}(p) + D_{jm}(p)) \right] \Pr(\tilde{q}_{jm} < \tilde{q}_{km}, k \neq j) + \sum_{m \in \mathcal{M}_{j1}} (p_j - c_{jm})(1 - \delta)D_{jm}(p) \right\} dF(c_{jm}),
$$

$$
+ \sum_{m \in \mathcal{M}_{j3}} \int \left[ (\tilde{q}_{jm} - c_{jm})d_m + (p_j - c_{jm})\delta \sum_{k \neq j} D_{km}(p_j, p_{-j}) \right] \Pr(\tilde{q}_{jm} < \tilde{q}_{km}, k \neq j)dF(c_{jm}) + \sum_{m \in \mathcal{M}_{j2}} (p_j - c_{jm}) \delta \sum_{k \neq j} D_{km}(p_j, p_{-j})dF(c_{jm})
$$

$$
+ \sum_{m \in \mathcal{M}} (p_j - c_{jm}) \int (1 - \delta)D_{jm}(p_j, p_{-j})dF(c_{jm}),
$$

(2)

where the expectation is taken with respect to their opponent’s private costs $c_{-jm}$, $k \neq j$. In the profit function above, both the demand $D_{jm}(p)$ and winning probability $\Pr(\tilde{q}_{jm} < \tilde{q}_{km}, k \neq j)$ depend on costs of firm $j$’s opponents. Since the government requires the firm to readjust their rebates when the wholesale prices increase to keep the net price unchanged, we do not include the WIC market demand in the states that firm $j$ has already won the auction before.

In the auction stage, firm $j$ submits the price for the WIC market $q_{jm}$ to maximize profits in state $m$. Given that the national whole prices of all firms are common knowledge at the auction stage, the expected profit from both WIC and non WIC market for firm $j$ in market $m$ can be represented as:

$$
\pi_{jm} = \left\{ (\tilde{q}_{jm} - c_{jm})d_m + (p_j - c_{jm})\delta \sum_{k \neq j} D_{km}(p) \Pr(\tilde{q}_{jm} < \tilde{q}_{km}, k \neq j) + \delta(p_j - c_{jm})D_{jm}(p) [1 - \Pr(\tilde{q}_{jm} < \tilde{q}_{km}, k \neq j)] \right\}
$$

$$
+ \left\{ (\tilde{q}_{jm} - c_{jm})d_m + (p_j - c_{jm})\delta \sum_{k \neq j} D_{km}(p_j, p_{-j}) \Pr(\tilde{q}_{jm} < \tilde{q}_{km}, k \neq j) + (1 - \delta)(p_j - c_{jm})D_{jm}(p) \right\}
$$

$$
+ \left\{ (\tilde{q}_{jm} - c_{jm})d_m + (p_j - c_{jm})\delta \sum_{k \neq j} D_{km}(p_j, p_{-j}) \Pr(\tilde{q}_{jm} < \tilde{q}_{km}, k \neq j) + (1 - \delta)(p_j - c_{jm})D_{jm}(p) \right\}
$$

(3)

where $\lambda_m = \frac{\delta \sum_{k \neq j} D_{km}(p)}{d_m}$, $q_{km} = \frac{\tilde{q}_{km}}{1+\lambda_m}$, $k = 1, 2, 3$, and $a_{jm} = c_{jm} - \frac{\lambda_m}{1+\lambda_m}p_j$ can be viewed as the “pseudo-cost” of firm $j$ for the WIC market in market $m$. Note that in the auction stage the information set $\mathcal{S} = \{p_j, d_m, D_{jm}(p), j \in \mathcal{J}, m \in \mathcal{M}\}$ is common knowledge to all firms. Thus the only private information in $a_{jm}$ is the production cost $c_{jm}$. 

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3.2 Characterization of Equilibria

We maintain that auctions are independent in different markets. The equilibrium concept we employ for the model is Perfect Bayesian Equilibria (PBE). We characterize the PBE as follows using backward induction due to the sequential feature in our setting.

**The second stage.** At the auction stage, firm $j$ maximizes the expected payoff function in equation (3). Given that the national wholesale price is known in the auction stage, the maximization problem is equivalent to the following:

$$
\max_{q_{jm}} \left\{ (q_{jm} - a_{jm}) \Pr(q_{jm} < q_{km}, k \neq j) \right\}.
$$

Thus, firm $j$’s profit maximization problem is equivalent to a procurement auction with firm $j$’s cost being $a_{jm}$, and bids $q_{jm} = \frac{q_{jm}}{1 + \lambda_m}$. Consequently, firm $j$’s optimal bidding strategy $\sigma_{jm}$ is a mapping from its private pseudo cost $a_{jm}$ to net price: $\sigma_j : A_{jm} \rightarrow \mathbb{R}_+$, where $A_{jm}$ is the support of $a_{jm}$ and can be expressed as the follows:

$$
A_{jm} \equiv \left[ c_{jm} - \frac{\lambda_m}{1 + \lambda_m}p_j, c_{jm} - \frac{\lambda_m}{1 + \lambda_m}p_j \right].
$$

It is worth noting that even we assume the cost $c_{jm}$ are identically distributed, the pseudo-costs $a_{jm}, j \in J$ are not identically distributed for a given $m$. Thus, asymmetry presents in the auction stage.

In the auctions with asymmetry, following Lebrun (2006), we can still characterize the equilibrium conditions similar to that with symmetric bidders. Let $G_k(\cdot)$ and $g_k(\cdot)$ denote the cdf and pdf of firms’ net prices in the auction, then the first order condition of firm $j$ can be written as the following equation:

$$
q_{jm} = a_{jm} + \frac{1}{\sum_{k \neq j} \frac{g_{km}(q_{jm})}{1 - G_{km}(q_{jm})}}, \quad \text{(4)}
$$

or equivalently,

$$
c_{jm} = a_{jm} + \frac{\lambda_m}{1 + \lambda_m}p_j \quad \text{(5)}
$$

Under some regularity conditions, there exist strictly increasing equilibria (e.g., see Athey, 2001 and Lebrun, 2006).

**The first stage** At the national wholesale price stage, firm $j$ chooses the national wholesale price $p_j$ to maximize its overall profit taking into account the winning probability from the optimal bidding strategies in the states that auction are upcoming.

---

4Firms submit their rebates, say $r$ on the national wholesale price. The rebate is equivalent to a net price $q$ after rebate, i.e., $q = (1 - r)p$ with $p$ being the national wholesale price. For simplicity of our analysis, we focus on $q$ instead of $r$. 

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Plugging in the winning probability from the bidding equilibrium conditions leads to the following expected total profit for firm $j$:

$$
\pi_{1j} = \sum_{m \in M_{j3}} d_m \int \left(1 + \lambda_m\right)(q_{jm} - a_{jm}) \prod_{k \neq j} \left[1 - G_{km}(q_{jm}|p)\right] dF(c_{-j})
\quad + \sum_{m \in M_{j2}} (p_j - c_{jm}) \int \delta \sum_k D_{km}(p_j, p_{-j}) dF(c_{-j})
\quad + \sum_{m \in M} (p_j - c_{jm}) \int (1 - \delta) D_{jm}(p_j, p_{-j}) dF(c_{-j}).
$$

(6)

Then the first-order-condition for firm $j$’s profit maximization problem at the first stage becomes

$$
0 = \sum_{m \in M_{j3}} d_m \int \left(1 + \lambda_m\right) \left(\frac{\partial q_{jm}}{\partial p_j} - \frac{\partial a_{jm}}{\partial p_j} + \frac{\partial \lambda_m}{\partial p_j} (q_{jm} - a_{jm})\right) \prod_{k \neq j} \left[1 - G_{km}(q_{jm}|p)\right] dF(c_{-j})
\quad - \frac{\partial q_{jm}}{\partial p_j} \left(1 + \lambda_m\right)(q_{jm} - a_{jm}) \sum_{k \neq j} \frac{g_{km}(q_{jm}|p)}{1 - G_{km}(q_{jm}|p)} \prod_{k \neq j} \left[1 - G_{km}(q_{jm}|p)\right] dF(c_{-j})
\quad + \sum_{m \in M_{j2}} \delta \int \left[\sum_k D_{km}(p_j, p_{-j}) + (p_j - c_{jm}) \frac{\partial \sum_k D_{km}(p_j, p_{-j})}{\partial p_j}\right] dF(c_{-j})
\quad + \sum_{m \in M} (1 - \delta) \int \left[D_{jm}(p) + (p_j - c_{jm}) \frac{\partial D_{jm}(p)}{\partial p_j}\right] dF(c_{-j}).
$$

(7)

From the optimal auction condition, $(q_{jm} - a_{jm}) \sum_{k \neq j} \frac{g_{km}(q_{jm}|p)}{1 - G_{km}(q_{jm}|p)} = 1$. Consequently, the definition of $\lambda_m$ into the last line of the equation above leads to the FOC at the first stage.

$$
0 = \sum_{m \in M_{j3}} d_m \int \left(\frac{\partial \lambda_m}{\partial p_j} (q_{jm} - a_{jm}) - \left(1 + \lambda_m\right) \frac{\partial a_{jm}}{\partial p_j}\right) \prod_{k \neq j} \left[1 - G_{km}(q_{jm}|p)\right] dF(c_{-j})
\quad + \sum_{m \in M_{j2}} \delta \int \left[\sum_k D_{km}(p_j, p_{-j}) + (p_j - c_{jm}) \frac{\partial \sum_k D_{km}(p_j, p_{-j})}{\partial p_j}\right] dF(c_{-j})
\quad + \sum_{m \in M} (1 - \delta) \int \left[D_{jm}(p) + (p_j - c_{jm}) \frac{\partial D_{jm}(p)}{\partial p_j}\right] dF(c_{-j}).
$$

(7)

If there is no spillover effect, that is, $\delta = 0$, then $\lambda_m = 0$, the FOC is simplified as,

$$
\sum_{m \in M} \int \left\{p_j \frac{\partial D_{jm}}{\partial p_j} + D_{jm} - c_{jm} \frac{\partial D_{jm}}{\partial p_j}\right\} F(c_{-j}) = 0.
$$

(8)

So far we allow the private cost of each firms to indexed by a dimension of $M$, and so an individual firm’s optimal pricing strategy is a mapping from all $M$ costs $c_j \equiv \{c_{j1}, ..., c_{jM}\}$ to a national wholesale price $p_j$, denoted as $p_j = \phi(c_j, S)$ with $S$ includes all relevant information.
Bayesian updating using national wholesale price. Given that this is a game with incomplete information, each individual firm only knows the distribution from which their rivals’ cost parameters are drawn from, but not the realization of the cost parameters. After their national wholesale prices are revealed, firms might try to update their beliefs over the distribution of the cost parameters. The updated distributions are employed in the second (bidding) stage. Let \( \psi(c_j|p) \) denote the joint posterior distribution:

\[
\psi(c_j|p_j) = \frac{f(p_j|c_j)f(c_j)}{\int f(p_j|c_j)f(c_j)dc_j}
\]

(9)

where \( f(p_j|c_j) \) depends on equilibrium pricing strategy \( p_j = \phi(c_j, S) \).

\[
F_p(p_j|c_j) = Pr(P_j \leq p_j|c_j) = Pr(\phi(c_j; S) \leq p_j|c_j)
\]

\[
= \int_{\phi(c_j) \leq p_j} f(c_j)dc_j.
\]

Firms’ bidding strategies and pricing functions are consistent with the posterior \( \psi(c|p) \).

The equations above together characterize how a firm balances the profits in WIC and non-WIC market when setting the price for non-WIC market.

**Proposition 1 (The Equilibrium Characterization)** For the two-channel competition in the infant formula markets, firm \( j \)’s national wholesale price \( p_j \) and its net price \( q_{jm} \) for the \( m \)-th market (\( \forall m \in M_j \)) at a Perfect Bayesian Equilibrium (PBE) are characterized by the following conditions:

1. Auction stage optimal conditions, i.e., equation (5).
2. Pricing stage optimal conditions, i.e., equation (7).
3. Consistency of beliefs: i.e., equation (9).

In general, the model we present might admits multiple BNE because (5) and (7) could well admit multiple solutions that are consistent with (9). We follow the convention of literature on empirical games (e.g. Bajari, Hong, Krainer, and Nekipelov (2010) and Lewbel and Tang (2013)), and assume that data-generating process only involves a single BNE.

### 4 Structural Estimation and Results

This section presents the estimation strategies and the results. Specifically, the estimation is proceed sequentially. First, we use the Nielsen ScanTrack data to estimate the demand function and the spillover effect using GMM. Then we move on to recover the cost using the auction data.
4.1 Estimation Strategies - Demand

We specify the a linear demand function for non-WIC consumers when there is no procurement auction for exclusive right to serve WIC consumers,

\[ D_{jm}(p) = D_j(p, X_m; \alpha, \beta, \gamma) = \alpha_j + \sum_{k=1}^{3} \beta_{jk} p_k + \sum_{l=1}^{L} \gamma_l X_{ml}, \]  

(10)

where \( X_m = \{X_{m1}, \cdots, X_{mL}\} \) is a vector of characteristics of state \( m \). For a given state \( m \in \mathcal{M} \), let \( I_{jm}, j = 1, 2, 3 \) be an indicator of whether firm \( j \) wins the auction or not.

\[ I_{jm} = \begin{cases} 1, & \text{if } j \text{ wins;} \\ 0, & \text{if } j \text{ loses.} \end{cases} \]  

(11)

Thus the sales of firm \( j \) in state \( m \), \( Q_{jm} \), can be expressed as:

\[ Q_{jm} = I_{jm} \left( D_j(p, X_m) + \delta(X_m) \sum_{k \neq j} D_k(p, X_m) + \varepsilon_{jm} \right) + (1 - I_{jm}) \left( [1 - \delta(X_m)]D_j(p, X_m) + \eta_{jm} \right), \]  

(12)

where the spillover effect \( \delta \) is allowed to depend on state characteristics \( X_m \)

\[ \delta(X_m) = \delta_0 + X_m \delta_1. \]

The terms \( \varepsilon_{jm} \) and \( \eta_{jm} \) are mean zero demand shocks to the winner and losers, respectively.

Note that the prices may be endogenous, therefore identifying and consistently estimating the demand parameters requires instrumental variables. Let \( V_{m1}, \cdots, V_{mR} \) be \( R \) instruments in state \( m \)\(^5\) and \( Z_m = (1, X_{m1}, \cdots, X_{mL}; I_{m1}, I_{m2}, I_{m3}; V_{m1}, \cdots, V_{mR}) \). For a given firm \( j \), we have the following moment conditions,

\[
E[g_j(Q_{jm}, Z_m, p; \theta)] = E[(I_{jm}\varepsilon_{jm} + (1 - I_{jm})\eta_{jm})Z_m] = E \left[ Z_m \left( Q_{jm} - I_{jm}[D_j(p, X_m) + \delta(X_m) \sum_{k \neq j} D_k(p, X_m)] - (1 - I_{jm}) ([1 - \delta(X_m)]D_j(p, X_m)) \right) \right] = 0,
\]

(13)

\(^5\)We might model the spillover effects from consumers' preference over the winning brand. However, this approach would lead to identity-dependent externalities in WIC auctions, i.e., the effects on sales of losing firms do depend on the identity of winner. Our reduced-form evidence shows that such asymmetric effects are not supported by our data. The linear demand system is for simplicity and we could model the demand system differently given the spillover effects are described by (12).

\(^6\)\(V_{mr}, r = 1, \cdots, R \) can be the same across states.
where $\theta$ denote the parameters, $\theta \equiv (\delta_0, \delta_1; \alpha_j, \beta_j; \gamma_l)$, $l = 1, \ldots, L; j, k = 1, 2, 3$. To be specific, $g_j(Q_m, Z_m, p; \theta)$ is a column vector with $1 + L + R$ rows.

$$g_j(Q_m, Z_m, p; \theta) = \begin{pmatrix} Q_{jm} - I_{jm} D_j(p, X_m) + \delta(X_m) \sum_{k \neq j} D_k(p, X_m) - (1 - I_{jm}) ([1 - \delta(X_m)] D_j(p, X_m)) \\ x_1 (Q_{jm} - I_{jm} D_j(p, X_m) + \delta(X_m) \sum_{k \neq j} D_k(p, X_m) - (1 - I_{jm}) ([1 - \delta(X_m)] D_j(p, X_m))) \\ \vdots \\ x_L (Q_{jm} - I_{jm} D_j(p, X_m) + \delta(X_m) \sum_{k \neq j} D_k(p, X_m) - (1 - I_{jm}) ([1 - \delta(X_m)] D_j(p, X_m))) \\ v_1 (Q_{jm} - I_{jm} D_j(p, X_m) + \delta(X_m) \sum_{k \neq j} D_k(p, X_m) - (1 - I_{jm}) ([1 - \delta(X_m)] D_j(p, X_m))) \\ \vdots \\ v_R (Q_{jm} - I_{jm} D_j(p, X_m) + \delta(X_m) \sum_{k \neq j} D_k(p, X_m) - (1 - I_{jm}) ([1 - \delta(X_m)] D_j(p, X_m))) \end{pmatrix}.$$  

By stacking the moment conditions of three firms, we have

$$E[g(Q_m, Z_m, p; \theta)] = \begin{pmatrix} E[g_1(Q_m, Z_m, p; \theta)] \\ E[g_2(Q_m, Z_m, p; \theta)] \\ E[g_3(Q_m, Z_m, p; \theta)] \end{pmatrix} = 0. \quad (14)$$

The total number of moments is $3(R + L + 1)$ while the number of parameters is $3 \times 4 + L + L + 1 = 13 + 2L$. Identification using IV requires $R \geq 3$. Thus, $3(R + L + 1) \geq 12 + 3L$, which is greater than $13 + 2L$ given $L > 1$.

The sample analog of the moment conditions is

$$\frac{1}{TM} \sum_{m=1}^{M} \sum_{t=1}^{T} g(Q_{mt}, Z_{mt}, p_t; \theta) = 0. \quad (15)$$

The GMM estimator of $\theta$ is:

$$\hat{\theta} = \arg \min_{\theta \in \Theta} \left( \frac{1}{TM} \sum_{m=1}^{M} \sum_{t=1}^{T} g(Q_{mt}, Z_{mt}, p_t; \theta) \right)' W \left( \frac{1}{TM} \sum_{m=1}^{M} \sum_{t=1}^{T} g(Q_{mt}, Z_{mt}, p_t; \theta) \right), \quad (16)$$

where our sample contains $T$ year and $M$ state, and $W$ is the weighting matrix.

Denote the demand functions and the spillover effects estimated in this $\hat{D}_j(p, X_m)$ and $\hat{\delta}(X_m)$, respectively.

### 4.2 Estimation Strategies

#### 4.2.1 Costs

This subsection describes how we estimate the cost parameters. Specifically, the firms’ problem in the second stage is equivalent to determining optimal bidding in auctions with asymmetric bidders due to the spillover effect. The pseudo cost for the auction is
function of the spillover effect and the national wholesale price, i.e., $a_{jm} = c_{jm} - \frac{\lambda_m}{1 + \lambda_m}p_j$, where $\lambda_m$ is a market-specific spillover effect, and $p_j$ is firm $j$’s national wholesale price. Moreover, the true costs are also heterogeneous to the extent that the cost distribution is determined by firm and state characteristics. To control for cost heterogeneity but still able to pool data from different states for estimation, we make the following assumption regarding the cost.

$$e_{jm} = w_{jm}u_j + \epsilon_{jm},$$  \hspace{1cm} (17)

where $\epsilon_{jm}$ is i.i.d. across players and states, and $w_{jm}$ includes production inputs such as milk, wage, gasoline and aluminum to capture the production cost, and the covariates such as the distance of state $m$ from the plant to capture state specific cost as the transportation and operation costs. Under the assumption of additively separability above, and the independence of $w_{jm}u_j$ and $\epsilon_{jm}$, Haile et al. (2006) show that the bids would be additively separable, too.

Following this standard approach to control for auction-level heterogeneity, we run a first-stage regressions on the bids/net prices $(\tilde{q}_{jm}^{1+\lambda_m})$ over observed bidders’/market characteristics $W_{jmt} = \{w_{jmt}, \frac{\lambda_m}{1 + \lambda_m}p_{jt}\}$ as follows

$$q_{jmt} = W_{jmt}\rho + e_{jmt}.$$  \hspace{1cm} (18)

The resulting residuals $e_{jmt}$ can be viewed as homogenized bids corresponding to the i.i.d cost $\epsilon_{jmt}$. Such an approach is widely used in the literature, e.g., [Bajari et al.] (2014). Since auctions are hosted every three years or longer, the correlation between values of the same firm in two auctions (hosted in the same state) is weak. With the homogenized bids information, we can use empirical cdf and kernel estimation to recover the cdf and pdf of the homogeneous cost distribution, and we denote the cdf and pdf as $h(\cdot)$ and $H(\cdot)$, respectively. Then we proceed to estimate the distribution of the net prices with heterogeneity as follows.

$$G_{jmt}(q) = \Pr (q_{jmt} \leq q) = \Pr (W_{jmt}\rho + e_{jmt} \leq q) = \Pr (e_{jmt} \leq q - W_{jmt}\rho)$$

$$\equiv H(q - W_{jmt}\rho).$$  \hspace{1cm} (19)

Consequently, the density distribution of the net prices can be estimated through taking derivatives of the cdf, i.e., $g_{jmt}(q) = h(q - W_{jmt}\rho)$. Next, the pseudo-value $a_j$ can be estimated following the equilibrium condition.

$$\hat{a}_{jmt} = q_{jmt} - \left(\sum_{k \neq j} \frac{\hat{g}_{kmt}(q_{jmt})}{1 - \hat{G}_{kmt}(q_{jmt})}\right)^{-1} = q_{jmt} - \left(\sum_{k \neq j} \frac{\hat{h}(q_{jmt} - W_{kmt}\hat{\rho})}{1 - \hat{H}(q_{jmt} - W_{kmt}\hat{\rho})}\right)^{-1}.$$  \hspace{1cm}

Consequently, we can recover the true cost $c_{jm}$ as

$$\hat{c}_{jmt} = \hat{a}_{jmt} + \frac{\hat{\lambda}_m}{1 + \hat{\lambda}_m}p_{jt}.$$  \hspace{1cm} (20)
Next step is to estimate how those characteristics affect firms’ cost. With the structure on the cost and observed characteristics specified in (17)

$c_{jm} = w_{jm}u + \epsilon_{jm}$.

Assume that $\epsilon_{jm}$ are i.i.d. and follow a log normal distribution with mean $\mu$ and variance $\sigma^2$. We can estimate $\theta \equiv \{u, \mu, \sigma\}$ as the follow through MLE using the cost recovered from the auction stage. In particular, we can write down the log likelihood function as

$L_n = \sum_{m} \sum_{j} \log \phi\left( \frac{\log(c_{jm} - w_{jm}u) - \mu}{\sigma} \right)$

4.3 Estimation results

We estimate the demand and the spillover effect for non-WIC consumers in the infant formula market jointly using GMM. The standard errors are calculated via bootstrap.

Table 7 presents the estimation results on spillover effects $\delta_0$, which measures the mean spillover effects across all states, is estimated to be positive and significant. This results suggests that if a firm wins the exclusive right to serve WIC consumers, the firm will attract more non WIC consumers. Further, $\delta_0 = 0.306$ suggests that winning the auction in the WIC program would “steal” 30.6% of demand from all other competing firms in the non WIC market. In addition, we include demographic variables to capture the possible variation in spillover effects across states. The results suggest that the spillover effects are homogeneous across states.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std.Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant ($\delta_0$)</td>
<td>0.306***</td>
<td>0.0510</td>
</tr>
<tr>
<td>Non-WiC Infant (in 1,000)</td>
<td>0.0001</td>
<td>0.0015</td>
</tr>
<tr>
<td>High School Education (%)</td>
<td>0.0003</td>
<td>0.0059</td>
</tr>
<tr>
<td>Median Income (in $1,000)</td>
<td>-0.0002</td>
<td>0.0051</td>
</tr>
<tr>
<td>Median Age</td>
<td>0.0001</td>
<td>0.0005</td>
</tr>
<tr>
<td>Hispanic (%)</td>
<td>0.0007</td>
<td>0.0054</td>
</tr>
<tr>
<td>White (%)</td>
<td>0.0005</td>
<td>0.0050</td>
</tr>
<tr>
<td>African American (%)</td>
<td>0.0010</td>
<td>0.0056</td>
</tr>
</tbody>
</table>

The rest of the demand parameters are presented in Table 8. We assume an asymmetric demand system for the three brands and we use the sales volume (in million ounces) to represent a firm’s demand. The signs of the price coefficients are all as expected. Take Enfamil for example, the brand’s own price coefficient has a negative and significant impact on their demand. On the other hand, Gerber and Similac’s prices have a positive and significant impact. But the magnitude of the impact is much smaller than the Enfamil’s own price effects. Similarly for Gerber and Similac. To better capture all other factors
that might affect the demand of infant formula, we also include several demographic variables into the demand estimation. Most demographic variables have no significant impact on demand for infant formula except for non-WIC Birth and Women Labor Participation Rate. A higher number of non-WIC infants born in a state in a given year is a strong positive demand shifter and thus are expected to contribute positively to all three firms’ demand. In addition, the demand for infant formula is stronger in a state with a higher percent of working women. In general, a higher percent of women labor participation may indicate a lower percentage of breastfeeding rate or a shorter breastfeeding time. Therefore, it may leads to a higher demand for infant formula in a market.

Table 8: Demand Estimation Results

<table>
<thead>
<tr>
<th></th>
<th>Enfamil</th>
<th>Gerber</th>
<th>Similac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>Std.Dev</td>
<td>Mean</td>
<td>Std.Dev</td>
</tr>
<tr>
<td>Price (Enfamil)</td>
<td>-33.108***</td>
<td>6.798</td>
<td>7.085***</td>
</tr>
<tr>
<td>Price (Similac)</td>
<td>7.801***</td>
<td>4.134</td>
<td>-0.064</td>
</tr>
<tr>
<td>non-WIC Infant (in 1,000)</td>
<td>0.032***</td>
<td>0.006</td>
<td>0.026***</td>
</tr>
<tr>
<td>Women Labor Participation (%)</td>
<td>-0.041</td>
<td>0.272</td>
<td>-0.024</td>
</tr>
<tr>
<td>High School Education (%)</td>
<td>0.026</td>
<td>0.102</td>
<td>0.015</td>
</tr>
<tr>
<td>Median Income (in $1,000)</td>
<td>0.123***</td>
<td>0.020</td>
<td>0.099***</td>
</tr>
<tr>
<td>Median Age</td>
<td>0.031</td>
<td>0.260</td>
<td>0.157</td>
</tr>
<tr>
<td>Hispanic (%)</td>
<td>0.017</td>
<td>0.022</td>
<td>0.019</td>
</tr>
<tr>
<td>White (%)</td>
<td>0.035</td>
<td>0.065</td>
<td>0.025</td>
</tr>
<tr>
<td>African American (%)</td>
<td>0.053</td>
<td>0.054</td>
<td>0.046</td>
</tr>
<tr>
<td>Constant</td>
<td>2.108***</td>
<td>0.009</td>
<td>-0.777***</td>
</tr>
</tbody>
</table>

*, **, and *** represents significance levels at 10%, 5% and 1%, respectively. Standard errors are calculated by bootstrapping.

Table 9 presents the estimated own- and cross-price elasticities. Each entry $i,j$, where $i$ indexes row and $j$ column, gives the elasticity of product $i$ with respect to a chance in the price of $j$. The elasticities are calculate using the average value of each firm in the data. The results are intuitive and the substitution are persistent across the table. For example, Similac has an own-elastic demand of -4.72 and are slightly less sensitive to the prices of Gerber than that of Enfamil.

Table 9: Mean Own and Cross Elasticities

<table>
<thead>
<tr>
<th></th>
<th>Enfamil</th>
<th>Gerber</th>
<th>Similar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enfamil</td>
<td>-6.882</td>
<td>1.965</td>
<td>0.570</td>
</tr>
<tr>
<td>Gerber</td>
<td>1.561</td>
<td>-7.992</td>
<td>1.920</td>
</tr>
<tr>
<td>Similac</td>
<td>1.622</td>
<td>-0.018</td>
<td>-4.719</td>
</tr>
</tbody>
</table>
Based on the estimation of demand functions and spillover effects, we recover manufacturers’ marginal costs. For comparison, we plot the marginal costs together with wholesale and net prices in Figure 3. The figure shows that the cost is sufficiently higher than the net prices paid by the WIC program. This suggests that firms do not make profit from WIC markets. The reason that firms bid so aggressively maybe due to the strong spillover effect to the non-WIC market and their loss in WIC markets are compensated by non-WIC consumers. In the meantime, the cost is significantly lower than the wholesale price, suggesting that firms enjoy large market power. The possible sources of market power are (1) the demand of consumers in non-WIC markets is inelastic; (2) manufacturers collude in setting their national wholesale prices. On the one hand, the results in Table 9 reveal that consumers in non-WIC markets are price sensitive and their demand is elastic. On the other hand, theory indicates that repeated interaction within oligopolies could support collusion if there are few enough competitors in a market (e.g., Abreu (1988)). We will investigate this possibility through a counterfactual analysis in the next section.

The mean of cost, net price, and wholesale price are 0.1567, 0.0836, and 0.4314, respectively.

Figure 3: Comparison of Cost, Net Price and Wholesale Price
5 Counterfactual analysis (pending)

In this section, we analyze how the WIC bidding affect the non-WIC consumers. For this purpose, we compare wholesale prices predicted by a model with WIC bidding and the one without it. When there is no procurement auction, all three firms can supply to the WIC consumers and they compete for both WIC and non-WIC consumers together. There will be no spillover effect across two markets and we set $\delta = 0$. Consequently, each manufacturer’s problem becomes to set the national wholesale price to maximize the overall profit in the non-WIC markets, the equilibrium conditions are described in (8)

$$
\sum_{m \in M} \int \left\{ p_j \frac{\partial D_{jm}(p_j, p_{-j})}{\partial p_j} + D_{jm}(p_j, p_{-j}) - c_{jm} \frac{\partial D_{jm}(p_j, p_{-j})}{\partial p_j} \right\} F(c_{-j}) = 0.
$$

Manufacturer $j$’s optimal strategy denoted as $\Phi_j(c_j) \rightarrow p_j$, where $c_j \equiv \{c_{j1}, \ldots, c_{jM}\}$, is a mapping from a vector of all costs $c_j$ to a national wholesale price $p_j$. Solving for the equilibrium provides us how the national wholesale price will be for a given set of costs.

On the other hand, with the procurement auction to grant the exclusive right to serve the WIC market, the firms’ optimal pricing strategy denoted as $\tilde{\Phi}_j(c_j) \rightarrow p_j$ takes into account the probability of winning in the later auctions so the first order condition becomes (7)

$$
\sum_{m \in M_{j3}} d_m \int \left[ (\frac{\partial \lambda_m}{\partial p_j} (q_{jm} - a_{jm}) - (1 + \lambda_m) \frac{\partial a_{jm}}{\partial p_j}) \prod_{k \neq j} [1 - G_{km}(q_{jm}|p)] dF(c_{-j}) \right.
+ \sum_{m \in M_{j2}} \delta \int \left[ \sum_k D_{km}(p_j, p_{-j}) + (p_j - c_{jm}) \frac{\partial \sum_k D_{km}(p_j, p_{-j})}{\partial p_j} \right] dF(c_{-j})
+ \sum_{m \in M} (1 - \delta) \int \left[ D_{jm}(p) + (p_j - c_{jm}) \frac{\partial D_{jm}(p)}{\partial p_j} \right] dF(c_{-j}) = 0.
$$

A comparison between the mapping $\Phi(\cdot)$ and $\tilde{\Phi}(\cdot)$ provides with the information how non-WIC consumers are affected by the WIC biddings. To estimate the mapping $\Phi_j$, we simplify the equilibrium conditions, leading to

$$
0 = \sum_{m \in M} \int \left\{ (p_j - c_{jm}) \beta_{jj} + \alpha_j + \sum_{k=1}^{3} \beta_{jk} p_k + \sum_{l=1}^{L} \gamma_l X_{ml} \right\} dF(c_{-j}), j = 1, 2, 3. (21)
$$

$$
p_j = \frac{\sum_{m} c_{jm}}{2M} - \frac{\alpha_j}{2} - \frac{\sum_{k \neq j} \beta_{jk} E_{pk}}{2\beta_{jj}} - \frac{\sum_{l=1}^{L} \gamma_l X_{ml}}{2M} \equiv \frac{1}{2} \bar{\beta}_j - \frac{\alpha_j}{2} - \frac{\sum_{k \neq j} \beta_{jk} E_{pk}}{2\beta_{jj}} - \frac{1}{2} \sum_{l=1}^{L} \gamma_l \bar{X}_{tl}, j = 1, 2, 3.
$$
The mapping without auction $\Phi_j(c_j)$ only depends on the average cost over all states $\bar{c}_j$. With the specification of linear demand function, firms only care for the average cost instead of the whole distribution of cost over different states. Thus, we can express the pricing strategy as $\Phi_j(\bar{c}_j) \rightarrow p_j$.

Note that the pricing strategy for firm $j$ with potential procurement auctions is a mapping from $M$ state-specific costs $c_j = \{c_{j1}, ..., c_{jM}\}$ to a national whole sale price. From the above simplification of the first order condition, we can see that the mapping depends on several aggregate costs. Specifically, the pricing strategy only depends on the average cost across all states, $\bar{c}_j = \frac{1}{M} \sum_{m \in M} c_{jm}$, the average cost across states that firm $j$ won auction last year, $\bar{c}_j = \frac{1}{M_2} \sum_{m \in M_2} c_{jm}$, and the costs of the states about to have an auction. Without loss of assume that there is only one state to host the auction, and denote this state as $m'$. Consequently, the pricing strategy can be expressed as $p_j = \tilde{\Phi}(c_{jm'}, \bar{c}_j, \tilde{c}_j)$.

It takes multiple steps to solve the mapping $\tilde{\Phi}(\cdot)$. First of all, for a given set of costs $c_{jm}$, we obtain $G_{km}(q_{jm}|p)$ by simulating $S$ draws of $q_{jm}$ for any given $p$ ($\lambda_m$ is known for given $p$ and non-WIC demand $d_m$).

To see the effect of procurement auction on the non WIC consumers, we compare pricing strategies $\Phi_j(\bar{c}_j)$ predicted without procurement auctions with that without procurement auctions $\tilde{\Phi}(c_{jm'}, \bar{c}_j, \tilde{c}_j)$. The difference between the two pricing strategies provide the magnitude of the impact of the existence of procurement auctions on the non WIC consumers.

The fact that we do not need to use the equilibrium conditions in the pricing stage for estimation allows us to further investigate firms’ behavior in the wholesale pricing stage. We do not need to assume firms’ competition behaviors in the pricing stage to recover the cost parameters. This allows us to detect whether infant formula manufacturers collude in determining their wholesale prices, we recover the optimal wholesale price in a Bertrand competition pricing game stage. If there is not collusion, the optimal price recovered from the pricing stage should be close to the wholesale price in the data. If the gap between the optimal wholesale price and that of Bertrand competition is too big, it is an indication of possible collusion.

6 Conclusions

References


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Appendix

.1 Counterfactual analysis

.1.1 Pricing strategy without auction

When there is no procurement auction, firm $j$’s pricing strategy satisfy following conditions.

$$0 = \sum_{m \in M} \int \left\{ p_j \frac{\partial D_{jm}}{\partial p_j} + D_{jm} - c_{jm} \frac{\partial D_{jm}}{\partial p_j} \right\} dF(c_{-j}).$$

$$0 = \sum_{m \in M} \int \left\{ p_j \beta_{jj} + \alpha_j + \sum_{k=1}^3 \beta_{jk} p_k + \sum_{l=1}^L \gamma_l X_{ml} - c_{jm} \beta_{jj} \right\} dF(c_{-j}).$$

$$0 = \sum_{m \in M} \left\{ p_j \beta_{jj} + \alpha_j + \beta_{jj} p_j + \sum_{k \neq j} \beta_{jk} p_k + \sum_{l=1}^L \gamma_l X_{ml} - c_{jm} \beta_{jj} \right\}$$

$$p_j = \frac{\sum_m c_{jm}}{2M} - \frac{\alpha_j}{2} - \frac{\sum_{k \neq j} \beta_{jk} p_k}{2 \beta_{jj}} - \frac{\sum_m \sum_{l=1}^L \gamma_l X_{ml}}{2M}$$

$$\equiv \frac{1}{2} \bar{c}_j - \frac{\alpha_j}{2} - \frac{\sum_{k \neq j} \beta_{jk} p_k}{2 \beta_{jj}} - \frac{1}{2} \sum_{l=1}^L \gamma_l \bar{X}_l,$$  

As a result, the optimal pricing strategy depends on the expectation of opponent’s wholesale prices, which can be identified through taking expectation of the equilibrium conditions on all three first order conditions as follows. Note that $c_{jm} = w_{jm} u + \epsilon_{jm}$, where $\epsilon_{jm}$ are i.i.d. normal distribution. $\frac{\sum_m c_{jm}}{M} = \frac{\sum_m w_{jm}}{M} u + \frac{\sum_m \epsilon_{jm}}{M}$, i.e., $\bar{c}_j = \bar{w}_j u + \bar{\epsilon}_j$,

$$E p_j = \frac{1}{2} (\bar{w}_j u + E \bar{\epsilon}) - \frac{\alpha_j}{2} - \frac{\sum_{k \neq j} \beta_{jk} E p_k}{2 \beta_{jj}} - \frac{1}{2} \sum_{l=1}^L \gamma_l \bar{X}_l,$$

Matrix representation leads to

$$\begin{pmatrix} 1 & \frac{\beta_{12}}{2 \beta_{11}} & \frac{\beta_{13}}{2 \beta_{11}} \\ \frac{\beta_{21}}{2 \beta_{22}} & 1 & \frac{\beta_{23}}{2 \beta_{22}} \\ \frac{\beta_{31}}{2 \beta_{33}} & \frac{\beta_{32}}{2 \beta_{33}} & 1 \end{pmatrix} \begin{pmatrix} E p_1 \\ E p_2 \\ E p_3 \end{pmatrix} = \frac{1}{2} \begin{pmatrix} \bar{w}_1 u - \alpha_1 \\ \bar{w}_2 u - \alpha_2 \\ \bar{w}_3 u - \alpha_3 \end{pmatrix} + \frac{1}{2} E \bar{\epsilon} - \frac{1}{2} \sum_{l=1}^L \gamma_l \bar{X}_l$$

Note that the cross price coefficients are smaller than own price coefficient, the left-hand side matrix

$$A \equiv \begin{pmatrix} 1 & \frac{\beta_{12}}{2 \beta_{11}} & \frac{\beta_{13}}{2 \beta_{11}} \\ \frac{\beta_{21}}{2 \beta_{22}} & 1 & \frac{\beta_{23}}{2 \beta_{22}} \\ \frac{\beta_{31}}{2 \beta_{33}} & \frac{\beta_{32}}{2 \beta_{33}} & 1 \end{pmatrix}$$

26
is always invertible. As a result, the expectation of prices can be computed through following inversion,

\[
\begin{pmatrix}
Ep_1 \\
Ep_2 \\
Ep_3
\end{pmatrix} = \begin{pmatrix}
1 & \beta_{12} & \beta_{13} \\
\beta_{21} & \frac{1}{2\beta_{11}} & \frac{1}{2\beta_{11}} \\
\beta_{31} & \frac{1}{2\beta_{33}} & \frac{1}{2\beta_{33}}
\end{pmatrix}^{-1} \frac{1}{2} \begin{pmatrix}
\bar{w}_1 u + E\bar{\epsilon}_1 - \alpha_1 \\
\bar{w}_2 u + E\bar{\epsilon}_2 - \alpha_2 \\
\bar{w}_3 u + E\bar{\epsilon}_3 - \alpha_3
\end{pmatrix} - \sum_{l=1}^{L} \gamma_l \bar{X}_l
\]

Then, the pricing strategy can be represented as

\[
\begin{pmatrix}
p_1 \\
p_2 \\
p_3
\end{pmatrix} = \begin{pmatrix}
0 & -\beta_{12} & -\beta_{13} \\
-\beta_{21} & 0 & -\beta_{23} \\
-\beta_{31} & -\frac{1}{2\beta_{33}} & 0
\end{pmatrix} \begin{pmatrix}
Ep_1 \\
Ep_2 \\
Ep_3
\end{pmatrix} + \frac{1}{2} \begin{pmatrix}
\bar{c}_1 - \alpha_1 \\
\bar{c}_2 - \alpha_2 \\
\bar{c}_3 - \alpha_3
\end{pmatrix} - \sum_{l=1}^{L} \gamma_l \bar{X}_l
\]

\[
\equiv \frac{1}{2} A \begin{pmatrix}
\bar{w}_1 u + E\bar{\epsilon}_1 \\
\bar{w}_2 u + E\bar{\epsilon}_2 \\
\bar{w}_3 u + E\bar{\epsilon}_3
\end{pmatrix} - \frac{1}{2} (A + I) \begin{pmatrix}
\alpha_1 \\
\alpha_2 \\
\alpha_3
\end{pmatrix} + \sum_{l=1}^{L} \gamma_l \bar{X}_l
\]

where

\[
A \equiv \begin{pmatrix}
0 & -\beta_{12} & -\beta_{13} \\
-\beta_{21} & 0 & -\beta_{23} \\
-\beta_{31} & -\frac{1}{2\beta_{33}} & 0
\end{pmatrix} \begin{pmatrix}
1 & \frac{1}{2\beta_{11}} & \frac{1}{2\beta_{11}} \\
\frac{1}{2\beta_{22}} & \frac{1}{2\beta_{22}} & \frac{1}{2\beta_{22}} \\
\frac{1}{2\beta_{33}} & \frac{1}{2\beta_{33}} & \frac{1}{2\beta_{33}}
\end{pmatrix}^{-1}
\]

This provides us firm j’s pricing strategy for different \(\bar{c}_j\) and \(\sum_{l=1}^{L} \gamma_l \bar{X}_l\). The variation of \(\bar{c}_j\) and \(\sum_{l=1}^{L} \gamma_l \bar{X}_l\) leads to different national wholesale prices

\[
p_j = \Phi_j(\bar{c}_j, \sum_{l=1}^{L} \gamma_l \bar{X}_l).
\]

Note that \(c_{jm} = w_{jm} u + \epsilon_{jm}\), where \(w_{jm}\)'s are not random variable, and \(\epsilon_{jm} \sim N(\mu_\epsilon, \sigma_\epsilon^2)\). Consequently, the average cost over all states have following distribution,

\[
\bar{c}_j = \bar{w}_j u + \bar{\epsilon}_j \sim N\left(\bar{w}_j u + \mu_\epsilon, \left(\frac{\sigma_\epsilon}{M}\right)^2\right).
\]

### 1.2 Pricing strategy with auctions

To solve for the equilibrium pricing strategy with with state-specific procurement auctions, we simplify the equilibrium condition for pricing in following steps. Note that
the equilibrium conditions are
\[
\sum_{m \in M_j \delta_m} \int \left( \frac{\partial \lambda_m}{\partial p_j} (q_{jm} - a_{jm}) - (1 + \lambda_m) \frac{\partial a_{jm}}{\partial p_j} \right) \prod_{k \neq j} \left[ 1 - G_{km}(q_{jm}|p) \right] dF(c_{-j}) \\
+ \sum_{m \in M_j \delta_m} \int \left[ \sum_k D_{km}(p_j, p_{-j}) + (p_j - c_{jm}) \frac{\partial \sum_k D_{km}(p_j, p_{-j})}{\partial p_j} \right] dF(c_{-j}) \\
+ \sum_{m \in M_j \delta_m} \left( 1 - \delta \right) \int \left[ D_{jm}(p) + (p_j - c_{jm}) \frac{\partial D_{jm}(p)}{\partial p_j} \right] dF(c_{-j}) = 0.
\]

We simply the above equilibrium conditions by parts. First we simply the optimization part in the states about to host an auction,
\[
\sum_{m \in M_j \delta_m} \int \left( \frac{\partial \lambda_m}{\partial p_j} (q_{jm} - a_{jm} + p_j) + \lambda_m \right) \prod_{k \neq j} \left[ 1 - G_{km}(q_{jm}|p) \right] dF(c_{-j}) = \delta \sum_{m \in M_j \delta_m} \int \left( \sum_k \beta_{kj}(q_{jm} - c_{jm} + p_j) + \sum_k D_k(p_j, p_{-j}) \right) \prod_{k \neq j} \left[ 1 - G_{km}(q_{jm}|p) \right] dF(c_{-j})
\]

To promote tractability but deliver the essential message, we assume that only one state is going to host auction and denote this state as \( \tilde{m} \). As a result, this part of optimization becomes
\[
\delta \int \left( \sum_k \beta_{kj}(q_{j\tilde{m}} - c_{j\tilde{m}} + p_j) + \sum_k \alpha_k + \sum_j \sum_k \beta_{kj} p_j + \sum_j \sum_l \gamma_l X_{\tilde{m}l} \right) \prod_{k \neq j} \left[ 1 - G_{km}(q_{j\tilde{m}}|p) \right] dF(c_{-j}) \\
\equiv \delta \int \left( \beta_j (q_{j\tilde{m}} - c_{j\tilde{m}} + p_j) + \alpha + \sum_k \beta_k p_k + 3 \sum_l \gamma_l X_{\tilde{m}l} \right) \prod_{k \neq j} \left[ 1 - G_{km}(q_{j\tilde{m}}|p) \right] dF(c_{-j})
\]

The second part of optimization in the states that firm \( j \) has won auctions already can
be simplified as

$$\sum_{m \in \mathcal{M}_{j2}} \delta \int \left[ \sum_{k} D_{km}(p_j, p_{-j}) + (p_j - c_{jm}) \frac{\partial \sum_{k} D_{km}(p_j, p_{-j})}{\partial p_j} \right] dF(c_{-j})$$

$$= \sum_{m \in \mathcal{M}_{j2}} \delta \int \left[ \sum_{k} \left( \alpha_k + \sum_{j'} \beta_{kj} p_{j'} + \sum_{l} \gamma_l X_{ml} \right) + (p_j - c_{jm}) \sum_{k} \beta_{kj} \right] dF(c_{-j})$$

$$= \sum_{m \in \mathcal{M}_{j2}} \delta \left[ \sum_{k} \alpha_k + 2 \sum_{k} \beta_{kj} p_j + \sum_{j' \neq j} \sum_{k} \beta_{kj} E p_{j'} + \sum_{k} \sum_{l} \gamma_l X_{ml} - c_{jm} \sum_{k} \beta_{kj} \right]$$

$$= \delta M_2 \left[ \sum_{k} \alpha_k + 2 \sum_{k} \beta_{kj} p_j + \sum_{j' \neq j} \sum_{k} \beta_{kj} E p_{j'} + \sum_{k} \sum_{l} \gamma_l \frac{\sum_{m \in \mathcal{M}_{j2}} X_{ml}}{M_2} - \sum_{k} \beta_{kj} \frac{\sum_{m \in \mathcal{M}_{j2}} c_{jm}}{M_2} \right]$$

$$\equiv \delta M_2 \left[ \alpha + 2 \beta_j p_j + \sum_{k \neq j} \beta_k E p_k + 3 \sum_{l} \gamma_l X_l - \beta_j c_j \right]$$

The third part of optimization in all states can be simplified as

$$\sum_{m \in \mathcal{M}} (1 - \delta) \int \left[ D_{jm}(p) + (p_j - c_{jm}) \frac{\partial D_{jm}(p)}{\partial p_j} \right] dF(c_{-j})$$

$$= \sum_{m \in \mathcal{M}} (1 - \delta) \int \left[ \alpha_j + \sum_{k=1}^{3} \beta_{jk} p_k + \sum_{l=1}^{L} \gamma_l X_{ml} + (p_j - c_{jm}) \beta_{jj} \right] dF(c_{-j})$$

$$= (1 - \delta) M \left( \alpha_j + 2 \beta_{jj} p_j - \beta_{jj} \sum_{m \in \mathcal{M}} \frac{c_{jm}}{M} + \sum_{k \neq j} \beta_{jk} E p_k + \sum_{l} \gamma_l X_l \right)$$

$$\equiv (1 - \delta) M \left( \alpha_j + 2 \beta_{jj} p_j - \beta_{jj} \bar{c}_j + \sum_{k \neq j} \beta_{jk} E p_k + \sum_{l} \gamma_l \bar{X}_l \right)$$

Combining all three parts leads to following equilibrium conditions

$$0 = \int \left( \beta_j (q_{jm} - c_{jm} + p_j) + \alpha + \sum_{k} \beta_{kp} + 3 \sum_{l} \gamma_l X_{ml} \right) \prod_{k \neq j} \left[ 1 - G_{k\bar{m}}(q_{jm} | p) \right] dF(c_{-j})$$

$$+ \delta M_2 \left( \alpha + 2 \beta_j p_j + \sum_{k \neq j} \beta_k E p_k + 3 \sum_{l} \gamma_l \bar{X}_l - \beta_j \bar{c}_j \right)$$

$$+ (1 - \delta) M \left( \alpha_j + 2 \beta_{jj} p_j - \beta_{jj} \bar{c}_j + \sum_{k \neq j} \beta_{jk} E p_k + \sum_{l} \gamma_l \bar{X}_l \right) \quad \forall j = 1, 2, 3$$
Algebra manipulation leads to the following equation:

\[
p_j = -\frac{1}{2(\delta M_2 \beta_j + (1-\delta)M_{\beta j})} \left[ \delta M_2 \left( \alpha + \sum_{k \neq j} \beta_k E p_k + 3 \sum_l \gamma_l X_l - \beta_j \tilde{c}_j \right) \right. \\
+ \left. \delta \int \left( \beta_j (q_j \bar{m} - c_j \tilde{m} + p_j) + \alpha + \sum_k \beta_k p_k + 3 \sum_l \gamma_l X_l \right) \prod_{k \neq j} [1 - G_{k\bar{m}}(q_{j\bar{m}}|p)] dF(c_{-j}) \right] \\
+ \left. (1-\delta)M \left( \alpha_j - \beta_j \tilde{c}_j + \sum_{k \neq j} \beta_{jk} Ep_k + \sum_l \gamma_l X_l \right) \right) \quad \forall j = 1, 2, 3 \tag{23}
\]

Solving above system of nonlinear equations leads to all three firms optimal pricing strategies, denoted as \( \Phi_j \). From the first order conditions, covariates \( c_{jm}, \sum_l \gamma_l X_{ml}, \tilde{c}_j, \sum_l \gamma_l \tilde{X}_l \) should enter firm \( j \)'s optimal pricing strategy, that is,

\[
p_j = \Phi(c_{jm}, \tilde{c}_j, \tilde{c}_j, \sum_l \gamma_l X_{ml}, \sum_l \gamma_l \tilde{X}_l, \sum_l \gamma_l \tilde{X}_l).
\]

Note that \( c_{jm} = w_{jm} u + \epsilon_{jm} \) and \( \epsilon_{jm} \sim N(\mu, \sigma^2) \). Consequently, above cost have following distributions,

\[
\tilde{c}_j = \bar{w}_j u + \tilde{c}_j \sim N \left( \bar{w}_j u + \mu, \left( \frac{\sigma}{M} \right)^2 \right)
\]

\[
\tilde{c}_j = \bar{w}_j u + \tilde{c}_j \sim N \left( \bar{w}_j u + \mu, \left( \frac{\sigma}{M_2} \right)^2 \right)
\]

\[
c_{jm} = w_{jm} u + \epsilon_{jm} \sim N \left( w_{jm} u + \mu, \sigma^2 \right)
\]

Fix \( \{\bar{w}_j u, \bar{w}_j u, w_{jm} u, \sum_l \gamma_l X_{ml}, \sum_l \gamma_l \tilde{X}_l, \sum_l \gamma_l \tilde{X}_l\} \), we solve the equilibrium conditions for the pricing strategy

\[
p_j = \Phi_j(c_{jm}, \tilde{c}_j, \tilde{c}_j, \sum_l \gamma_l X_{ml}, \sum_l \gamma_l \tilde{X}_l, \sum_l \gamma_l \tilde{X}_l).
\]

We use iteration to solve for \( \Phi_j \) and describe the procedure in the following. First we simulate the winning probability \( \prod_{k \neq j} [1 - G_{k\bar{m}}(q_{j\bar{m}}|p)] \) for different values of \( p \).

1. To start the iteration, we use the pricing strategy without auction

\[
p_j = \Phi_j(c_{jm}, \tilde{c}_j, \tilde{c}_j, \sum_l \gamma_l X_{ml}, \sum_l \gamma_l \tilde{X}_l, \sum_l \gamma_l \tilde{X}_l) = \Phi_j(\tilde{c}_j, \sum_{l=1}^L \gamma_l \tilde{X}_l)
\]

as the initial value.

2. In iteration step \( \tau \), suppose we know \( p_j^\tau = \Phi^\tau(c_{jm}, \tilde{c}_j, \tilde{c}_j, \sum_l \gamma_l X_{ml}, \sum_l \gamma_l \tilde{X}_l, \sum_l \gamma_l \tilde{X}_l) \).
With $\Phi^\tau$, we can compute the expectation $E p_j^\tau$.

For different values $c_{jm}$, we know $q_{jm}$ and the probability of winning $\prod_{k\neq j}[1 - G_{km}^{\tau}(q_{jm}|p^\tau)]$.

Then we update the pricing strategy for different values of $c_{jm}, \tilde{c}_j, \bar{c}_j$ according to equation 24.

$$p_j^{\tau+1} = -\frac{1}{2(\delta M_2 \beta_j + (1 - \delta)M \beta_{jj})} \left[ \delta M \left( \alpha + \sum_{k\neq j} \beta_k E p_k^\tau + 3 \sum_l \gamma_l \bar{X}_l - \beta_j \bar{c}_j \right) \right.$$ 

$$+ \delta \int \left( \beta_j (q_{jm} - c_{jm} + p_j^\tau) + \alpha + \sum_k \beta_k p_k^\tau + 3 \sum_l \gamma_l X_{ml} \right) \prod_{k\neq j} \left[ 1 - G_{km}(q_{jm}|p_j^\tau, p_{-j}^\tau) \right] dF(c_{-j})$$

$$+ (1 - \delta)M \left( \alpha_j - \beta_{jj} \bar{c}_j + \sum_{k\neq j} \beta_{jk} E p_k^\tau + \sum_l \gamma_l \bar{X}_l \right) \right] \quad \forall j = 1, 2, 3$$

3. We keep iterating until $p_j^{\tau+1}$ is very close to $p_j^\tau$.

For better comparison, we are going to consider following different scenarios.

- There is only one big state about to host the procurement auction.
- There is only one small state about to host the procurement auction.
- There are one big and one small states to host the procurement auctions.
- There are two big states to host the procurement auctions.