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ORIGINAL EMPIRICAL RESEARCH

Dynamic relationships among R&D, advertising, inventory and firm performance

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Abstract Firms' spending on R&D, advertising, and inventory holding affect firm performance, which in turn affects future spending in each of these three areas. Effective allocation of resources across R&D, advertising, and inventory holding is challenging since an understanding of their dynamic inter-relationships is necessary. Past research has not examined these spending issues simultaneously. We estimate inter-relationships among the effects of firms' R&D spending, advertising spending, and inventory holding on sales and firm value (as measured by its Tobin's Q) using a vector auto regression model of a panel of publicly listed U.S. high technology manufacturing firms. Insights from the computation of long-term effects indicate that advertising spending and inventory holding increase sales, while R&D spending does not, and advertising and R&D spending increase firm value, while inventory holding does not. In addition, firm spending in all three functions is positively affected by sales but negatively by firm value. We discuss the implications of the study for marketing literature and managerial practice.

Keywords R&D · Advertising · Inventory holding · Sales · Firm value · Vector auto regression models

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Introduction

A key responsibility for managers is to coordinate their firm's research and development (R&D), advertising activities, and inventory holding to improve performance. R&D spending helps develop new products and improve existing products, crucial for customer acquisition and retention and improved performance (Anderson 1988). Advertising spending increases differentiation and awareness (Aaker and Myers 1987) and creates brand equity, an intangible market-based asset (Mizik and Jacobson 2003), which also increases firm performance. Similarly, inventory holding stimulates product demand and improves a firm's ability to service customers (Cachon et al. 2005), which increases performance (Gaur et al. 2005; Rumyantsev and Netessine 2007). In this paper, we investigate how spending in R&D, advertising, and inventory holding are interdependent in improving firm performance. We first provide the motivation.

From a managerial standpoint, practitioners feel the pinch of demonstrating long-term performance through marketing spending (Dekimpe and Hanssens 1999). Effective resource allocation across R&D spending, advertising spending, and inventory holding is challenging and requires knowledge of three types of dynamic inter-relationships. First, managers quantify differential long-term effects of spending on multiple metrics of firm performance (e.g., sales, firm value). Second, managers allow past performance to guide future spending decisions. For example, marketing budgets are set as a percentage of sales to help constrain spending to a preset value, a practice termed as the "percentage of sales" heuristic (Sinha and Zoltners 2001). Managers also use past stock market metrics, which serve as a proxy of investor expectations, to guide spending (e.g., Chakravarty and Grewal 2011; Markovitch et al. 2005). Accordingly, we need to incorporate the idea that managers' spending is guided by past performance to accurately quantify the long-term effects of spending on firm

performance. Third, in the increasingly technology-enabled environments characterizing most companies, spending in a given function may not be fully under the purview of that function alone. For example, a firm's Chief Marketing Officer (CMO) is responsible for R&D and advertising spending decisions (Nath and Mahajan 2008), which may be influenced by its inventory holdings—which may not be under the purview of the CMO.[1] Accordingly, we need to quantify the long-term impact of the firm's R&D spending, advertising spending, and inventory holding on each other. Decomposing the three dynamic inter-relationships enables better understanding of resource allocation across R&D spending, advertising spending, and inventory holding (Calantone and Rubera 2012).

From a theoretical standpoint, a first differentiator in our research is to consider all potential dynamic relationships among R&D, advertising, inventory holding, and performance simultaneously. We build on marketing theory on organizational adaptive learning (Argyris 1977; Baker and Sinkula 1999; Slater and Narver 1995) to rationalize dynamic relationships among spending and performance. Adaptive learning in organizations is a basic form of organizational learning where the firm performs a recurring activity, observes the outcome, and makes changes to the activity based on the outcome and environmental criteria. Adaptive learning is employed in the context of firms' spending decisions to help managers detect and correct errors in spending (Mantrala et al. 2007).

In this paper, we propose that managers use past performance (sales, firm value), past own spending, and past spending of allied functions to constantly adapt their current period spending, to simplify what is inherently a complex resource allocation problem. By simultaneously considering all potential dynamic inter-relationships, we also extend the marketing literature, which has modeled the framework only in parts. Ignoring relationships among the three kinds of spending and performance, when they do exist, may impede effective resource allocation. This paper's focus on inventory holding serves as a second differentiator. Specifically, inventory holding is a crucial mechanism to deliver value through the firm's products, and incorporation of inventory holding into marketing response models extends the marketing literature, which has overlooked the issue of inventory holding.

We study dynamic relationships among R&D, advertising, inventory holding, and performance in the high technology sector, a choice motivated by the following reasons. High technology firms face rapid technological changes creating environmental uncertainty (Slater et al. 2007). Thus, marketing, R&D, and operations capability are key to effective performance in the high technology industry (Dutta et al. 1999). Stressing the importance of the three functions, Chauvin and Hirschey (1993) note that an overwhelming share of R&D investments occur in firms in the high technology sector. They note: "Little R&D activity takes place in most business and consumer service industries, the financial sector, and retailing. In fact, COMPUSTAT reports zero R&D activity for firms in 31 out of 63 two-digit industry groups" (Chauvin and Hirschey 1993, p.131). Managing inventory with short product life cycles and changing product market conditions is challenging in the high technology industry (Bargenda and Jandhyala 2011). Twenty-six of the top 100 innovators identified in the most recent Forbes selection are high technology firms.[2] Thus, high technology firms offer the right setting to test the dynamic interplay among R&D, advertising, and inventory holding and their effects on firm performance (Mohr et al. 2010).

We empirically illustrate the proposed dynamic relationships on a panel dataset of publicly listed high technology manufacturing firms in the United States, obtained from Standard and Poor's Compustat database. We estimate a vector auto regressive (VAR-X) model of R&D spending, advertising spending, inventory holding, and two performance metrics, sales and firm value. By synthesizing the complex dynamic feedback loops among all variables in the system (Pauwels et al. 2004), the VAR-X model is useful to calibrate and statistically assess the long-term effects of variables in a dynamic system on one another. We measure firm value by its Tobin's Q.

Foreshadowing our results, first, advertising spending and inventory holding have a positive long-term impact on sales (while R&D spending does not), and R&D and advertising spending have a positive long-term impact on firm value (while inventory holding does not). Next, increases in sales have a positive long-term impact on the three spending decisions, while increases in firm value have a negative long-term impact on the three spending decisions. Turning to the inter-functional effects, R&D spending and inventory holding impact each other positively. Our results are robust to alternative lag structures, high-tech industry definitions, and estimation methods.

We generate two key theoretical takeaways. First, we highlight the long-term impact of firm performance on spending, complementing the extant literature's focus on the impact of spending on performance. We document a novel finding of asymmetric managerial reactions in R&D spending, advertising spending, and inventory holding decisions, to increases in sales versus firm value. This finding builds on recent literature focusing on marketing reactions to the stock market (Chakravarty and Grewal 2011) by underscoring heterogeneity in the impact of different performance metrics on marketing strategy. Second, we demonstrate the role of

[1] The literature on marketing and operations coordination provides more examples of operations decisions not under the purview of the CMO and its consequent impact on the firm (e.g., Balasubramanian and Bhardwaj 2004).

[2] List from http://www.forbes.com/powerful-brands/list/ accessed on September 30, 2013.

inventory alongside the performance impact of R&D and advertising spending. The long-term effect of inventory holding on sales is comparable to that of advertising spending, suggesting the need to include inventory holding in marketing response models.

We generate three key takeaways for practice. First, we provide a model-based approach to decompose the challenging marketing resource problem into three types of dynamic interdependencies: (a) the impact of spending decisions on performance, (b) the impact of performance on spending decisions, and (c) the impact of spending decisions on one another. We estimate the impact and directionality of the interdependencies, which sheds light on how spending decisions and performance simultaneously evolve. Second, the findings indicate that in the high technology industry, the long-term impact of R&D spending on firm value is greater than that of advertising spending and that the impact of inventory holding on sales is comparable to that of advertising spending. The empirical estimates we generate in the paper serve as a guide for resource allocation. Third, we show that incorrect conclusions may be drawn when inventory holding is omitted while estimating the long-term impact of R&D spending and advertising spending on sales and firm value, further stressing the importance of modeling such dynamic interdependencies.

Theory

Spending decisions as adaptive learning

Organizational learning is the development of new knowledge or insights that have potential to facilitate behavior change that could lead to improved firm performance (Slater and Narver 1995). Adaptive learning, which has also been discussed as single-loop learning (Argyris 1977), is a basic form of organizational learning where the firm performs a recurring function, observes the outcome of the function, and uses the outcome and other environmental criteria to modify the function in the future. Though basic in nature, adaptive learning is crucial in detecting and correcting error and in enabling sequential and incremental progress toward objectives (Argyris 1977; Slater and Narver 1995).

There is conceptual support for the argument that adaptive learning may be involved in firms' spending decisions. Firms' resource allocation decisions are complex and involve multiple trade-offs in dynamic and turbulent business environments (Mantrala 2002; Slater and Narver 1995). A recent global McKinsey survey reports that firms decide marketing spending based on historical allocations and rules of thumb far more than on quantitative measures (Doctorow et al. 2009). The rules of thumb reflect adaptive learning about spending decisions from past spending and performance levels. Indeed, Mantrala et al. (2007) refer to this practice of budget determination as adaptive resolution. Spending levels decided with rules of thumb or adaptive learning practices may not always lead to optimal spending from a profit-maximizing perspective (Fraser and Hite 1988; Slater and Narver 1995). However, adaptive learning allows internal metrics (i.e., spending in their departments and other departments) and external metrics (i.e., firm performance) to guide managerial spending levels. Baker and Sinkula (1999) argue that adaptive learning sufficiently rationalizes tactical adjustments such as spending decisions in operations and planning.

With managers employing adaptive learning in setting spending levels over time, a firm's spending–performance link should be conceptualized as dynamically co-evolving system of variables. We employ such a conceptualization in this paper. First, integrating developments in the marketing literature on the effects of R&D and advertising spending on firm value (McAlister et al. 2007; Mizik and Jacobson 2003) and the effects of the stock market on firm's decision making on spending (Chakravarty and Grewal 2011; Markovitch et al. 2005), we discuss the following inter-relationships that reflect adaptive learning in managerial spending decisions: (a) the effects of firm value on spending decisions (R&D spending, advertising spending, and inventory holding), (b) the effects of the firm's sales (also referred to as sales) on spending decisions, (c) the effects of the firm's three spending decisions on firm value, (d) and the effect of the firm's three spending decisions on each another. We also consider the effects of spending decisions on sales. Our focus is in the net long-term effects of the spending decisions on one another and on firm performance. Accordingly, we refrain from developing directional hypotheses and instead discuss the theoretical relationships.

Effect of firm value on spending decisions

R&D spending Considering the importance of R&D spending in generating new products, in theory, managers ought to plan R&D spending according to their expectations about the benefits from R&D to provide competitive advantage (e.g., Mizik and Jacobson 2003). Yet, there is some evidence that R&D spending may also be driven by stock market performance. Specifically, firms may deploy expense reduction strategies in the face of inputs from the stock market. Firms owned by institutional investors with high portfolio turnover are conservative on R&D spending to avoid earnings shortfalls (Bushee 1998). In the context of high technology firms, Chakravarty and Grewal (2011) show that firms display myopic reactions, i.e., increases in stock returns and volatility create pressure to maintain and stabilize stock returns in the future, leading to unanticipated decreases in R&D spending. Moorman et al. (2012) note that publicly listed firms slow innovation rates to withstand high stock

market expectations. Thus, we anticipate that increases in firm value may create pressure to maintain stock returns leading to a decrease in the firm's future R&D spending.

Advertising spending As with R&D spending, stock market performance and expectations affect firms' advertising spending. For example, Chakravarty and Grewal (2011) report that increases in a firm's stock returns and volatility increase advertising spending, with the expectation that such increases in advertising spending may increase short-term financial returns because they influence immediate consumer perceptions and choices. This evidence suggests that increases in firm value would increase the firm's future advertising spending. In addition, a firm's advertising spending also increases its reputational capital (Fombrun et al. 2000) and affects its ability to appropriate value via the creation of brand equity. The recognition of advertising resulting in reputational capital and thus increasing firm value might result in managers focusing on building the value of the firm via increased advertising (cf., Srivastava et al. 1999).

Inventory holding As firm value increases, we expect managers to focus on reducing inventories. Specifically, with increase in firm value, there will also be increased expectations of continuity in firm value in future periods with a pressure to cut its costs. The costs of a firm's inventory holding are a significant component of its expenses (Carpenter et al. 1994), especially in high technology firms where products have a short shelf life and unsold inventory may have to be disposed at prices significantly lower than book values (Teach 2001). Accordingly, inventory holding needs to be managed closely (Bargenda and Jandhyala 2011). Thus, managers may feel compelled to decrease their inventory holdings, with a view to liquidate potentially obsolescent inventory, reduce costs, and increase their free cash flow (Teach 2001). Based on these arguments, we expect that an increase in firm value will decrease its inventory holding.

Effect of sales on spending

R&D spending Innovation scholars have identified firm size, the diversity of business segments, and industry concentration as factors influencing R&D spending (e.g., Cohen and Klepper 1996). Since R&D spending is discretionary, firms on an upward performance trajectory will spend more on research activities (Bhagat and Welch 1995). As sales increases, firms are able to better garner additional resources needed to increase their R&D efforts (Tsai and Wang 2005). Further, firms may prefer to fund R&D programs through internal accruals (which increase as sales increases) than through external financing, which may involve more statutory information disclosures about their R&D programs (Erickson and Jacobson 1992). Firms with higher sales are more likely to secure such funding and increase R&D spending. Finally, with increase in sales, firms might also gain economies of scale in R&D spending due to complementarities between various functions (Whittington et al. 1999). Given these arguments, we expect that as sales increases, R&D spending will increase.

Advertising spending As advertising budgeting decisions are complex, managers use heuristics to set advertising budgets (Mantrala 2002). The "percentage of sales" rule is a common heuristic for advertising budgeting, where advertising is set as a percentage of sales to help constrain spending to a preset maximum (e.g., Lilien and Little 1976). Managers believe that this heuristic leads to advertising spending close to optimal values (Aaker and Myers 1987). The prevalence of the percentage of sales heuristic makes the consideration of endogeneity in advertising–sales response models imperative. Thus, we expect that as sales increases, advertising spending will increase.[3]

Inventory holding A key motivation for holding inventory is production smoothing and avoidance of costly stock outs (Blinder and Maccini 1991). An increase in sales can increase inventory holdings through two mechanisms. First, an increase in sales can increase expectations of future sales and consequent increase in inventory holdings through the "bullwhip" effect (Lee et al. 1997). Thus, an increase in sales might also increase sales volatility, which in turn can increase production volatility and inventories (Kahn 1987). Second, firms seek to prevent potential stock outs because of higher anticipated sales, and consequently they have higher inventory holdings (Kesavan et al. 2010). It is also likely that a firm's increasing sales will move its products faster through distribution channels and deplete inventory holding, especially if inventory is not replenished adequately.

Effect of spending on firm value

R&D spending Firms' R&D programs create new technologies, products, and solutions designed to satisfy customer needs and overcome competitive advances (Gatignon and Xuereb 1997). R&D spending increases stock returns (e.g., Chan et al. 2001) and firm value (e.g., Lev and Sougiannis 1996) and decreases systematic risk (e.g., McAlister et al. 2007). R&D may affect a firm's value through its effects on price premiums and margins. R&D spending in recessions increases profits and shareholder value (Graham

[3] It is also possible that as firm sales increases, managers may consider further advertising spending unnecessary since it is already effective. Hence, managers may cut back on advertising to conserve scarce resources and increase firm profits (Naik and Raman 2003).

and Frankenberger 2008). Thus, we expect that the firm's R&D spending should increase firm value.

Advertising spending Advertising spending carries significant rewards including lower marketing and distribution costs, higher price realizations, and late mover advantages (Kaul and Wittink 1995; Kirmani and Zeithaml 1993). These rewards create higher brand equity, price premiums, profits (Keller 1998), and profit persistence (Kessides 1990). There is evidence that advertising increases firm value (Chauvin and Hirschey 1993; Connolly and Hirschey 1984; Salinger 1984) and market capitalization (Joshi and Hanssens 2010). Thus, we expect that as the firm's advertising spending increases, firm value will increase.

Inventory holding Past literature finds that inventory holding increases (Thomas and Zhang 2002) or inventory holding decreases can both be associated with higher firm performance, due to the non-linear relationship between inventory holding and performance (Thomas and Zhang 2002, p. 183). Chen et al. (2005) show that firms with abnormally high inventories obtain poor long-term stock returns and low firm value. This evidence suggests a negative relationship between inventory holding and firm value.

Effects of R&D spending on advertising spending and inventory holding

Advertising spending Extant literature suggests opposing effects of an increase in R&D spending on advertising spending. On one hand, since R&D spending may result in new products, firms may increase advertising spending to increase visibility and awareness for their technology-based new products (Slotegraaf and Pauwels 2008). On the other hand, R&D and advertising are discretionary spending items and may compete for scarce firm resources. High R&D spending may be a result of the firm's emphasis on rent seeking through value creation (i.e., new products) at the expense of value appropriation (i.e., brand equity) (Mizik and Jacobson 2003), a documented phenomenon in technology-intensive industries (Lunn 1989). Thus, R&D and advertising could be substitutes in the firm's rent seeking efforts. Hence, the firm may decrease advertising spending to meet its resource commitments to R&D programs.

Inventory holding Higher R&D spending will create technologically superior products (Cohen and Levinthal 1989), which, *ceteris paribus*, will increase inventory holding, either in anticipation of higher demand or a result of increased product line breadth (Bayus and Putsis 1999; Cohen and Levinthal 1989). Thus, as R&D spending increases, we expect inventory holding to increase.

Effects of advertising spending on R&D spending and inventory holding

R&D spending Increased advertising spending may either decrease or increase R&D spending. On the one hand, because resources are limited, firms may trade off spending between their advertising and R&D programs as discussed earlier. Thus, a firm with increasing advertising may reduce R&D spending to focus on advertising. On the other hand, R&D spending and advertising spending may be viewed as complements in firms' rent seeking efforts. Vinod and Rao (2000) argue that innovative firms increase advertising spending to ensure higher market acceptance ensuring the appropriability of their R&D efforts. Thus, firms with increased advertising spending may increase R&D spending.

Inventory holding A firm's higher advertising spending stimulates primary product sales through product differentiation (Aaker and Myers 1987). To cope with anticipated advertising effects on sales, the firm increases inventory holding to achieve sales fulfillment, prevent stock outs, and avoid customer dissatisfaction (Fitzsimons 2000). If the firm underestimates advertising effects on sales, the increased demand associated with advertising spending increases could also decrease inventory holding, especially if inventory is not quickly replenished.

Effects of inventory holding on R&D spending and advertising spending

R&D spending Firms have limited cash flow resources and face trade-offs in allocating resources to inventory holdings and R&D (Himmelberg and Petersen 1994). Increased inventory holdings may have a negative impact on cash flows (Carpenter et al. 1994). However, as noted above, R&D spending also relies on cash flows as R&D programs are typically financed through internal accruals. As a result of cash flow trade-offs, we expect a negative effect of inventory holding on R&D spending, i.e., as inventory holding increases, R&D spending decreases.

Advertising spending There are two mechanisms by which the firm's inventory levels affect its advertising spending. First, the higher the firm's inventory holdings, the higher its emphasis on differentiation and service levels (Deshpande et al. 2003; Dutta et al. 1999). Increased inventory spending is likely to trigger higher advertising spending as a means to reinforce differentiation emphasis. Second, when the firm's

inventory levels are high, the firm will increase its advertising spending to generate demand and liquidating inventories. This second mechanism is likely in high technology industries where product life cycles are short and obsolescence rates are higher (Bargenda and Jandhyala 2011). Shapiro (1977) and Piercy (1987) show that spending on marketing programs is decided based on the inventory levels in the distribution channels. Integrating these ideas, we expect that as the firm's inventory levels increase, its advertising spending increases.

Data and methods

As stated earlier, we focus on the high technology industry to demonstrate dynamic inter-relationships among spending and performance. We follow Francis and Schipper (1999) in defining the high technology sector, we and consider firms from the following four-digit Standard Industrial Classification (SIC) codes between 1990 and 2011: 2834–2836, 3570–3572, 3575–3579, 3600, 3612–3613, 3620–3621, 3630, 3634, 3640, 3651–3652, 3661, 3663, 3669–3670, 3672, 3674, 3677–3679, 3821–3829, and 3841–3845.

Measures

We start with a dataset of firms' R&D spending, advertising spending, inventory holding, and sales from Standard and Poor's Compustat database where we could obtain complete data on all measures. The dataset comprises 6,815 observations of 903 firms in 44 four-digit SIC codes. We use measures of R&D spending and advertising spending from the Compustat annual database. We operationalize inventory holding using data from the Compustat database similar to Gaur et al. (2005), who adjust the raw inventory holding measure to account for seasonal fluctuations induced by different inventory valuation approaches followed by firms. Specifically, the adjusted inventory holding measure is defined as follows:

$$INVA_{it} = \frac{1}{4}\sum\nolimits_{q=1}^{4} INVU_{itq} + LIFO_{it} \quad (1)$$

In Eq. 1, q represents a quarter ($1 \le q \le 4$), INVA represents the annual adjusted inventory holding, *INVU* represents the firm's quarterly unadjusted inventory holding (summed over four quarters to create annual data), and *LIFO* (last-in-first-out) is the inventory holding adjustment amount associated with a firm's inventory valuation approach. We scale R&D spending, advertising spending, and inventory holding by the total assets of the firm to enable comparisons. Turning to performance metrics, we use data on firm sales from Compustat. We measure firm value (FV) using Tobin's Q based on Berger and Ofek (1995). We scale both performance metrics by assets.

We provide further details of the measure construction in Table 1. We plot a histogram of the five key endogenous variables in Figs. 1 and 2.

Control variables

Based on precedence in the literature, we allow the five constructs (R&D spending, advertising spending, inventory holding, sales, and firm value) to be influenced by industry

Table 1 Variable and measures

Variable	Measure	Description
Research and development spending (*RD*)	Annual research and development spending (\$M)/Total assets (\$M)	Variable XRD/Variable AT in Compustat annual database
Advertising spending (*ADV*)	Annual advertising expenditure (\$M)/Total assets (\$M)	Variable XAD/Variable AT in Compustat annual database
Inventory holding (*INV*)	Average of the firm's inventory holding at the end of each quarter (\$M)/Total assets (\$M)	Average of Variable INVTQ in Compustat quarterly database adjusted for Last-in-First-Out (LIFO reserve)/Variable AT in Compustat annual database
Sales (*SALE*)	Annual Sales (\$M)/Total assets (\$M)	Variable SALE/Variable AT in Compustat annual database
Firm Value (*FV*)	Tobin's Q	Market Value/Total Assets – The Tobin's Q numbers were calculated based on Berger and Ofek (1995).
Industry turbulence (*INDT*)	Coefficient of variation of industry sales	Standard deviation of annual sales of all firms in the industry defined by 4-digit Standard Industrial Classification (SIC) code for the previous three years.
Industry concentration (*CONC*)	The four-firm concentration index in the industry	The sum of the square of annual market shares of the four largest firms in the industry defined by the 4-digit SIC code in the previous year.
Adjusted Cost of Goods Sold (*COGS*)	Cost of Goods Sold adjusted by the annual change in LIFO reserve	Variable COGS and LIFO reserve, FO in Compustat annual database

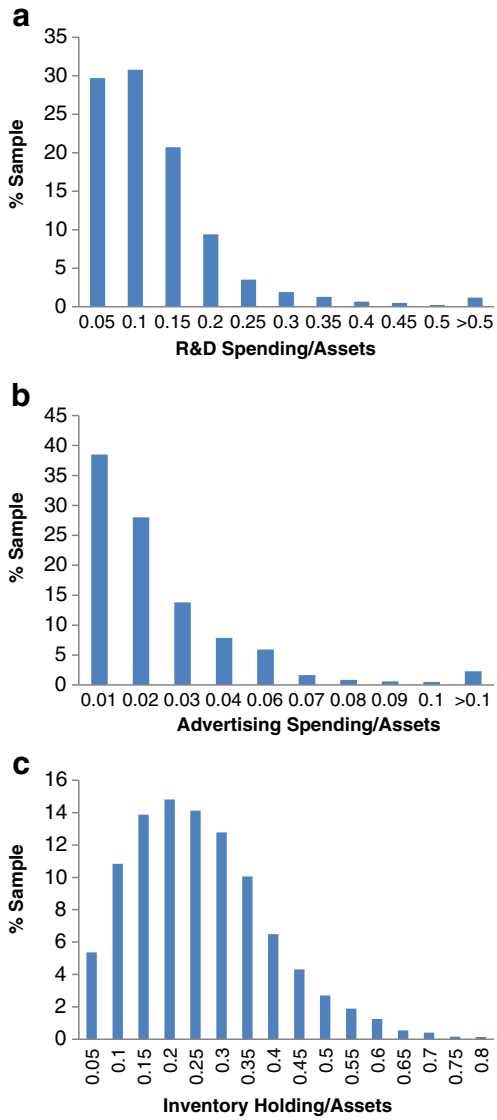


Fig. 1 Histogram of spending variables

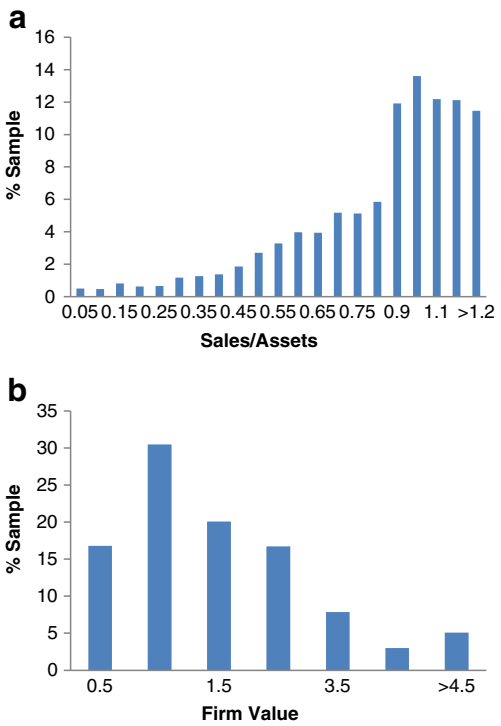


Fig. 2 Histogram of performance variables

$$COGS_{it} = UCOGS_{it} - LIFO_{it} + LIFO_{it-1} \quad (2)$$

In Eq. 2, *UCOGS* is the unadjusted *COGS* and *LIFO* is the inventory adjustment variable. We provide descriptive statistics in Table 2 and the correlations between the key endogenous variables in Table 3.

turbulence (*INDT*), industry concentration (*CONC*), and cost of goods sold (*COGS*) (Miller and Friesen 1983). High industry turbulence and industry concentration influence sales due to demand volatility (Keats and Hitt 1988). Industry turbulence can also influence R&D spending (Tingvall and Poldahl 2006), advertising spending (Davies and Geroski 1997), and inventory holding (Marino and Lange 1982).

We measure industry turbulence (*INDT*) using the methodology developed by Keats and Hitt (1988), by regressing the 3 years' past industry sales on a time trend variable and using the standard error of the time coefficient. We measure industry concentration (*CONC*) as the four-firm concentration ratio of the past year's sales of the four largest firms scaled by the combined past year's sales of all firms (Harris 1998). We compute cost of goods sold (*COGS*) as follows:

VAR-X model specification and estimation

We specify and estimate a vector autoregressive model specification with provision for exogenous variables (VAR-X) (e.g., Dekimpe and Hanssens 1999; Pauwels et al. 2004). VAR-X models are well-suited to capture dynamic effects of marketing variables and are used to study the long-run impact of advertising (Dekimpe and Hanssens 1995), price promotions (Pauwels 2004; Pauwels et al. 2004), and new products (Pauwels et al. 2004). The main advantages of using a VAR-X model include (a) the ability to study immediate and accumulated period effects of marketing, (b) the joint treatment of marketing actions and firm performance as endogenous, and (c) insights on performance implications of spending through complex feedback loops that allow for dynamic interactions between the system variables.

The five key endogenous variables are R&D spending, advertising spending, inventory holding, sales, and firm value. We specify the model as shown:

Table 2 Descriptive statistics

Variable	Mean	Standard deviation	Median
R&D spending (*RD*) (\$M)[a]	0.112	0.286	0.081
Advertising spending (*ADV*) (\$M)[a]	0.030	0.584	0.014
Inventory holding (*INV*) (\$M)[a]	0.251	0.396	0.224
Sales (*SALE*) (\$M)[a]	1.184	0.789	1.107
Firm value (*FV*)	1.663	2.885	1.061
Industry turbulence (*INDT*)	1.137	0.560	1.024
Industry concentration (*CONC*)	0.435	0.250	0.380
Cost of goods sold (*COGS*) (\$M)	298.17	2383.13	17.60

[a] Scaled by assets

$$\begin{bmatrix} RD_{it} \\ ADV_{it} \\ INV_{it} \\ SALE_{it} \\ FV_{it} \end{bmatrix} = \begin{bmatrix} \alpha_{1i} \\ \alpha_{2i} \\ \alpha_{3i} \\ \alpha_{4i} \\ \alpha_{5i} \end{bmatrix} + \sum_{k=1}^{K} B_K \begin{bmatrix} RD_{it-k} \\ ADV_{it}-k \\ INV_{it-k} \\ SALE_{it-k} \\ FV_{it-k} \end{bmatrix} + \begin{bmatrix} \gamma_1 Z_{it} \\ \gamma_2 Z_{it} \\ \gamma_3 Z_{it} \\ \gamma_4 Z_{it} \\ \gamma_5 Z_{it} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \\ \varepsilon_{3it} \\ \varepsilon_{4it} \\ \varepsilon_{5it} \end{bmatrix} \quad (3)$$

In Eq. 3, i is the subscript for the firm, t is the year, k is the time lag, *RD* and *ADV* denote R&D spending and advertising spending respectively, *INV* denotes inventory holding, *SALE* denotes sales, and *FV* denotes firm value. Additionally, α_{1i}, α_{2i}, α_{3i}, α_{4i}, and α_{5i} represent a firm-random intercept of R&D spending, advertising spending, inventory holding, sales, and firm value respectively. For a given time lag k, B_k is a 5×5 coefficient matrix capturing the interrelatedness between the five endogenous variables, and K (number of lags) is chosen based on Schwartz Bayesian Information Criterion. We include a vector of exogenous control variables $\mathbf{Z_{it}}$ in each equation, whose effects are captured by γ_j, for each j, j=1 to 5. Finally, $_{kit}$, for each k, k=1 to 5 represent the error terms that are normally distributed. We estimate the model using feasible generalized least squares which controls for heteroscedasticity in errors due to unobserved heterogeneity.

We first perform unit root tests on each of the five variables to examine if they are stationary or evolving (i.e., non-stationary). The unit root test results indicate that all the five variables are stationary, allowing us to estimate the VAR-X model in levels (i.e., without differencing or co-integration corrections). If we were to estimate the model in differences, i.e., the variables were considered evolving, we would interpret the results of the long-term effects analysis as the impact of the growth of one variable on the growth in another in steady-state (e.g., as in Dekimpe and Hanssens 1995, p. 9).[4] Based on the Schwartz Bayesian Information Criterion, the VAR-X model with two lags was selected, and the model shows good model-fit (R^2=0.53).

[4] We thank an anonymous reviewer for highlighting this point.

Results

Long-term effects

Using the VAR-X model's estimates, we apply the impulse-response function approach to estimate the long-term impact of any one variable (e.g., R&D) on any other variable in the system (e.g., firm value). The impulse-response function method computes two long-term forecasts of the five endogenous variables, one based on the information set (i.e., starting values, coefficients) without a shock in one variable (e.g., R&D spending), and another with a shock of one standard error in the same variable, all else held equal. The difference between the two forecasts is the incremental long-term effect of one variable (e.g., R&D spending) on any other variable in the system (e.g., firm value) (Dekimpe and Hanssens 1995, 1999; Pauwels et al. 2004). We adopt the generalized simultaneous-shock approach, which uses the information in the residual variance-covariance matrix of the VAR-X model to derive a shock vector that comprises of contemporaneously correlated expected shock values.

We assess the statistical significance of the long-term effect using Monte Carlo simulations (e.g., Pauwels et al. 2004). Using the initial start-up values of the five endogenous variables, we sample from the multivariate normal error covariance matrix 1000 times. For each draw of the sampled residuals, we use the estimated coefficients to create a synthetic dataset of the five endogenous variables and the long-term effects. Using the standard error of the long-term effect from each of the 1000 draws, we statistically infer whether the long-term effect is statistically different from zero.

Long-term effects of spending on performance

Table 4 shows the long-term effects of spending on sales and firm value. Advertising spending (long-term effect (*LTE*)= 0.251, p< 0.05) and inventory holding (*LTE* =0.483, p< 0.10) have a positive and significant long-term impact on sales, while R&D spending does not have a significant long-term effect on sales (*LTE* =0.027, not significant [*ns*]). The long-

Table 3 Correlations

Variable	*RD*	*ADV*	*INV*	*SALE*	*FV*
R&D spending (*RD*) (\$M)[a]	1.000				
Advertising spending (*ADV*) (\$M)[a]	0.051	1.000			
Inventory holding (*INV*) (\$M)[a]	0.734	0.055	1.000		
Sales (*SALE*) (\$M)[a]	0.691	0.037	0.784	1.000	
Firm value (*FV*)	0.148	0.002	−0.010	0.001	1.000

[a] Scaled by assets

All correlations above 0.50 are statistically significant at $p < 0.05$

term effect of inventory holding on sales is not statistically different from the long-term effect of advertising spending on sales ($\Delta LTE = 0.231$[*se.* = *0.221, ns*]).

Next, R&D spending ($LTE = 3.756$, $p < 0.05$) and advertising spending ($LTE = 1.028$, $p < 0.05$) have a positive and significant impact on firm value, while inventory holding does not have a significant long-term impact on firm value ($LTE = -0.161$, *ns*). The long-term effect of R&D spending on firm value is significantly greater than the long-term effect of advertising spending on firm value ($\Delta LTE = 2.727$ [*s.e.* = *0.604*, $p < 0.05$]).

Thus, we confirm previous findings that advertising spending has a positive long-term impact on sales (Dekimpe and Hanssens 1995), as well as on firm value (Pauwels et al. 2004), and R&D spending has a positive impact on firm value (Mizik and Jacobson 2003). A novel finding is that inventory holding has a positive long-term impact on sales, but not on firm value.

We plot the impulse response results in Figs. 3 and 4. In Fig. 3, we plot the impact of spending on sales. Since advertising and inventory holding have a positive and significant impact on sales, we observe non-zero gains in their cumulative long-term impact (Fig. 3, Panel b and Panel c respectively). We see a pronounced gain for five periods as inferred from the steep slope, with steady-state being achieved close to 12 periods after the initial impulse.

In Fig. 4, we plot the impulse response functions of spending on firm value. Since R&D and advertising spending have a positive and significant impact on firm value, we observe non-zero gain in their cumulative long-term impact (Fig. 4, Panel a and Panel b respectively). Similar to Fig. 3, pronounced gains last for five periods and steady-state is achieved about 12 periods after the initial impulse. Finally, of interest is that in Fig. 4, Panel c, the impact of inventory holding on firm value is negative (and insignificant) while its impact on sales is negative.

Long-term effects of performance on spending

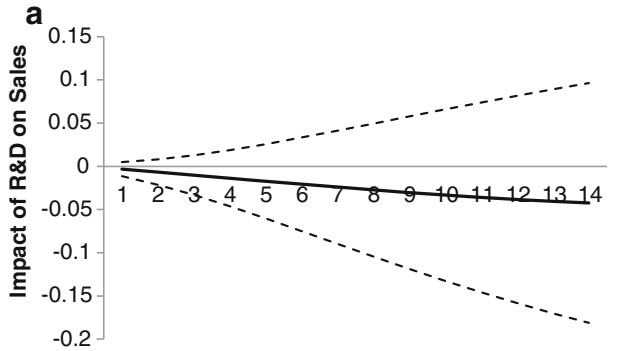
Table 5 shows that increases in sales lead to a positive and significant impact on R&D spending ($LTE = 0.239$, $p < 0.05$), advertising spending ($LTE = 0.037$, $p < 0.05$), and inventory holding ($LTE = 0.183$, $p < 0.05$). We confirm previous research findings that advertising (Lilien and Little 1976; Mantrala 2002) and R&D (Bhagat and Welch 1995) spending are influenced by sales-based heuristics. A novel finding is that the sales-based heuristic for spending also holds for inventory holding as seen in the significant long-term effect of sales on inventory holding.

Turning to the effects of firm value on spending (Table 5), increases in firm value lead to a negative and significant impact on R&D spending ($LTE = -0.006$, $p < 0.05$), advertising spending ($LTE = -0.006$, $p < 0.05$), and inventory holding decisions ($LTE = -0.083$, $p < 0.05$).

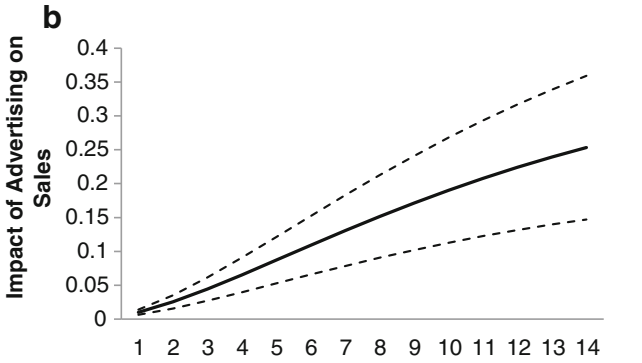
Consistent with Chakravarty and Grewal (2011), this finding provides evidence that managers change marketing strategies in response to changes in firm value. Of interest is that a reduction in inventory appears to be an efficiency-oriented approach to increasing firm value, as opposed to reduction in R&D and advertising, which are both growth-oriented approaches to increasing firm value. Since we employ a VAR-X model which accounts for dynamic interdependencies, we obtain long-term effects, extending Markovitch et al.'s (2005) findings of short-term changes in R&D spending and advertising spending in response to stock market performance metrics.

Table 4 Long-term effects of spending on performance

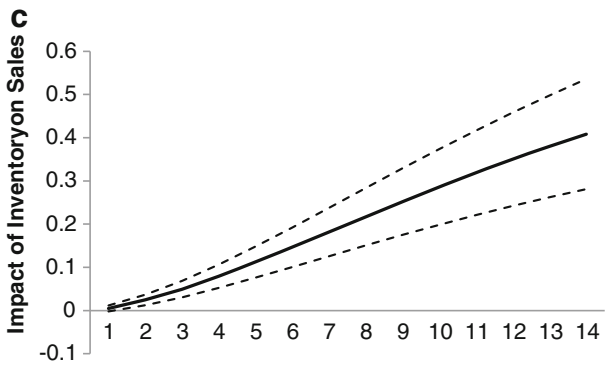
	Sales			Firm value		
	Long-term effect	s.e.	*t*-value	Long-term effect	s.e.	*t*-value
R&D	0.027	0.198	0.138	***3.756***	***0.482***	***7.779***
Advertising	***0.251***	***0.119***	***2.106***	***1.028***	***0.362***	***2.833***
Inventory	***0.483***	***0.186***	***2.600***	−0.161	0.45	−0.355



Note: Dotted lines represent the ±1 SD confidence interval.

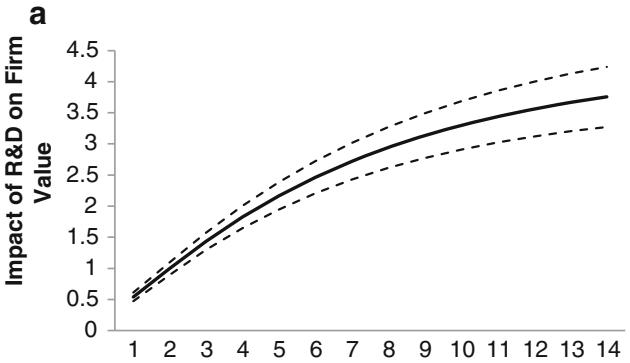


Note: Dotted lines represent the ±1 SD confidence interval.

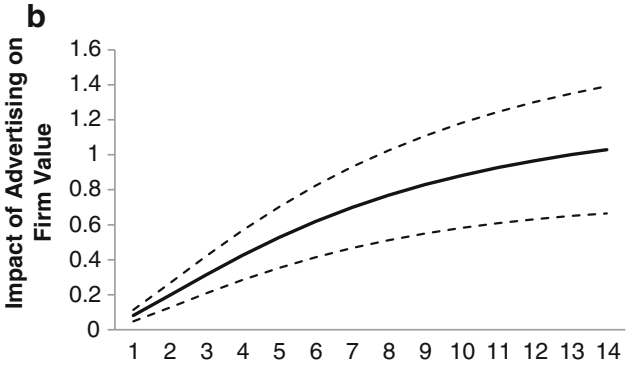


Note: Dotted lines represent the ±1 SD confidence interval.

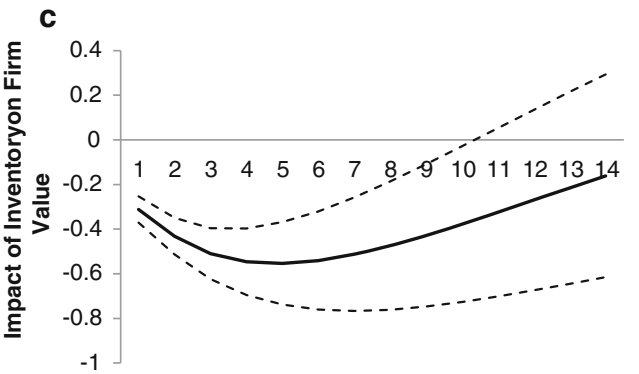
Fig. 3 Impulse response functions for the effects of spending on sales



Note: Dotted lines represent the ±1 SD confidence interval.



Note: Dotted lines represent the ±1 SD confidence interval.



Note: Dotted lines represent the ±1 SD confidence interval.

Fig. 4 Impulse response functions for the effects of spending on firm value

Long-term effects of spending on one another

Table 6 shows the long-term effects of R&D spending, advertising spending, and inventory holding on one another. The main finding is that inventory holding has a positive long-term impact on R&D spending ($LTE = 0.157$, $p < 0.05$), and R&D spending also has a positive long-term impact on inventory holding ($LTE = 0.055$, $p < 0.10$). It appears that R&D programs result in new products that increase inventory holding, and inventory holding appears to play an important role in influencing R&D spending. This novel insight on cross-functional spending effects adds to the literature on long-term effects, which has primarily focused on documenting the impacts of spending on performance.

Robustness checks

Alternative time period To examine the robustness of the results to time, we estimated a model using a smaller sample between 1995 and 2005. The pattern of results for the reduced period (not reported here in the interest of brevity) is qualitatively similar to the full sample results, reported in Tables 4, 5, and 6.

Alternative high-tech sample We estimated the model with a more conservatively defined set of three-digit high technology SIC codes by excluding firms that do not report any inventory

Table 5 Long-term effects of performance on spending

	R&D			Advertising			Inventory		
	Long-term effect	s.e.	*t*-value	Long-term effect	s.e.	*t*-value	Long-term effect	s.e.	*t*-value
Impact of sales	***0.239***	***0.049***	***4.889***	***0.037***	***0.008***	***4.727***	***0.183***	***0.052***	***3.516***
Impact of firm value	***−0.006***	***0.002***	***−2.750***	***−0.006***	***0.003***	***−1.903***	***−0.083***	***0.024***	***−3.469***

data. The pattern of results (not reported here) is again qualitatively similar to those reported in Tables 4, 5, and 6.

Additional analysis: what if inventory holding is excluded?

Next, we benchmark a key differentiator of our research. As mentioned, the literature has not considered the effects of inventory holding, while studying the impact of R&D spending and advertising spending on firm performance. Thus, our incorporation of inventory holding into the work of Mizik and Jacobson (2003), who consider advertising and R&D, extends the past marketing literature in this domain in inventory in the framework. In this context, Mizik and Jacobson (2003) view advertising and R&D as value appropriation and value creation, respectively. Our addition of inventory holding, a way of delivering products to customers, incorporates the impact of "value delivery" in increasing sales and firm value.

To obtain a benchmark of the bias obtained when inventory holding is considered, we estimate the long-term effects from a VAR-X model with four equations, i.e., R&D spending, advertising spending, sales, and firm value, but without inventory holding. The results show that both firm advertising spending ($LTE = 0.196$, $p < 0.05$) and R&D spending have a positive and significant long-term impact on sales ($LTE = 0.131$, $p < 0.05$). In the model which included inventory holding, we find that firm advertising spending (long-term effect (LTE)$=0.251$, $p < 0.05$) has a positive and significant long-term impact on sales, while R&D spending does not have a significant long-term impact on sales ($LTE = 0.027$, *ns*). Not including inventory holding in the model results in incorrect conclusions about the long-term effect of R&D spending on sales.

Next, R&D spending ($LTE = 5.554$, $p < 0.05$) has a positive and significant impact on firm value, while advertising spending does not have a significant long-term impact on firm value ($LTE = 0.876$, *ns*). In the model which includes inventory holding, both advertising spending ($LTE = 1.028$, $p < 0.05$) and R&D spending ($LTE = 3.756$, $p < 0.05$) have a positive and significant impact on firm value. Not including inventory holding results in incorrect conclusions about the long-term effects of advertising spending on firm value.

Discussion

Extending developments in the marketing literatures, we propose and empirically validate a VAR-X model relating firms' R&D spending, advertising spending, and inventory holding to one another and on top-line and bottom-line firm performance. Overall, the results of the VAR-X model support three types of dynamic inter-relationships: the impact of R&D spending, advertising spending, and inventory holding on sales and firm value; the impact of sales and firm value on R&D spending, advertising spending, and inventory holding; and the impact of R&D spending and inventory holding on one another. While past studies have separately examined some of these dynamic inter-relationships, this study is the first to demonstrate all three types of dynamic inter-relationships. In this section, we discuss the theoretical and managerial implications of our work.

Theoretical implications

First, we highlight the long-term impact of firm performance on spending, complementing extant literature's focus on the

Table 6 Long-term effects among spending decisions

	R&D			Advertising			Inventory		
	Long-term effect	s.e.	*t*-value	Long-term effect	s.e.	*t*-value	Long-term effect	s.e.	*t*-value
Impact of R&D	***0.502***	***0.051***	***9.926***	−0.005	0.008	−0.581	***0.055***	***0.055***	***1.004***
Impact of advertising	0.039	0.030	1.285	***0.080***	***0.005***	***16.392***	0.040	0.034	1.162
Impact of inventory	***0.157***	***0.047***	***3.342***	−0.004	0.008	−0.531	***0.606***	***0.050***	***12.061***

impact of spending on performance. In particular, we document a novel finding of asymmetric managerial reactions to R&D spending, advertising spending, and inventory holding to increases in sales and firm value. Specifically, firms increase spending in response to increases in sales. In contrast, they decrease spending in response to increases in firm value. This adds to the recent and growing literature on marketing strategy reactions to the stock market (Chakravarty and Grewal 2011; Markovitch et al. 2005). Thus, firms could be focusing on expense reduction as an important source of further increasing firm value. However, such expenses increase the value of the firm in the first place (Thomas and Zhang 2002). An alternative explanation for the cutbacks could be the "ratchet effect." Specifically, spending cutbacks could help reduce market expectations of faster firm growth (cf., Moorman et al. 2012). From an adaptive learning standpoint, the asymmetric influence of sales and firm value demonstrates how managers adjust their spending patterns based on multiple information sources. While sales has been the typically documented influencer of spending decisions (e.g., Lilien and Little 1976; Mantrala 2002), there is a need to further study managers' spending reactions to market-based metrics such as firm value.

Second, we demonstrate the crucial role of inventory holding in complementing value creation (R&D) and appropriation (advertising) efforts. We find that the long-term effect of inventory holding on sales is comparable to that of advertising, suggesting the need to integrate inventory holding in sales and performance response models of advertising. In particular, for marketing scholars studying the effects of R&D spending and advertising spending on firm value, our findings suggest that they must consider incorporating inventory holding in their analysis. Also, the impact of sales on inventory holding is higher than the impact of sales on either R&D spending or advertising spending. This again reflects the importance of value delivery (inventory holding) in addition to value appropriation (advertising) and value creation (R&D) examined in the extant literature. Further, the negative long-term influence of firm value on inventory holding is also higher than for either R&D spending or advertising spending, suggesting that the intensity of cost cutting in firms might be strong (Carpenter et al. 1994).

Managerial implications

We also generate three takeaways for practice. First, we provide a model-based approach to tackle the challenging problem of efficiently and dynamically allocating scarce dollars toward increasing firm performance. This involves understanding the three types of dynamic interdependencies: the impact of spending decisions on performance, the impact of performance on spending decisions, and the impact of spending decisions on one another. We find evidence for all three interdependencies and document the specific nature of these relationships and their long-term effects, which may be useful to managers in managing the interdependencies.

Second, in the context of the high technology sector, we find that the long-term impact of R&D spending on firm value is greater than that of advertising spending, and we find that the impact of inventory holding on sales is comparable to that of advertising spending. These estimates of the relative impact of marketing spending could serve as a guide for resource allocation for marketing managers in the high technology industry.

Third, the findings highlight the need to account for the role of inventory holding, while estimating the long-term impact of R&D spending and advertising spending on firm performance. Specifically, not including inventory holding will result in incorrect conclusions about the impact of the long-term effects of R&D spending and advertising spending on sales and firm value.

Limitations

We conclude by highlighting some limitations of our work, which offer opportunities for future research. We focus our empirical application on the high technology sector, where R&D spending, advertising spending, and inventory holding decisions are critical to firms' success. A study that allows for the dynamic interdependencies to vary by industries could lead to further empirical generalizations.

Further, driven by our interest in insights on firm-level investments in R&D, advertising, and inventory, we use aggregate firm spending. Future studies can examine dynamic interdependencies by focusing on other metrics (e.g., profits, stock returns) and on other industry sectors (e.g., automotive, consumer goods), with other marketing spending (e.g., promotions) and with more granular data at the monthly or weekly level. Also, similar research at the product-, brand-, and category-level using finer temporal aggregations may generate useful insights for both marketing and operations managers.

Finally, firms may sometimes set their R&D, advertising, and inventories based on competitive actions and their competitors' responses. Future studies can consider such competitive responses in their model specification, and the relationships among inventory holding, production, and supply chain management efficiency.

In sum, we believe that this paper takes a first step toward examining the interconnectedness of firms' R&D spending, advertising spending, and inventory holding on one another and on sales and firm value. We hope that this stimulates future research to explore other inter-relationships among spending and processes in different functions in the firm, and their effects on firm performance.

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