Modeling Productivity in Supermarket Operations: Incorporating the Impacts of Store Characteristics and Information Technologies

Robert P. King and Timothy A. Park

Data from the 2002 Supermarket Panel are used to estimate a supermarket production function with weekly gross margin as the output measure and store selling area and total labor hours as variable inputs. The model also includes productivity shifters describing format and service offerings, store ownership structure, unionization, and adoption of new information technologies and related business practices. The null hypothesis of constant returns to scale cannot be rejected. Increases in ownership-group size, warehouse and supercenter formats, unionization of the workforce, and adoption of vendor-managed inventory and a frequent-shopper program are all associated with significantly higher productivity.

The supermarket industry experienced profound changes during the 1990s. Changes in store characteristics were readily apparent to consumers. Median store size grew from 31,000 square feet in 1990 to 44,600 square feet in 2000 (Food Marketing Institute 2002b). New formats also emerged, most notably the supercenter. There were less-visible but equally important changes in industry structure. In 1990, independent supermarkets operated by companies owning ten or fewer stores accounted for 22.2% of all grocery sales, while chain supermarkets operated by companies with eleven or more stores accounted for 51.5% of grocery sales (*Progressive Grocer* 1991). By 2000 the respective shares of independent and chain supermarkets were 14.3% and 63.6% of grocery sales (*Progressive Grocer* 2001). This prompted a shift away from distribution by independent wholesalers toward self-distributing systems with retail stores and primary distribution centers under common ownership. Between 1992 and 1997 the percentage of total retail grocery sales supplied by independent wholesalers fell from 42.3% to 37.3% (A.T. Kearney 1998, p. 8), and it is likely that this trend has continued.

New information and communications technologies have also had important impacts on business operations, decision processes, and trading-partner relationships in food retailing. Widespread adoption of scanning technology and the Uniform Product Code during the 1980s provided the technological foundation for the introduction of electronic transmission of order data, industry-supported mechanisms for sharing scanner data, and computer-based product-movement analysis at the store level. Information technology also was the basis for significant changes in warehouse operations, logistics systems, and manufacturing processes. (Walsh 1993, pp. 89-106; King and Phumpiu 1996). In the mid-1990s the Efficient Consumer Response initiative brought together food retailers, wholesalers, brokers, and manufacturers in an industry-wide effort to foster adoption of new technologies and business practices based on information technology (Kurt Salmon Associates, Inc. 1993). More recently, rapid development of Internet-based technologies has fostered new initiatives in electronic commerce; scan-based trading; and collaborative planning, forecasting, and replenishment (Kinsey 2000).

While the general impacts of larger stores and new formats, changing industry structure, and new operating practices and trading-partner relationships based on information technology have been described and discussed by many, relatively little is known about how these changes have affected productivity at the store level. In this study we use data from a unique national survey of supermarkets, the 2002 Supermarket Panel, to estimate a store-level production function that includes explanatory variables describing not only store and organizational characteristics but also the adoption of new information technologies and related business practices. The overall objective is to analyze empirically how changes in supermarket operations—reflected in

---

King is professor, Department of Applied Economics, University of Minnesota, St. Paul. Park is associate professor, Department of Agricultural and Applied Economics, University of Georgia, Athens.

This research was funded in part by the Alfred P. Sloan Foundation through The Food Industry Center at the University of Minnesota.

store size and format, relationships with key suppliers, and new operating practices and trading-partner relationships based on information technology—are affecting productivity at the store level.

Size Economies, Business Organization, and Information Technology

The supermarket emerged as the dominant business model for food retailing in the years immediately following World War II. This fundamentally transformed the way consumers purchase food, combining self-service concepts pioneered in the 1930s with significantly larger stores that carried a much wider range of product offerings. As the size of the typical supermarket grew, not only in the U.S. but also in Europe, economists began to focus attention on economies of size and scale in food retailing. The empirical evidence has been mixed.

Using data collected in the mid 1970s from fifty-eight stores operated by a large retail firm, Marion et al. (1979, footnote, pp. 135–137) find no statistically significant relationship between store size and per-unit operating expenses. In a 1981 review of published analyses of economies of size in food retailing, Grinnell (1981) concludes that most evidence available at that time indicated scale economies at the store level. Citing statistics reported by *Progressive Grocer* for 1988 and analytical results presented by Nooteboom (1983), Oi (1992) also asserts that there are size economies in supermarket operations. Still more recently, for a study using data collected by the Economic Research Service of USDA (Kaufman and Handy 1989), Betancourt and Malanoski (1999) report constant marginal cost for their measure of supermarket output (a quantity index constructed by dividing sales by an index of price relatives) but declining marginal costs for their measure of distribution services (an index based on store offerings for twenty specific services). They conclude that this implies overall multiproduct scale economies for supermarkets.

Grinnell (1981) and Marion, Parker, and Handy (1986) also emphasize the importance of considering economies achieved through ownership of multiple stores and through vertical integration of retail and wholesale functions—i.e., through differences in the structure of the business organization that operates a particular supermarket. Multistore economies can be achieved through advertising, increased buying power enjoyed by high volume firms, and savings on administrative functions that can be centralized to corporate headquarters. Retail companies that own their own distribution facilities may realize added cost savings through improved coordination in logistics and product-assortment decisions. Both Grinnell (1981) and Marion, Parker, and Handy (1986) assert that there are significant economies associated with multistore ownership and self distribution, but it is not clear whether these would be observed at the store level. Betancourt and Malanoski (1999) find that stores belonging to chains with more than ten stores enjoy statistically significant cost savings, but they are not able to separate the effects of multistore ownership and self distribution.

A large, wide-ranging literature on the relationship between information-technology investment and productivity has emerged since the late 1980s, when researchers puzzled over the apparent lack of productivity gains associated with rapidly growing investments in computer hardware and software. As Devaraj and Kohli (2000) note in their review of previous research, this relationship has been explored at three distinct levels: the overall economy, an industry or cross section of industries, and the individual firm or establishment within an industry. Since this study focuses on store-level productivity, we limit our review to firm-level studies.

Hitt and Brynjolfsson (1996) note that inconclusive or inconsistent findings regarding the economic impacts of information technology can sometimes be attributed to differences in performance measures. They assert that information technology can affect productivity, profitability, and consumer surplus. They go on to argue that conceptual frameworks and analytical methods for assessing relationships between information technology and each of these performance dimensions can be quite different. Production-function analysis has been the most commonly used framework for investigating firm-level relationships between information-technology inputs and productivity, which is the focus of this study.

Most recent firm-level studies have found statistically significant, positive relationships between information-technology investments and productivity. Brynjolfsson and Hitt (1996) and Hitt and Brynjolfsson (1996) report results of Cobb-Douglas production-function analyses using panel data on spending for information-system inputs by large firms. These data were collected through annual surveys conducted by the International Data Group in 1987–1991 and 1988–1992, respectively. Both of these studies report statistically significant positive relationships between information-technology capital expenditures and the level of output. Bresnahan, Brynjolfsson, and Hitt (2002) use panel data for Fortune 1000 firms for 1987–1994 in a study designed to measure the degree to which worker skills and organizational change complement information-technology investments. Their central hypothesis is that productivity gains can only be fully realized by firms that hire more highly skilled workers and adopt organizational changes that give skilled workers more autonomy and discretion in using the data and decision-support tools embedded in information systems. They estimate information system input-demand functions and a production function. Results from both approaches support their hypothesis that high worker skill levels and appropriate organizational change are complements to information-technology investment.

Production Technology of Food-Retailing Firms

Productivity analysis of retail businesses such as supermarkets adapts standard production theory relating inputs to outputs by recognizing that retail firms provide not only goods and services for purchase but also a set of unpriced distribution services that affect the costs consumers bear in their purchase activities. Betancourt and Gautschi (1988, pp. 135–136) classify distribution services into six broad categories: (1) provision of goods and services for purchase; (2) ambiance; (3) breadth and depth of product assortment, i.e., the number of product lines and the number of varieties within a product line; (4) accessibility of location; (5) degree of assurance that product will be available immediately; and (6) information on price, availability, and product characteristics. Providing higher levels of distribution services results in higher costs for food retailers, as the distribution services are viewed as an output in the production-function framework. On the other hand, provision of distribution services that are not directly purchased by the customer can enhance retail sales by attracting more customers or by allowing the retailer to charge higher prices. The analysis of supermarket operations presented here accounts for the relationship between sales volume and the level of distribution services by including measures of distribution services as explanatory variables.

The output measure used in this analysis is weekly gross margin, a measure of value-added defined as weekly sales minus the cost of goods sold.[1] This measure has three components: the quantity and assortment of goods sold, prices charged for goods sold, and the cost of acquiring goods sold. Each can be affected by store characteristics and distribution-service offerings, by store operating practices, and by the adoption of new information technologies and related business practices. For example, implementation of category-management practices may increase physical sales volume and shift sales volume to more profitable items, offering more services can increase the prices consumers are willing to pay for the items they purchase, and better relationships with suppliers and more-effective inventory management may lower the cost of goods sold. Limiting the output measure to sales, another commonly used measure of retail output, would ignore the contributions to productivity made by "back-room" labor and new information technologies that add store-level value not by increasing sales revenue but by reducing the cost of goods sold.[2]

Two inputs are considered in this analysis: store selling area and weekly labor hours. Store selling

[1] In this study, weekly value-added was calculated by multiplying average weekly sales by gross margin as a percentage of sales.

[2] The proper output measure for retailing has long been a topic for debate. McAnally (1963) asserts that gross margin is superior to sales as a productivity measure. He then goes on to note that neither measure fully captures the nuances of differences in the services provided by retailers. In sector-level studies of productivity growth, Ratchford and Brown (1985) and Baily and Solow (2001) emphasize the need to account for both services and goods sold in measuring retail output, and both studies argue that value added is preferred to sales as a measure of retail productivity. Baily and Solow (2001, p. 160) state that "value-added generated by retailers provides the best simple measure of retailing output." Texts on retailing, such as Berman and Evans (2004, pp. 511–517), identify both sales and gross margins as valuable performance measures for retail operations. Finally, while the Bureau of Labor Statistics uses deflated sales as a measure of retail output, the Census of Retail Trade (Bureau of the Census, 1996, p. 2-2) uses gross margin and value added—gross margin less "the cost of office supplies, postage, electricity, fuel, and packaging materials"—as measures of the value produced by retail firms. Both sales and gross margin are useful output measures for supermarkets, but the gross-margin measure is better-suited for the productivity analysis that is the focus of this study.

area is a good—though not perfect—measure of the capital used in a retail operation. Store energy costs and other major capital inputs, such as refrigeration equipment and lighting, shelving and display cases, and front-end checkout equipment, are highly correlated with store selling area. The second input, weekly labor hours, is the sum of full-time and part-time labor hours. Preliminary analysis with full-time and part-time labor hours treated as distinct inputs indicated that they can be aggregated without loss of explanatory power.

Variables representing differences in distribution-service offerings and other store and market characteristics are incorporated into the model as productivity shifters that have the same proportional impact on the marginal productivity of each input. Binary variables indicating investments in new information technologies and adoption of related business practices are also included in the model as proportional productivity shifters.

A simple Cobb-Douglas production-function specification is used in this analysis.[3] In log-linear form, the model is

$$(1)\quad \ln GM_i = \alpha_0 + \alpha_1 \ln SSize_i + \alpha_2 \ln TotHr_i + \beta\mathbf{DS_i} + \gamma\mathbf{SMC_i} + \delta\mathbf{IT_i} + \epsilon_i,$$

where GM_i is weekly gross margin for supermarket i; $SSize_i$ and $TotHr_i$ are store selling area and weekly labor hours for supermarket i; $\boldsymbol{DS_i}$ is an r x 1 vector of variables representing distribution service levels for supermarket i; $\boldsymbol{SMC_i}$ is an s x 1 vector of store and market characteristics for supermarket i; $\boldsymbol{IT_i}$ is a t x 1 vector of binary variables representing information technology and related business-practice adoption by supermarket i; α_0, α_1, and α_2 are scalar parameters; β is a 1 x r vector of parameters; γ is a 1 x s vector of parameters; δ is a 1 x t vector of parameters; and ϵ_i is a stochastic error term for supermarket i.

Data Collection and Sample Characteristics

The Supermarket Panel is an annual nation-wide survey of supermarkets that collects data on store characteristics, operating practices, and performance. The Panel was established in 1998 by The Food Industry Center at the University of Minnesota as a basis for ongoing study of the supermarket industry. Panel data booklets are mailed directly to store managers each January. Each respondent receives a customized benchmark report comparing his/her store to a peer group of stores similar in size and format. This is the only incentive store managers receive for participation. The Panel is unique because the unit of analysis is the individual store, and stores are tracked over time. In contrast, findings presented in the *Annual Report of the Grocery Industry* published by *Progressive Grocer* and the Food Marketing Institute's (2002a) annual *SPEAKS* report are based on company-level responses for representative stores.

Data collection procedures for the 2002 Supermarket panel are described in detail by King, Jacobson, and Seltzer (2002). The population for the 2002 Supermarket Panel was defined as the 31,879 establishments classified as supermarkets on a USDA list of the 151,999 establishments in the United States that accept food stamps. The sample for 2002 included 396 stores that had previously participated in the Panel, all 1642 IGA-affiliated stores in the U.S., 313 stores affiliated with two major retailers that established working relationships with The Food Industry Center that made it possible to include some or all of their stores in the Panel, and an additional 1550 stores drawn at random from the remaining stores in the population, yielding a total sample of 3901 stores. Of these, 866 stores returned useable data booklets, an overall response rate of 22.2%, which compares favorably with other surveys of business establishments.[4]

The Supermarket Panel provides detailed data on store characteristics, operating practices, and performance. King, Jacobson, and Seltzer (2002) present extensive descriptive information for stores in the 2002 Supermarket Panel grouped by format, ownership-group size, and relative scores for each of six management-practice indices. Differences in store characteristics, information-technology adoption rates, and selected productivity measures for stores grouped by selling area are especially relevant for this analysis. These are presented in Table 1.

[3] Several other specifications were considered, including the class of ray-homothetic production functions proposed by Färe, Jansson, and Lovell (1985), but in no case were we able to reject the null hypothesis that this production process can be represented by the Cobb-Douglas specification.

[4] The number of repeat stores in the Panel is relatively small and the maximum history for any store is only three years. Therefore, the data are not well-suited for a true panel-data analysis.

Table 1. Supermarket Characteristics and Performance for Stores Grouped by Selling Area.

	Store Selling Area (sq.ft)				
	5,000 to 15,000	15,001 to 30,000	30,001 to 45,000	45,001 to 60,000	More than 60,000
Number of Stores Represented	6,356 (278)	10,042 (248)	7,845 (142)	3,708 (105)	2,404 (47)
Store Characteristics					
• Median selling area (sq.ft.)	10000	25000	38000	50000	80000
• Median weekly labor hours	818	1612	2400	3140	4666
• Median weekly labor hours per 100 sq.ft of selling area	7.94	6.83	6.25	6.11	4.94
• Percent conventional-superstore-food/drug combo format	100	99	92	90	45
• Percent warehouse-super warehouse-supercenter/hypermarket format	0	1	8	10	55
• Percent with full-service pharmacy	2	23	57	65	91
• Percent undergoing a major remodeling in 2001	6	8	7	14	4
• Percent with union workforce	9	27	54	48	37
• Median population density (per sq.mi.)	106	415	603	953	1262
• Median household income ($/year)	$40,173	$44,526	$50,501	$53,506	$48,568
Organization Characteristics					
• Distribution of stores by ownership group size					
- Single store	54	15	2	2	0
- 2 to 10 stores	22	19	8	3	5
- 11 to 50 stores	14	16	15	20	17
- 51 to 750 stores	4	32	32	33	29
- More than 750 stores	6	19	43	42	49
• Percent wholesaler supplied	87	50	19	22	39

As expected, total weekly labor hours increase with store selling area; but labor intensity, measured by weekly labor hours per 100 square feet of selling area, falls steadily across store-size categories. Store format is a good indicator of the level of distribution services. In general, stores with conventional, superstore, and food/drug-combination formats offer a wider range of services, including bagging and service meats. At least 90% of stores in each of the four smallest size categories have conventional, superstore, or food/drug-combination formats, suggesting that they offer a higher level of distribution services. Warehouse, super warehouse, and supercenter/hypermarket stores are most common in the largest store-size category. Trends across size categories for other store and organizational characteristics are not always consistent. In general, larger stores are more likely to have a union workforce, and they are located in more densely populated areas with higher median household incomes. Larger stores also tend to be part of larger ownership groups and are less likely to be wholesaler-supplied.

In their analysis of supply-chain technologies, King, Jacobson, and Seltzer (2002, pp. 14-23) group information technologies and information-technology-based business practices into three general categories:

- data-sharing technologies: Internet/Intranet links to corporate headquarters and/or key suppliers, electronic transmission of movement data to headquarters or key suppliers, electronic receipt of invoices from primary warehouse, electronic receipt of invoices from Direct Store Delivery (DSD) vendors, and electronic transmission of orders to vendors/suppliers
- decision-sharing technologies and practices: vendor-managed inventory (orders generated by vendors based on store movement data), scan-based trading (payment to vendor based on sale to consumer), and computer-assisted ordering (scanning data used for automatic inventory refill)
- technologies that support product assortment, pricing, and merchandising decisions: product-movement analysis/category management, plan-o-grams for shelf space allocation, electronic shelf tags, and frequent-shopper/loyalty-card programs.

Adoption rates for all information technologies except electronic shelf tags and frequent-shopper programs generally trend upward with store size. These upward trends in adoption rates are often quite pronounced. It is important to note, however, that store size is also correlated with organizational characteristics that may also influence technology-adoption decisions.

Finally, differences are less clear-cut with respect to the store-performance measures presented in the lower portion of Table 1. As expected, weekly sales and gross margins both increase with store size. There is no clear trend in selling-area productivity, as measured by sales and gross margin per square foot of selling area. However, labor productivity, measured by sales and gross margin per labor hour, does tend to be higher for large stores. This pattern could be consistent with decreasing, constant, or increasing returns to scale.

Empirical Model

Weekly gross margin is the output measure used in this study. Store selling area and weekly total labor hours are the two inputs considered. Gross margin can vary significantly with the level of distribution service offerings. For example, Baily and Zitzewitz (2001) document a case where a specialty retailing chain with high service levels achieved value-added per dollar of sales that was 2.3 times higher than that of a mass-market discounter. Distribution service levels are closely related to store format. Stores in the 2002 Supermarket Panel are grouped into six mutually exclusive, exhaustive format categories based on store size and distribution-service offerings: (1) conventional, (2) superstore, (3) food/drug combination, (4) warehouse, (5) super warehouse, and (6) supercenter/hypermarket. King, Jacobson, and Seltzer (2002) report considerable variation in median store characteristics and performance measures for stores grouped by format. In this analysis, format is represented by two binary variables. The first is equal to one for stores with conventional, superstore, or food/drug-combination formats (which generally offer more services) and zero otherwise.[5] The second is equal to one for stores with a full-service pharmacy and zero otherwise. An index

[5] Preliminary analysis showed no statistically significant differences among formats within the broader groupings defined by this variable.

Table 1. Store Characteristics and Performance for Stores Grouped by Selling Area (Cont.).

	Store Selling Area (sq.ft)				
	5,000 to 15,000	15,001 to 30,000	30,001 to 45,000	45,001 to 60,000	More than 60,000
Information-Technology Adoption (Percent)					
• Internet/Intranet	40	59	73	76	82
• Electronic transmission of movement data	37	69	79	90	82
• Electronic receipt of invoices from primary warehouse	30	48	61	69	78
• Electronic receipt of invoices from DSD vendors	20	51	76	87	57
• Electronic transmission of orders	77	79	80	80	86
• Vendor managed inventory	17	25	22	32	54
• Scan-based trading	11	19	34	33	44
• Scanning data used for automatic inventory refill	2	10	18	21	61
• Product movement analysis/ category management	68	85	89	96	83
• Shelf-space allocation plan-o-grams	46	72	89	97	100
• Electronic shelf tags	30	25	18	31	40
• Frequent shopper/loyalty card program	15	49	57	51	22
Performance Measures (Median)					
• Weekly sales	$74,000	$171,715	$300,000	$390,000	$615,000
• Gross margin as a percent of sales	24	24.5	24	25	24.6
• Weekly gross margin	$15,750	$40,320	$55,900	$103,200	$110,700
• Weekly sales per square foot	$7.40	$7.50	$7.69	$7.17	$8.06
• Sales per labor hour	$94.81	$109.09	$129.87	$125.00	$123.23
• Weekly gross margin per square foot	$1.72	$1.82	$1.47	$1.82	$1.55
• Gross margin per labor hour	$20.81	$25.14	$31.13	$34.13	$27.41

measuring a wider range of service offerings (such as bagging, carryout, home delivery, and in-store banking) was also considered for inclusion in the analysis, but it did not add significantly to the explanatory power of the model. The empirical model also includes a binary variable equal to one if the store underwent a major remodeling during the current year and zero otherwise. While remodeling can lead to long-run improvements in store efficiency and distribution services, it can be highly disruptive in the short run for both store operations and customer shopping experience.

Characteristics of the store's factor and product markets may also affect productivity. Workforce unionization is a key descriptor of a store's labor market. Unionization will affect gross margin if it is associated with significant differences in worker skills and/or workforce stability or if stores are able to pass higher labor costs on to consumers. A binary variable equal to one if at least 25% of the store's workforce is covered by a collective bargaining agreement and zero otherwise is included in the empirical model.[6] For the product market, location is often cited as a key determinant of sales volume and store performance. Two variables associated with the attractiveness of a retail market are included in this analysis: population density and median household income. Both measures are based on data from the 2000 Census prepared by the United States Census Bureau for the zip codes in which each store is located. Population density is an indicator of the potential number of customers near the store. Median household income is an indicator of affluence, affecting not only the volume of food purchases but also the product mix, since higher-income shoppers are expected to purchase higher-valued food products.[7]

Characteristics of the organization that owns and operates a store may also impact gross margin. Two organizational descriptors are included in the empirical model. The first is ownership-group size. As noted in the review of previous studies, membership in a larger group may boost productivity through multistore economies in procurement and advertising and through centralization of some managerial functions. The second organizational descriptor is a binary variable equal to zero if the store is wholesaler-supplied and one if the store is part of a self-distributing group. Stores and distribution centers are under common ownership in self-distributing chains. This facilitates coordination between these two segments of the retail supply chain and so may yield productivity gains.

Finally, in-store investments in information technology and adoption of business practices based on new information technologies are also expected to affect productivity. Binary variables for seven of the twelve supply-chain technologies and practices identified by King, Jacobson, and Seltzer (2002) are included in the model:

- three data-sharing technologies: Internet/Intranet links to corporate headquarters and/or key suppliers, electronic transmission of movement data to headquarters or key suppliers, electronic receipt of invoices from primary warehouse
- two decision-sharing technologies: vendor managed inventory (orders generated by vendors based on store movement data) and scan-based trading (payment to vendor based on sale to consumer)
- two product-assortment, pricing, and merchandising technologies: product movement analysis/category management and frequent-shopper/loyalty-card programs.

The other technologies were excluded because of low adoption rates or high correlation with adoption of other technologies. Finally, recognizing that technology-adoption decisions are likely to be influenced by output level and so may be endogenous, the binary variable for each technology was set equal to one only if the store reported adoption of the technology one or more years prior to the survey. Therefore, the technology adoption variables are predetermined in the model.[8]

[6] Meat cutters have special skills and are often unionized when other workers are not. The 25% threshold for unionization excludes stores where meat cutters are the only union workers.

[7] A store's competitive position may also affect productivity. For their local market, Panel respondents reported whether their store was the leader with respect to price, service, quality, and variety. Binary variables indicating leadership in each of these four dimensions were considered for inclusion in the empirical model, but preliminary analysis showed that they did not add significantly to explanatory power.

[8] Brynjolfsson and Hitt (1996) provide a useful discussion of potential problems due to endogeneity of information-technology input levels. They performed a Hausman specification test comparing OLS and 2SLS

The loglinear specification of the empirical model is

$$(2)\ \ln GM_i = \alpha_0 + \alpha_1 \ln SSize_i + \alpha_2 \ln TotHr_i + \beta_1 ConSSFD_i + \beta_2 Pharm_i + \beta_3 Remod_i + \gamma_1 Union_i + \gamma_2 \ln PopDen_i + \gamma_2 \ln HHinc_i + \gamma_2 \ln GSize_i + \gamma_2 SDist_i + \delta_1 Internet_i + \delta_2 EMove_i + \delta_3 EIWH_i + \delta_4 VMI_i + \delta_5 SBT_i + \delta_6 CatMan_i + \delta_7 FqtShop_i + \epsilon_i.$$

Variable definitions are presented in Table 2. Stores with a missing value for any explanatory variable in the model were excluded from this analysis. This reduced the sample size to 365 stores. Stores with selling area less than 5,000 square feet and stores with extreme outlier values for gross margin as a percentage of sales, weekly sales per square foot of selling area, or sales per labor hour were also excluded.[9] This further reduced the sample size to 316 stores. Each observation was weighted by a sampling weight constructed to account for differences in response rates by region and store ownership-group size and to correct for over-representation of IGA stores in the sample. Weighted sample means and standard deviations are also presented in Table 2 for each variable in the analysis.

Given the wide range of store sizes and types, the standard assumption of constant variance for the stochastic error term in this model is likely to be violated. Following the discussion of Harvey's (1976) model of multiplicative heteroscedasticity in Greene (2003, pp. 232–235), we assume errors are normally distributed with a variance that is a multiplicative function of all the explanatory variables in the model. Parameters of both the production function and the variance function were estimated using maximum-likelihood procedures in STATA to maximize the log likelihood specified in Greene (2003).

parameter estimates and failed to reject the null hypothesis that information-technology inputs are exogenous.

[9] Lower and upper bounds for gross margin as a percent of sales were set at 10% and 90%. Upper bounds for sales per square foot of selling area and sales per labor hour were set at $80 and $250, respectively. These bounds are far from industry norms. Values outside these ranges were almost certainly due to an inconsistent or incorrect response to a survey question.

Results

Parameter estimates for the production function and the variance function are reported in Table 3.[10] Production-function parameters for the two inputs considered in this analysis—store selling area and labor hours—sum to slightly less than one. However, the null hypothesis that these parameters sum to one—i.e., the null hypothesis of constant returns to scale—cannot be rejected at even the 50% level of significance.

Parameter estimates for the three binary variables describing distribution-service levels—ConSSFD, Pharm, and Remod—are all negative and significant at the 10% level. The negative signs for the first two indicate that the higher service levels offered by conventional, superstore, and food/drug-combination stores and by stores that have a full-service pharmacy lower overall operating efficiency. This is consistent with the lower sales per labor hour and weekly sales per square foot of selling area reported for these stores by King, Jacobson, and Seltzer (2002, p. 11). As expected, disruptions caused by a major store remodeling also have a negative effect on productivity.

The next three variables in the model describe the factor and product markets in which the store operates. The binary variable for union workforce has a statistically significant, positive parameter estimate. This is consistent with the descriptive findings of King, Jacobson, and Seltzer (2002, p. 36), who report that sales per labor hour, sales per square foot of selling area, and gross margin as a percentage of sales are all higher in stores with a union workforce. They also note that hourly payroll expenses are more than $3.00 higher in stores with a union workforce. The upward shift in weekly gross margin provides some justification for higher wages for union workers, since the marginal product of labor, given store selling area and total labor hours, will be higher in stores with a union workforce. Farber and Saks (1980) note that unionization generally raises the mean and lowers the dispersion of the wage distribution within firms. These shifts typically benefit workers at the lower

[10] The statistically significant parameter estimates for many of the variables in the variance function imply that errors are heteroscedastic. A likelihood-ratio test confirmed that the null hypothesis of a constant variance can be rejected at even the 0.001 level of significance.

Table 2. Variable Descriptions and Summary Statistics.

Variable	Description	Mean	Standard deviation	Survey question[a]
GM	Gross margin ($/week)	$72,218	$58,340	Q52, 54
SSize	Store selling area (square feet)	33483	24106	Q8
TotHr	Full-time and part-time labor (hours per week)	2386	1667	Q22
ConSSFD	Conventional, Superstore, or Food/Drug-Combination format, 1 if yes, 0 if no	0.91	0.29	Q6a, Q6q, Q8, Q46
Pharm	Full-service pharmacy, 1 if yes, 0 if no	0.32	0.46	Q6q
Remod	Major remodel in 2001, 1 if yes, 0 if no	0.05	0.22	Q12
Union	At least 25% of employees covered by a collective bargaining agreement, 1 if yes, 0 if no	0.27	0.45	Q24
PopDen	Population density in store's zipcode (people/square mile)	1007	1442	U.S. Census
HHInc	Median household income in the store's zipcode ($/year)	$47,861	$14,076	U.S. Census
GSize	Ownership-group size (number of stores)	427	663	Q14
SelfDist	Membership in a self-distributing group, 1 if yes, 0 if no	0.49	0.5	Q15
Internet	Internet/Intranet link to corporate headquarters and/or key suppliers, 1 if yes, 0 if no	0.72	0.45	Q1j
EMove	Electronic transmission of movement data to headquarters or key suppliers	0.7	0.46	Q1f
EIWH	Electronic receipt of invoices from primary warehouse	0.48	0.5	Q1e
VMI	Vendor-managed inventory, 1 if yes, 0 if no	0.22	0.41	Q1r
SBT	Scan-based trading, 1 if yes, 0 if no	0.26	0.44	Q1n
CatMan	Product-movement analysis/Category management, 1 if yes, 0 if no	0.85	0.36	Q1l
FqtShop	Frequent-shopper/loyalty-card program, 1 if yes, 0 if no	0.39	0.49	Q6h

[a] This is the question number in Appendix C of the *2002 Supermarket Panel Annual Report* (King, Jacobson, and Seltzer 2002), corresponding to each variable.

end of the firm's payscale. One interpretation of the positive sign of this parameter is that the wage effects associated with unionization have a positive impact on overall productivity, as measured by gross margin. Alternatively, some of this effect may be due to higher gross margins if retailers in markets where nearly all stores are unionized are able to pass some portion of their higher labor costs on to customers. Finally, parameter estimates for the two Census-based market characteristics—population density and median household income—confirm that location does matter and that the attractiveness of a location is more sensitive to affluence than to population density.

Of the two variables describing the characteristics of the organization that owns and operates the store—the log of ownership-group size and the binary variable for membership in a self-distributing group—only the first has a statistically significant parameter estimate, and it is positive. This suggests that there are productivity gains associated with multistore economies in procurement and advertising and centralization of some managerial functions, while common ownership of the store and its primary distribution center is not necessarily associated with higher productivity. If this is true, wholesaler-supplied stores, which currently account for approximately half of supermarkets and

Table 3. Production Function Estimation Results[a].

Variable	Production function Coefficient	Production function Std. err.	Variance function Coefficient	Variance function Std. err.
SSize	0.236**	0.054	1.254**	0.318
TotHr	0.733**	0.050	-0.497**	0.25
ConSSFD	-0.195**	0.060	0.183	0.427
Pharm	-0.143**	0.044	-1.155**	0.318
Remod	-0.243*	0.140	1.977**	0.428
Union	0.170**	0.035	-0.018	0.268
PopDen	0.024**	0.009	-0.081	0.066
HHInc	0.265**	0.069	1.241**	0.444
Gsize	0.028**	0.012	-0.121	0.098
SelfDist	0.054	0.056	-0.168	0.421
Internet	-0.05	0.049	-1.081**	0.277
Emove	0.063	0.044	-0.362	0.235
EIWH	-0.03	0.033	0.074	0.234
VMI	0.106**	0.037	0.329	0.297
SBT	-0.054	0.037	0.085	0.304
CatMan	0.064	0.048	0.213	0.35
FqtShop	0.094**	0.032	0.655**	0.257
Constant	-0.02	0.833	-23.442**	5.501
Log Likelihood	-3.435		Number of obs.	316
R^2	0.872		Wald $\chi^2(17)$	3178.52

[a] The dependent variable is gross margin, *GM*, measured in dollars per week.
[*] Significant at a 10% level with a two-tailed test.
[**] significant at a 5% level with a two-tailed test.

one-third of supermarket sales, can continue to be viable. It is important to note, though, that few companies operating wholesaler-supplied stores own more than thirty stores. Therefore, stores owned by these companies may not enjoy the same multistore economies that are realized by stores owned by large self-distributing chains.

Two of the seven binary variables for information-technology adoption have statistically significant positive parameter estimates at the 10% level: vendor-managed inventory and frequent-shopper/loyalty-card program. Vendor-managed inventory is a decision-sharing practice under which the store transfers responsibility for reorder decisions on some products to its primary distribution center. This generally requires accurate, timely electronic transmission of movement data (increasingly via Internet/Intranet links) and can reduce supply-chain costs through efficiency gains in logistics and reduced inventories at the store and distribution-center levels. King, Jacobson, and Seltzer (2002, pp. 25–26) report that industry-wide adoption of this practice has increased steadily over the past three years, approaching 30% of stores by the beginning of 2002, and the positive parameter estimate for this variable suggests that this trend is likely to continue.

Frequent-shopper/loyalty-card programs enhance sales by rewarding customers who regularly shop at a store. These systems also collect data on individual customer transactions that can be of great value for strategic decisions about store layout and service offerings and for operational decisions related to product pricing and promotions. Typically, these data are analyzed by corporate staff rather than by store personnel. The positive parameter estimate for this variable indicates that these programs do enhance productivity at the store level.

None of the three 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—has a statistically significant parameter estimate. This is somewhat surprising given the attention paid to these technologies in the supermarket-trade press in recent years. One explanation is that these are enabling technologies for other practices, such as vendor-managed inventory and frequent-shopper/loyalty-card programs. If this is true, the value of adopting data-sharing technologies may be reflected in the pay-off from adopting the more advanced decision-sharing and marketing practices. It is also important to recognize that the productivity gains associated with technologies that support data sharing with key suppliers may be greater at the distribution center than in the store, but these system-level gains can only be realized if the technologies are adopted at the store level. This helps explain higher adoption rates for these technologies among stores that are part of self-distributing chains, since technology decisions made at the corporate-headquarters level should reflect assessments of overall costs and benefits for both supply-chain segments. On the other hand, wholesaler-supplied stores may lack this more comprehensive perspective. This points to the problem of providing incentives for store-level adoption of these technologies when stores and their distribution centers are not under common control.

Finally, though not the primary focus of this study, parameter estimates for the variance function are also of interest. The two inputs, selling area and labor, have opposite effects on the variance of the error term. Selling area is variance-increasing, while labor is variance-reducing. Among variables describing service offerings, market setting, and organizational form, presence of a full-service pharmacy is variance-reducing, while a major remodeling and higher household income are linked to higher variance. Of the information-technology variables, adoption of Internet/Intranet links to key suppliers is associated with significantly lower variance of the error term, while adoption of a frequent-shopper/loyalty-card program is variance increasing.

Conclusions

This study presents results from a production-function analysis of supermarket operations using a unique data set from a national survey of supermarkets. We place particular emphasis on assessing the store-level productivity effects of store characteristics and information-technology adoption.

Despite historical trends toward larger stores, we find that there are essentially constant returns to scale in food retailing. Optimal store size depends on market setting and organizational structure, but small stores can compete effectively with larger stores. Store format, service offerings, and disruptions associated with remodeling are important productivity shifters. Warehouse, super warehouse, and supercenter stores; stores without a full-service pharmacy; and stores that are not undergoing a major remodeling have a significant productivity advantage. Unionization of the store's workforce is also associated with significantly higher levels of weekly gross margin. Two descriptors of the organization that owns and operates a stores are included in this analysis: ownership-group size, and a binary variable indicating ownership by a company that also owns distribution centers. While increases in ownership-group size are linked to higher productivity, there is no significant relationship between store productivity and membership in a self-distributing group.

We find significant store-level productivity gains associated with adoption of two information technologies: vendor-managed inventory and frequent-shopper/loyalty-card programs. We find little evidence that adoption of basic data-sharing technologies is linked to higher gross margins at the store level. However, these technologies may be important prerequisites for adoption of other practices that enhance store productivity. Also, productivity effects from store-level adoption of technologies that support data and decision sharing may only be evident at the distribution-center level. This may explain why adoption rates are higher among stores that belong to self-distributing groups that place stores and distribution centers under common corporate control.

References

Baily, M.N. and E. Zitzewitz. 2001. "Service Sector Productivity Comparisons: Lessors for Measurement." In *New Developments in Productivity Analysis*. C.R. Hulten, E.R. Dean, and M.J. Harper, eds. NBER Conference Report. University of Chicago Press, Chicago. pp. 419–55.

Baily, M.N. and R.M. Solow. 2001. "International Productivity Comparisons Built from the Firm Level." *Journal of Economic Perspectives* 15(3): 151–172.

Berman, B. and J.R. Evans. 2004. *Retail Management: A Strategic Approach*, 9th ed. Pearson Prentice Hall, Upper Saddle River, NJ.

Betancourt, R. and D. Gautschi. 1988. "The Economics of Retail Firms." *Managerial and Decision Economics* 9(2):133–144.

Betancourt, R., and M. Malanoski. 1999. "An Estimable Model of Supermarket Behavior: Prices, Distribution Services and Some Effects of Competition." *Empirica* 26(1):55–73.

Bresnahan, T.F., E. Brynjolfsson, and L.M. Hitt. 2002. "Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence." *Quarterly Journal of Economics* 117(1):339–376.

Brynjolfsson, E. and L. Hitt. 1996. "Paradox Lost? Firm-Level Evidence on the Returns to Information Systems Spending." *Management Science* 42(4):541–558.

Bureau of the Census. 1996. "Measures of Value Produced, Capital Expenditures, Depreciable Assets, and Operating Expenses." RC92-S-2. *1992 Census of Retail Trade*. U.S. Department of Commerce, Washington, D.C. http://www.census.gov/prod/2/bus/retail/rc92-s-2.pdf

Devaraj, S. and R. Kohli. 2000. "Information Technology Payoff in the Health-Care Industry: A Longitudinal Study." *Journal of Management Information Systems* 16(4):41–67.

Farber, H.S. and D.H. Saks. 1980. "Why Workers Want Unions: The Role of Relative Wages and Job Characteristics." *Journal of Political Economy* 88(2):349–369.

Färe, R., L. Jansson, and C.A.K. Lovell. 1985. "Modeling Scale Economies with Ray-homothetic Production Functions." *Review of Economics and Statistics* 67(4):624–629.

Food Marketing Institute. 2002a. *The Food Marketing Industry Speaks, 2002*. The Food Marketing Institute, Washington, D.C.

Food Marketing Institute. 2002b "Key Industry Facts." The Food Marketing Institute, Washington, DC. http://www.fmi.org/facts_figs/keyfacts/storesize.htm

Greene, W.H. (2003) *Econometric Analysis*, fifth edition. Prentice Hall, Upper Saddle River, NJ.

Grinnell, G. 1981. "Economies of Size in Food Retailing." *Journal of Food Distribution Research* 12(1):161–168.

Harvey, A.C. 1976. "Estimating Regression Models with Multiplicative Heteroscedasticity." *Econometrica* 44(3):461–465.

Hitt, L.M. and E. Brynjolfsson. 1996. "Productivity, Business Profitability, and Consumer Surplus: Three Different Measures of Information Technology Value." *MIS Quarterly* 20(2):121–142.

Kaufman, P.R. and C.R. Handy. 1989. *Supermarket Prices and Price Differences: City, Firm, and Store-Level Determinants*. Technical Bulletin No. 1776. USDA/ERS, Washington, D.C.

Kearney, A.T. 1998. *Strategies 2005: Vision for the Wholesale-Supplied System, Executive Summary*. Food Distributors International, Inc., Falls Church, VA.

King, R.P., E.M. Jacobson, and J.M. Seltzer. 2002. *The 2002 Supermarket Panel: Annual Report.* The Food Industry Center, Department of Applied Economics, University of Minnesota, St. Paul, MN. http://agecon.lib.umn.edu/mn/tr02supa.pdf

King, R.P. and P.F. Phumpiu. 1996. "Reengineering the Food Supply Chain: The ECR Initiative in the Grocery Industry." *American Journal of Agricultural Economics* 78(5):1181–1186.

Kinsey, J. 2000. "A Faster, Leaner Supply Chain: New Uses of Information Technology." *American Journal of Agricultural Economics* 82(5): 1123–1129.

Kurt Salmon Associates, Inc. 1993. *Efficient Consumer Response: Enhancing Consumer Value in the Grocery Industry*. Food Marketing Institute, Washington, D.C.

Marion, B.W., W.F. Mueller, R.W. Cotterill, F.E. Geithman, and J.R. Schmelzer. 1979. *The Food Retailing Industry: Market Structure, Profits, and Prices*. Praeger Publishers, New York.

Marion, B.W., R. Parker, and C. Handy. 1986. "The Organization and Performance of Food Distribution Industries." in *The Organization and Performance of the U.S. Food System*, Bruce W. Marion and NC 117 Committee, eds. Lexington Books, Lexington, MA, pp. 293–366.

McAnally, A.P. 1963. "The Measurement of Retail Productivity." *The Journal of Industrial Economics* 11(2):87–95.

Nooteboom, B. 1983. "Productivity Growth in the Grocery Trade." *Applied Economics* 15(5): 649–664.

Oi, W. 1992. "Productivity in the Distributive Trades: the Shopper and the Economics of Massed Reserves," *Output Measurement in the Service Sector*. Z. Griliches, ed. University of Chicago Press, Chicago, pp. 161–191.

Progressive Grocer. 2001. *Annual Report of the Grocery Industry*. Progressive Grocer Associates, Stamford, CT.

———. 1991. *Annual Report of the Grocery Industry*. Progressive Grocer Associates, Stamford, CT.

Ratchford, B.T. and J.R. Brown. 1985. "A Study of Productivity Changes in Food Retailing." *Marketing Science* 4(4):292–311.

Walsh, J.P. 1993. *Supermarkets Transformed: Understanding Organizational and technological Innovations*. Rutgers University Press, New Brunswick, NJ.