Assessing Performance Impacts in Food Retail Distribution Systems: A Stochastic Frontier Model Correcting for Sample Selection

Timothy A. Park

A key organizational decision for retailers is whether to self-distribute or rely on a wholesaler-supplied network and yet little is known about the impact of this strategic choice on store-level productivity. We estimate a stochastic frontier model for food retailers that accounts for selectivity effects linked to the choice of distribution strategy. We find that adoption of data-sharing technologies has a positive impact on store-level gross margins of stores in self-distributing chains. Technical inefficiency among U.S. food retailers leads to a gross margin that is around $5,000 less for a conventional food retailer and about $7,670 less for a supercenter.

Key Words: food retailing, sample selection, self-distribution, stochastic frontier

Many changes in the retail food environment are readily apparent to consumers, including the emergence of larger stores, a variety of new store formats, and enhanced service features offered by retailers. A less visible but equally important change is under way in the distribution structure of food retailing. The declining importance of independent supermarkets and rise of chain supermarkets have prompted a shift away from distribution by independent wholesalers and toward self-distribution systems in which retail stores and primary distribution centers operate under common ownership. Retail experts have highlighted a shift in volume from third-party wholesalers to chains' own self-distribution centers. Kinsey (2000) noted that wholesalers generally report lower costs in self-distributing channels and contended that increased retail consolidation has promoted the growth of self-distribution.

Food retailers that do not obtain their products through self-distribution or direct store delivery (DSD) from manufacturers are supplied through the wholesaler channel, and manufacturing (or packing), distribution, and retailing are performed by separate firms. Products flow from manufacturers to distribution centers operated by wholesalers and then to individual food service and food retail establishments. The Grocery Manufacturers Association (2008) noted that DSD represented 24 percent of unit sales and 52 percent of retail profits in the grocery channel and was "poised to become even more important to the retail trade in future years" (p. 2).

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Retail analysts (*DSN Retailing Today* 2008) have linked the effectiveness of Walmart's supercenters to its superior self-distribution network while Kmart's competitive disadvantages have been attributed in part to its lack of a self-distribution system. Self-distribution is recognized as a method by which to reduce supply chain costs and achieve greater efficiency, which allows stores to expand margins, improve in-stock availability, and enhance store productivity. Target developed a self-distribution initiative and established distribution centers following its decision to expand the assortment and quality of its food product lines.

Logistic and material-handling experts, on the other hand, continue to emphasize the strategic importance of wholesale distributors in the supply chain for retail goods. Wholesale distributors provide a range of services, including volume and transportation consolidation, bulk breaking, repackaging, material handling, and assumption of inventory risk. Sherman (2001) predicted an expanded role for wholesale distributors in the supply channel in collaborating with manufacturers and retailers and that wholesale distributors would continue to "offer tremendous economic value to the self-distributing retailer, the independent retailer, and the manufacturer" (digital article). King (2003) noted that wholesaler-supplied stores remain competitive due to lower labor costs and the retail area of such stores and explained that wholesaler-supplied stores may better adapt to their customers' needs since they usually are operated by smaller, locally owned companies.

The primary objective of this research is to understand how supply chain management decisions impact the efficiency of food retailing establishments. We examine how distribution choices by food retailers are influenced by store size and format and hiring decisions. We also analyze the effect of operating practices and trading-partner relationships associated with information technology. We estimate a stochastic frontier model for food retail stores that accounts for selectivity effects linked to the choice of distribution strategy. The impacts of variables that influence distribution strategies are estimated jointly with the stochastic frontier model, thus controlling for latent factors that influence both the retailer's distribution strategy and store performance. The analysis is the first to be applied to the stochastic frontier model corrected for selectivity bias to the retail sector to yield unbiased measures of the critical factors influencing retail performance.

We use data from a unique national survey of supermarkets by The Food Industry Center at University of Minnesota to estimate a store-level frontier production function that includes store and organizational characteristics along with adoption of new information technologies. The results are useful in assessing retail performance at the store level, establishing performance benchmarks, and identifying top-performing stores across retail formats and operating practices.

Distribution Strategies of Food Retailing Firms

A key organizational decision for retailers is whether to self-distribute or rely on a wholesaler-supplied network for product distribution. In self-distributing chains, the retail stores and distribution centers are under common ownership, which facilitates coordination between these two segments of the retail supply chain and enhances productivity gains. Grocery retailers often choose to vertically integrate to enhance the prospects for operational efficiency and gain strategic advantages over competitors.

Little is known about the impact of distribution strategies on retail performance at the store level. Akkerman, Farahani, and Grunow (2010) noted that "distribution network design is among the most critical operations management decisions facing a firm, as it affects costs, time, and quality of customer service" (p. 873). Previous studies of the retail sector typically did not incorporate information on the distribution strategies used (Keh and Chu 2003). Sellers-Rubio and Más-Ruiz (2009) estimated the technical efficiency of supermarket chains in Spain and incorporated marketing variables and characteristics of the retail firm (such as type of store) but did not include information on distribution strategies. Studies that have included an indicator variable for the distribution strategy, such as King and Park (2004), did not account for selectivity bias and thus generated biased results when selectivity was present.

The supermarket survey data in this analysis contain information that is used to distinguish stores that are wholesaler-supplied and stores that are part of a self-distributing group (*SelfDist*). Information on the role of wholesaler supply and self-distribution is featured prominently in industry surveys conducted by the Food Marketing Institute in *The Food Industry Speaks* survey (2010). According to surveys from The Food Industry Center, stores in self-distributing groups, which account for 33 percent of the stores in the sample, report a gross margin figure that is 2.4 times higher than the margin for stores that are wholesaler-supplied. Stores in self-distributing groups also typically provide higher levels of benefits and incentives for both full-time and part-time workers.

Self-distribution is also closely related to store formats. Retail food stores can be assigned to one of four format categories that are based on store size and distribution services: conventional, food/drug combination, supercenter, and warehouse/super-warehouse. The conventional store category accounts for the largest share across all distribution strategy categories. Conventional stores predominate in the wholesaler-supplied category (84 percent) but also represent about 38 percent of the stores in the self-distribution category.

We specify the decision to adopt self-distribution as a probit model:

$$I^* = \alpha'\mathbf{Z}_i + w_i \tag{1}$$

where $\mathbf{Z}$ is a vector of exogenous variables that influence the distribution model chosen by a retailer, α is a vector of parameters, and the error term is normally distributed between 0 and 1. The variable I^* (*SelfDist*) takes a value of 1 if the store is part of a self-distribution group and 0 otherwise. Our model specification follows King (2003), which noted distinct differences between wholesaler-supplied stores and self-distributing chains in adoption and use of supply chain technologies and decision sharing. Matsa (2011, p. 1572) found that a primary difference between warehouse and DSD distribution is that "the manufacturer's distributor typically plays the lead role in store-level category management, merchandising, and managing of shelf inventory for DSD products." We include five indicators of supply chain technology measures adopted at the store level: data sharing, decision sharing, and product assortment, pricing, and merchandising. Data on those measures in the supermarket panel were consistently collected in the annual surveys.

Stochastic production frontier models allow for both technical inefficiency and random shocks to the production function that are not controlled by producers. Stochastic frontier analysis assumes a composite error term that consists of two random variables. The first, v_i, is a symmetric noise term that reflects the influence of random noise on retail performance and can take on both positive and negative values. The second is an asymmetric inefficiency error term, u_i, that accounts for technical and managerial constraints and assumes only nonnegative values. A standard specification for a stochastic frontier model is

(2) $$\ln y_i = \ln f(x_i, r_i) + v_i - u_i$$

where y_i represents the gross margin of the retail store and $f(x_i, r_i)$ is the deterministic frontier with inputs x_i and store operational characteristics by r_i. The v_i are mean zero identically and independently distributed random variables with $v_i = \sigma_i V_i$ where $V_i \sim N[0,1]$. Technical inefficiency is represented by the one-sided error term, u_i, and follows a half-normal distribution with $u_i = |\sigma_u U_i|$ where $U_i \sim N[0,1]$.

The stochastic frontier model with sample selection accounts for correlation between unobserved factors in the selection model and random noise in the stochastic frontier:

(3) $$(w_i, v_i) \sim N_2[(0,1), (1, \rho\sigma_v, \sigma_v^2)].$$

The error terms indicated by N_2 follow a bivariate normal distribution, and ρ is the correlation coefficient. The model allows the idiosyncratic factors that enter the error term in the choice of distribution strategy to be correlated with the random shocks in the stochastic frontier model.

Empirically, we observe a significant degree of heterogeneity in adoption of information technologies by food retailers. We discuss the key features of this heterogeneity in the data section but first address the implications of such heterogeneity for the selectivity model. Unobserved factors that influence the adoption, use, and integration of information technology at the store level may be related to random shocks in the stochastic frontier model. These random shocks to production are unobserved by the econometrician but observed by store managers.

An extension of the stochastic frontier model with sample selection is required and we adapt Heckman's (1979) specification of the selectivity model. Terza (2009) extended Heckman's method to a broad class of nonlinear regression models (including probit, multinomial logit, and count data models) involving endogenous sample selection and endogenous treatment effects. Greene (2010) developed a selectivity approach for the stochastic frontier model based on a conditional simulated log-likelihood function. The model is estimated using a nonlinear search routine with asymptotic standard errors obtained from the Berndt-Hall-Hall-Hausman algorithm for nonlinear maximum-likelihood optimization problems.

We apply a two-step approach in which we first estimate a probit model that determines whether the store is part of a self-distribution chain or is wholesaler-supplied. Maximum-likelihood estimates of the parameters from the probit model are then inserted into the simulated log-likelihood to estimate the parameters of the stochastic frontier model. The standard errors from the second stage are corrected using Murphy and Topel's (2002) approach to account for the estimated parameters from the first step.

The store-specific estimates of technical efficiency are calculated as $TE_i = \exp(-\hat{u}_i)$ with values between 0 and 1 where 1 indicates an efficient food retailing establishment located on the frontier. Greene (2010) summarized the method by which we obtain producer-specific estimates of technical efficiency from the conditional distribution, $E[u_i \mid \varepsilon_i]$, using the simulated values of u_i obtained during estimation, and ε_i is defined as $\nu_i - u_i$.

The technical efficiency values are computed for each observation using the estimated parameters, the original data, and the same set of random draws used in the estimation procedure. An advantage of this simulation-based estimation technique is that it can, in principle, simulate any inefficiency distribution.

Data Collection and Sample Characteristics

We use data (summarized in Table 1) from a nationwide survey of food retailers conducted by The Food Industry Center at the University of Minnesota that reports information on stores' characteristics, operating practices, and performance for 2000, 2001, 2002, 2003, and 2007. The surveys were mailed directly to store managers, and each respondent subsequently received a customized benchmark report that compared his/her store to a peer group of stores that were similar in size and format. The survey is unique in that the unit of analysis is the individual store with information gathered directly from store managers. Findings presented in the *Annual Report of the Grocery Industry* published by Progressive Grocer and in the Food Marketing Institute's annual *The Food Industry Speaks* reports are based on company-level responses for representative stores. Data collection procedures for the company-level surveys are described by The Food Industry Center and Kinsey et al. (2003), which offers a representative example.

A standard output measure for retail stores is gross margin (*GrMarg*), which is defined as weekly sales minus the cost of goods sold. Baily and Solow (2001) suggested that the gross margin generated by a retailer is the best single measure of retailing output. It reflects the retail services that are provided, such as the variety of merchandise, convenience of the store location, and availability of checkout employees and food department personnel, plus provision of other nonretail in-store services. In this analysis, we use nominal gross margins, but our results do not change when real gross margins for the period are used.

The inputs for the food retail establishment are store size (*SSize*), full-time labor hours (*FTHrs*), and part-time labor hours (*PTHrs*). Store energy costs and other major capital inputs (e.g., refrigeration equipment and lighting, shelving and display cases, and front-end checkout equipment) are highly correlated with store size. In our data set, the average store size is about 28,000 square feet; conventional supermarkets have the smallest average size (about 16,611 square feet) and warehouse, supercenter, and super-warehouse formats have the largest stores (an average of about 62,954 square feet).

We measure the impact of workforce quality and composition on retail output by the store's use of full-time and part-time workers. Food retailing establishments in the surveyed stores scheduled full-time and part-time workers for an average of 1,927 hours per week with full-time employees accounting for about 55 percent of total hours worked. Average work hours are lowest for conventional stores (1,208 per week) and highest for superstores (4,210 per week). Oi (1992) noted that reliance on part-time workers is an indicator of the skill mix of the retail workforce.

In our sample, larger ratios of part-time to full-time employees are associated with larger store sizes. But larger stores also pay higher wages than smaller stores because their employees perform a greater variety of tasks. As a result, wages for part-time workers are higher at larger supermarkets than at smaller stores. In terms of full-time employees, larger stores must hire more clerks than smaller stores but the clerks are more productive because a larger store typically has a steady stream of customers through checkout. Full-time workers also benefit from the higher wages paid by larger supermarkets. The critical relationship to note is the size-wage premium: wages of part-time workers rise faster than wages of full-time workers as stores get bigger. Oi (1992) concluded that productivity gains associated with sales volumes in food retailing are

Table 1. Variable Descriptions and Summary Statistics for Food Retailing Establishments

Variable	Description	Self-Distribution	Wholesaler-Supplied
GrMarg	Gross margin (dollars per week)	94,636 (61,607)	39,298 (39,801)
SSize	Store selling area (square feet)	41,975 (22,829)	20,516 (15,329)
FTHrs	Full-time labor (hours per week)	1,491 (1,018)	818 (729)
PTHrs	Part-time labor (hours per week)	1,413 (901)	730 (690)
GSize	Ownership group size (number of stores)	722 (956)	17 (144)
Union	At least 25 percent of employees are covered by collective bargaining	0.52	0.25
EDIData	Electronic data interchange (EDI) and internet data-sharing technologies (five)	3.09 (1.39)	1.67 (1.37)
EDIDecis	Technologies that facilitate decision-sharing (three)	0.67 (0.85)	0.29 (0.54)
EDIMerch	Technologies that support product assortment, pricing, merchandising (four)	2.99 (0.61)	2.45 (0.95)
JobGrowth	Job growth at the establishment (percent change)	−0.64 (0.20)	1.88 (0.19)
Convl	Conventional format, 1 if yes	0.38	0.84
FoodDrug	Food/drug combination or upscale format, 1 if yes	0.21	0.06
SCenter	Warehouse, supercenter, or super-warehouse format, 1 if yes	0.12	0.05
Superstore	Superstore format, 1 if yes	0.29	0.05
Observations		378	760

Note: Standard errors are shown in parentheses for continuous and nondichotomous variables.

relatively greater for part-time employees. Our empirical model allows us to evaluate the relative impact of full-time and part-time employees on store performance measured by gross margins.

Key characteristics of the firms that own and operate stores may also impact gross margins and are included in the model. First, membership in a larger group of stores (*GSize*) may boost productivity through multistore economies in procurement and advertising and through centralization of some managerial functions. Hoppe (2002) commented on empirical evidence that large firms with a greater number of establishments tend to adopt new technologies sooner than small firms because the larger firms expect a greater return from adoption. The larger firms generate savings in nonproduction costs such as transportation, distribution, and inventory control while taking advantage of the economies of massed reserves and information-sharing between establishments.

Unionization is another organizational factor that may affect productivity if a unionized workforce is associated with significant differences in worker skills and/or workforce stability. Thus, our empirical model includes a binary variable that equals 1 if at least one-quarter of the workforce is covered by a collective bargaining agreement (*Union*) and 0 otherwise. About 23 percent of the stores in the sample were identified as unionized, and the average gross margin for those stores was more than two times greater than the average margin for the nonunionized stores. Unionized retail food stores in self-distributing chains gain additional synergies in store performance—their average gross margin was 3.17 times greater than the average margin for nonunionized wholesaler-supplied stores.

An analysis of supply chain technologies in Park and King (2007) grouped information technology practices into three general categories (see Table 2). The first category contains data-sharing technologies and includes components such as internet/intranet links to corporate headquarters and key suppliers, electronic transmission of movement data to headquarters and key suppliers, electronic receipt of invoices from a primary warehouse, electronic receipt of invoices from DSD vendors, and electronic transmission of orders to vendors and suppliers. The second category accounts for decision-sharing technologies and practices, such as vendor-managed inventories (orders generated by vendors based on store movement data), scan-based trading (payments to vendors based on sales to consumers), and computer-assisted ordering (scanning data used for automatic inventory refill). The third category encompasses technologies that support product assortment, pricing, and merchandising decisions and includes product movement analysis and category management, plan-o-grams for shelf space allocation, electronic shelf tags, and frequent-shopper and loyalty card programs.

In our data set, adoption rates for all of the information technologies except electronic shelf tags and frequent-shopper programs trend generally upward with store size. The self-distribution strategy is also closely linked to organizational characteristics that influence technology adoption decisions. Stores in self-distribution chains adopt a wider portfolio of technologies than wholesaler-supplied stores for each of the three technology categories: data sharing, decision sharing, and product assortment, pricing, and merchandising. Diffusion of the technologies through the self-distribution stores is also more advanced compared to wholesaler-supplied stores. Six of the twelve technologies (across the three categories) had been adopted by more than 60 percent of the self-distributing stores. For the wholesaler-supplied stores,

Table 2. Adoption of Supply Chain Technology Measures in the Supermarket Survey

Technology	Percent of Stores That Adopted: Self-Distribution	Percent of Stores That Adopted: Wholesaler-Supplied
Data Sharing		
Electronic invoices from DSD vendors	64	20
Electronic invoices from the primary warehouse	39	18
Electronic transmission of movement data to headquarters or key supplier	82	35
Electronic transmission of orders to vendors/suppliers	64	54
Internet/intranet link to corporate headquarters and/or key suppliers	60	39
Decision Sharing		
Scan-based trading	36	19
Scanning data used for automatic inventory refill	17	3
Vendor-managed inventory	14	8
Product Assortment, Pricing, and Merchandising		
Electronic shelf tags	18	20
Product movement analysis and/or category management	90	67
Frequent-shopper and/or loyalty card programs	100	99
Shelf-space allocation plan-o-grams	90	58

the only technologies that achieved that level of market penetration were category management techniques and frequent-shopper and loyalty card programs.

We include a measure of job market flow at the store level following Davis, Faberman, and Haltiwanger (2006): annual change in employment at the retail store divided by average employment at the store at the beginning of the year and at the end of the year. The flow measure of job growth is standard in labor studies and yields growth rates within an interval of –200 percent to +200 percent. In our sample, average job growth at the store level is negative for self-distributing stores, likely a result of negative rates for retailers in the warehouse, supercenter, and super-warehouse and superstore categories. Job growth is positive, on the other hand, for wholesaler-supplied stores and for retailers in the warehouse, supercenter, and super-warehouse and superstore categories that reported the largest increases in employment.

Model Interpretation and Assessment

The frontier production function for the *i*th food retailer is specified using a translog functional form for inputs along with store-level organizational and operational factors that directly influence the retail operation. The inputs for food retail establishments are store size (*SSize*), full-time labor hours (*FTHrs*), and part-time labor hours (*PTHrs*). The second-order terms in the translog production frontier are represented by *k*(*SSize, FTHrs, PTHrs*) with estimated coefficients denoted by α_{ij}. The logarithm of the gross margin of the retail store (*GrMarg*) is the dependent variable in the production frontier. The stochastic frontier model is thus expressed as

$$(4) \qquad \ln GrMarg_i = \alpha_0 + \alpha_1 \ln(SSize_i) + \alpha_2 \ln(FTHrs_i) + \alpha_3 \ln(PTHrs_i) + \alpha_{ij}\, k(SSize_i, FTHrs_i, PTHrs_i) + \sum_j \varphi_j r_{ij} + v_i - u_i .$$

Stores' operational characteristics are represented by *r* with estimated parameters denoted by φ. The random error term *v* accounts for idiosyncratic shocks that are not controlled by the food retailers. In the model, random shocks and events that impact the gross margin occur after the retailing establishment has committed resources to choosing a store size and established the size of its workforce.

Model Results

Table 3 reports the results from the probit model that compares wholesaler-supplied stores to self-distribution chain stores. For the dichotomous variables, the marginal effects denote the change in probability that a retail outlet is a member of a self-distribution chain (*SelfDist* = 1). Standard errors for the marginal effects are calculated using the delta method. The overall significance of the model is confirmed by the chi-square test statistic. The McFadden R-square from the probit model is 0.69 and the percentage of correct predictions is 92.7.

Table 3. Probit Model for Self-Distribution Stores vs. Wholesaler-Supplied Stores

Variable	Self-Distribution	Marginal Effects	Variable	Self-Distribution	Marginal Effects
Constant	−3.26* (9.87)		*EDIMerch*	0.08 (0.91)	0.02 (0.92)
ln(*GSize*)	0.82* (15.98)	0.24* (13.52)	*JobGrowth*	−0.53* (−1.63)	−0.15* (−1.63)
Union	0.24* (1.76)	0.08* (1.71)	*Convl*	−0.44* (−2.33)	−0.14* (−2.25)
EDIData	0.15* (3.06)	0.04* (3.08)	*SCenter*	−0.07 (−0.28)	−0.02 (−0.29)
EDIDecis	−0.22* (−2.19)	−0.06* (−2.21)	*SuperStore*	0.05 (0.22)	0.02 (0.21)
McFadden R-square		0.68			
Chi-square		989.72			
Number of observations		1,138			

Notes: Asymptotic t-values are shown in parentheses with significance at the α = 0.10 level. The critical value for $\chi^2_9 = 14.68$ at the α = 0.10 significance level.

Two variables that describe the stores' organizational characteristics have positive and statistically significant parameter estimates: the log of ownership group size and the binary variable for a union workforce. Foster, Haltiwanger, and Krizan (2006) pointed to entry by large national chains as a key step in enhancing retail productivity because the chains displace less productive single-unit establishments. We find that job growth has a negative impact on the probability that a food retailing establishment is part of a self-distribution chain.

A surprising finding is the significant impact of data-sharing technologies on the probability that a retailer operates in a self-distribution network. King and Park (2004) reported that data-sharing technologies (internet/intranet links to corporate headquarters and/or key suppliers, electronic transmission of product movement data, and electronic receipt of invoices from the primary warehouse) did not have a significant impact on store-level performance. King and Park (2004) also suggested that rates of adoption of information technologies are greater for stores that are part of self-distribution chains. Technology decisions made at the corporate headquarters likely reflect assessments of overall costs and benefits for both supply chain segments. The selectivity-corrected frontier model confirms this conjecture and thus provides new insight into the direct impact of information technology adoption on supply chain strategies developed by food retailers.

Wholesaler-supplied stores lack the more comprehensive decision-making perspective of stores embedded in self-distribution chains. Our analysis highlights the difficulty associated with providing incentives for store-level adoption of information technologies when the stores and their distribution centers are not under common control.

Adoption of decision-sharing technologies (scan-based trading, scanning data used for automatic inventory refill, vendor managed inventory) has a negative impact on the probability that a retailer operates in a self-distribution network. Kinsey et al. (2003, p. 20) in the 2003 *Supermarket Panel Annual Report* noted that "sharing or passing decisions to parties outside the store is considered 'advanced' supply chain management." Our results show that adoption of such technologies is driven primarily by store size.

The results of our model show that technologies that support product assortment, pricing, and merchandising do not have a significant impact on the retailer's choice of distribution network.

Stochastic Frontier of Store Performance

Parameter estimates from the gross-margin model for self-distribution retail establishments are reported in Table 4. The stochastic frontier model with no sample selection is obtained by constraining ρ to zero. The calculated value of the likelihood-ratio test statistic is 6.22 and exceeds the critical χ^2_1 value of 2.70 at the 90 percent confidence level, providing statistical support for our specification of the sample selection model. The Wald statistic (t-ratio) for the estimate of ρ is –2.04, confirming the presence of selectivity effects.

The return-to-scale measure is 1.51 but the estimate is not significantly greater than 1, implying constant returns to scale for the set of variable inputs (store space, full-time labor, and part-time labor). King and Park (2004) also found constant returns to scale for supermarkets. Economists studying retail markets typically suggest the presence of economies of scale and long-run average costs that are declining as retailers expand store size and hire more labor. With constant input prices for labor, the region of increasing returns to scale is identical to the region of economies of scale. Therefore, a finding of constant returns to scale implies no scale economies. The output elasticities from the stochastic production frontier are higher for both full-time labor and part-time labor for supercenters than for conventional food retailers.

In terms of economies of scale, economists studying retail markets have typically suggested their presence in food retailing firms with long-run average costs that decline as retailers expand store size and hire more labor. With constant input prices for labor, the region of increasing returns to scale is identical to the region of economies of scale. Thus, a finding of constant returns to scale for labor implies that there are no economies of scale. We find that the output elasticities from the stochastic production frontier for full-time

Table 4. Production Function Parameter Estimates for Food Retailing Establishments

Parameter	Variable	Estimate	t-Ratio
α_0	*Intercept*	3.26	0.85
α_1	*SSize*	0.06	0.08
α_2	*FTHrs*	–1.15*	–2.96
α_3	*PTHrs*	–0.12	–0.35
α_{11}	*SSize * SSize*	–0.04	–0.53
α_{22}	*FTHrs * FTHrs*	0.18*	4.91
α_{33}	*PTHrs * PTHrs*	0.19*	5.75
α_{12}	*SSize * FTHrs*	0.08	2.23
α_{13}	*SSize * PTHrs*	–0.03	–0.49
α_{23}	*FTHrs * PTHrs*	–0.10*	–3.66
φ_1	*EDIData*	0.02*	2.04
φ_2	*EDIDecis*	0.24E-02	0.02
φ_3	*EDIMerch*	–0.2	–1.35
φ_4	*JobGrowth*	–0.01	–0.16
φ_5	*Convl*	0.01	0.59
φ_6	*SCenter*	0.02	0.75
φ_7	*Superstore*	–0.16E-02	–0.63
σ_u		0.11*	2.11
σ_υ		0.13*	7.68
$\rho(w, \upsilon)$		–0.37*	–2.04

Number of observations: 378

Notes: Asterisks indicate asymptotic t-values with significance at the α = 0.10 level. Inputs are indicated by α and store-level organizational and operational factors by φ. $\lambda = \sigma_u / \sigma_v = 0.85$ and $\sigma = (\sigma_u^2 + \sigma_v^2)^{1/2} = 0.17$.

and part-time labor are greater for supercenters than for conventional food retailers.

The results from our stochastic frontier model align with work by Betancourt and Malanoski (1999) that estimated a multi-output cost function for supermarkets based on deflated sales and an index of distribution services provided by the stores. The most statistically robust results presented by Betancourt and Malanoski suggest the presence of economies of scale for the choice of distribution service but no returns to scale with respect to output or the gross margin measure used here. Oi (1992) contended that, due to economies of scale in distribution, large stores should have lower operating costs. That contention is not confirmed by our results. Guy, Bennison, and Clarke (2005) found economies of scale in store size based on a limited survey of 23 retailing firms in the United Kingdom. Our stochastic frontier production function allowed us to statistically test for the presence of returns to scale and economies of scale, and our results do not support the presence of economies of scale. We also analyze performance characteristics. In 2004, the National Grocers Association (2004) surveyed supermarket managers and found that nearly 80 percent of them listed competition from superstores as the primary concern in terms of marketing, pricing, and variety of offerings. However, our empirical results do not demonstrate such a competitive advantage in performance. In our model, the estimated coefficients for the store categories allow us to compare store performance across formats to the performance of the average supermarket in the sample. We find that the null hypothesis that the format (conventional, food/drug combination, supercenter, and warehouse/super-warehouse) effects are jointly equal to 0 is not rejected; the calculated χ^2 value of 0.87 is below the critical χ^2_3 value of 6.25 at the 90 percent confidence level. Our results provide useful insight for retail industry analysts who frequently report store performance grouped by store format. For example, the Points of Impact Retail Operations Survey by the National Grocers Association (2004) calculated average gross profit across store formats such as conventional supermarkets, upscale and conventional superstores, and upscale and discount stores. We control for inputs such as store size and labor use and find that store format does not have a significant influence on gross margins for food retailers.

We find that adoption of data-sharing technologies has a positive impact on store-level gross margins. Retailers who had adopted at least one data-sharing technology had an average gross margin that was about 30 percent higher than stores that had made no investment in such technologies. Retail operations that had adopted the complete portfolio of data-sharing technologies had an average gross margin that was about 190 percent higher than stores that had applied no data-sharing technologies. King (2003) noted two ways that data-sharing in the supply chain may expand gross margins at the store level. The distribution center may pass along cost savings in inventory management and logistics, leading to a lower cost of goods sold at the store level. And coordination of information between store-level managers and vendors, primary warehouses, and key suppliers may allow stores to adjust product offerings and expand sales of high-margin products, resulting in greater revenue.

Kulp, Lee, and Ofek (2004) suggested that information-sharing and data-sharing are necessary first steps toward integrating a supply chain and that such sharing provides initial benefits that boost margins and allow "firms to remain competitive but may not be sufficient to excel and achieve supra-normal margins" (p. 443). They noted that manufacturers in the food and consumer packaged goods industry reported the greatest benefits from collaborative practices, not from data-sharing. High-profit-margin manufacturers prefer to collaborate on new products and services and on vendor-managed inventory initiatives while manufacturers with lower profit margins tend to promote information-sharing practices. The estimates from our selectivity-corrected stochastic frontier model highlight synergies that result from data-sharing among stores in self-distribution chains.

Technical Efficiency in the Distribution Network

The need for an analysis of the impact of technical inefficiency on the performance of food retailers is confirmed by the statistical significance of our estimate of λ of 0.85. The ratio of the standard deviation of store-specific technical efficiency to the overall standard deviation of the gross margin of the retailer is 0.65, indicating that about 65 percent of variation in gross margins is due to the degree of technical efficiency.

Table 5 summarizes the estimates of overall technical efficiency from the stochastic frontier model. The estimated mean technical efficiency score is 91.0 percent for self-distributing stores, which indicates that those retailers face constraints in implementing production methods that would allow them to achieve maximum output levels given the inputs used. It thus implies that gross margins could feasibly be increased by 9.0 percent with current input use and

Table 5. Technical Efficiency Scores of Food Retailing Establishments

	Stochastic Production Frontier	
	With Selectivity Correction	**Without Selectivity Correction**
Efficiency Level		
Mean	0.91	0.94
Standard deviation	0.03	0.02
Maximum	0.97	0.98
Minimum	0.75	0.75
Number of Retailers at Efficiency Level		
Greater than 95 percent	24	117
90–95 percent	283	249
80–90 percent	68	10
Less than 80 percent	3	2
Efficiency level of retailers given adoption of top three technologies[a]	0.95	0.94

[a] The three most frequently adopted technologies are use of electronic invoices from DSD vendors, electronic invoices from the primary warehouse, and electronic transmission of movement data to headquarters or key suppliers.

existing production technologies. Of the 378 stores in the sample, 24 achieved technical efficiency exceeding 95 percent. Only three stores' efficiencies fell below 80 percent. We find that technical inefficiency reduces the average gross margin of conventional U.S. food retailers by about $5,000 and U.S. supercenters by about $7,670.

Sellers-Rubio and Más-Ruiz (2009) reported an average technical efficiency of 86.3 percent for Spanish supermarkets in a model that explicitly assumed that all firms shared the same technology. Barros and Alves (2003) used a data-envelopment analysis to assess the efficiency of a leading hypermarket and supermarket chain group in Portugal. They found an average efficiency for the hypermarket retailer of 0.894 under constant returns and 0.964 under variable returns to scale based on nine inputs and output for sales and operational results (value measures).

To provide guidance for managers, we identified the three data-sharing technologies that were adopted most frequently by top-performing retailers: use of electronic invoices from DSD vendors (80 percent adoption), electronic invoices from the primary warehouse (50 percent adoption), and electronic transmission of movement data to headquarters or key suppliers (80 percent adoption). Food retailing establishments that adopted all three of those technologies (three in our sample) achieved average technical efficiency of 95.6 percent. By contrast, the food retailers that had estimated technical efficiencies of 90–95 percent, just short of the top-performer category, reported much lower rates of adoption of those technologies.

To demonstrate the value added by this research, we also considered a model that examined food retail performance but neglected selectivity effects linked to the choice of distribution strategy and report the results in Table 5. Under that model specification, technical efficiency is overestimated. The estimated mean technical efficiency score is 94.0 percent for self-distributing stores, and the number of retailers with technical efficiency exceeding 95 percent rises to 117. Figure 1 provides a graphic summary of the distribution of the technical efficiency scores for the two models. There is distinct bunching of the technical efficiency estimates at the upper level in the model that ignores selectivity effects. In addition, the inefficiency estimates derived when the same production model applies to wholesaler-supplied and self-distributing stores are higher and establish benchmark performance standards that may be unrealistic for store managers. The expected gross margin is about $1,500 higher for conventional stores and $2,000 higher for supercenters under the standard stochastic frontier model.

Conclusions

This study presents results from a stochastic frontier analysis of supermarket operations that accounts for sample-selection effects associated with the choice of distribution strategy. Dubelaar, Bhargava, and Ferrarin (2002) highlighted the importance of developing models of retail performance that account for the efficiency effects of store characteristics and information technology adoption at the store level. Assessments of retail store performance in a supply chain should incorporate factors that are not directly under the control of store managers and move beyond the traditional sole emphasis on labor productivity. Recent work by Ellickson (2006) confirmed the importance of understanding how retail distribution influences productivity as escalating investments by supermarket chains in their distribution systems create natural oligopolies in retail food markets.

Statistical tests and our evaluation of decision-making implications confirm the validity of the selectivity-corrected stochastic frontier model for estimates for retail establishments in self-distributing chains. The model also provides new evidence of the need to assess direct impacts of information technology adoption on the supply chain strategies employed by food retailers. Adoption of data-sharing technologies (internet/intranet links to corporate headquarters and/or key suppliers, electronic transmission of product movement data, and electronic receipt of invoices from the primary warehouse) is positively linked to store-level gross margins. Retail operations that adopted the complete portfolio of data-sharing technologies reported a gross margin that was about 8.3 percent higher than stores with no investment in the technologies.

The results of this study suggest that store managers and retail supply-chain firms can find ways to demonstrate the link between adoption of data-sharing technologies and observable store-level metrics such as gross margins, sales per square foot, and annual sales growth. Establishing that link can assist firms in their efforts to develop incentives for managers to adopt new data-sharing technologies. The positive relation between data sharing and store performance is not observed in stochastic frontier models that ignore selectivity effects.

For managers, the model emphasizes the importance of hiring, recruitment, and retention decisions given the positive boosts to gross margins associated

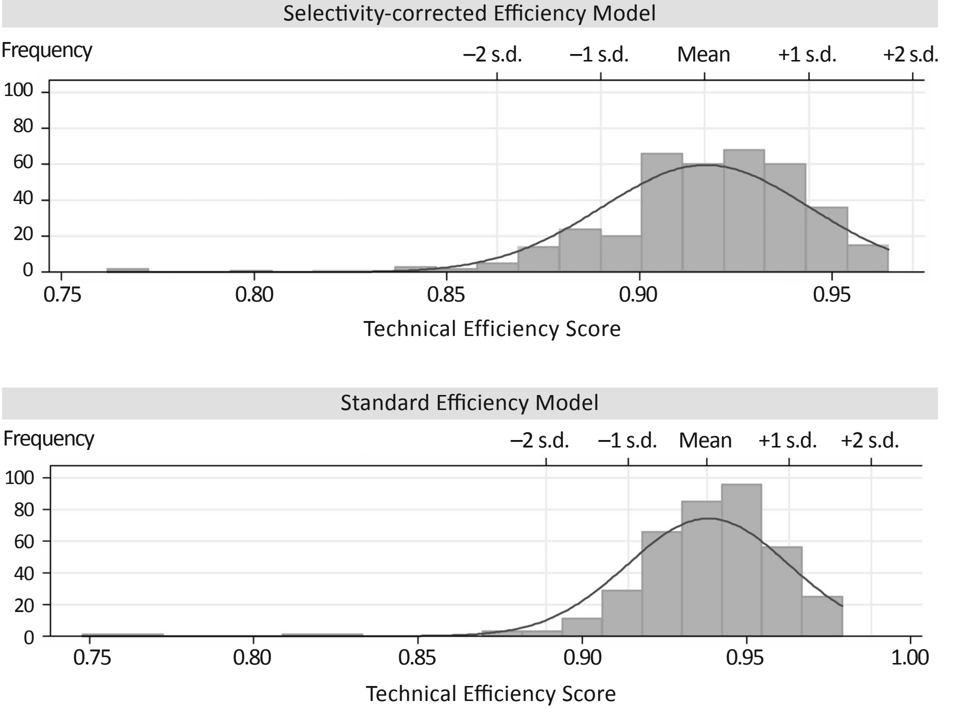

Figure 1. Comparison of Standard and Selectivity-corrected Technical Efficiency Scores of Food Retailing Establishments

Source: The Food Industry Center, University of Minnesota.

with expanding the number of full-time and part-time employees. These results are useful for retail industry analysts in demonstrating that store format is not a significant component of gross margins for food retailers after controlling for inputs such as store size and labor use.

A key assumption of the model is that unobservables in the selection equation are not correlated with inefficiency in the stochastic frontier model. This assumption seems reasonable in the food retailing industry since managers of inefficient stores do not have a propensity to uniformly adopt a specific distribution strategy (self-distribution vs. wholesaler-supplied distribution). Our results show that self-distribution stores are not systematically more efficient than wholesaler-supplied stores and that the distribution of efficiency scores for the two approaches shows a considerable degree of overlap (see Figure 1). Future applications of the stochastic frontier model could allow for correlation between inefficiency and heterogeneity in the production function; Kumbhakar, Tsionas, and Sipiläinen (2009) have developed a methodology for that approach.

Volpe (2011) examined how supermarket performance at the store level is linked to pricing strategies and the prevalence of private labels but did not consider the role of the distribution channel or the impact of selectivity effects in store performance. A fruitful area of research would be to develop a selectivity model of retail distribution that can examine multiple measures of store performance combined with various pricing and product management strategies.

We plan to extend this analysis in the future using data gathered by industry sources such as The Food Marketing Institute and the National Grocers Association. The impact of learning effects associated with new information technologies can be investigated using data from multiple years of the survey by The Food Industry Center and by more fully exploiting data on how long retailers have been using the supply chain technologies. Finally, the model can be specified to explore factors that differentiate performance across store formats and how information technology is related to the optimal choice of product and category variety at the store level.

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