



Dynamic capital asset accumulation and value of intangible assets: An operations management perspective

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ABSTRACT

Extending the dynamic resource accumulation framework to operations management, we propose that the stock of younger capital assets and flow of capital assets are positively associated with the value of intangible assets, an increasingly predominant basis of competitive advantage. Based on a sample of 1390 manufacturing firms representing 8255 firm-year observations, the stock of younger capital assets was positively related to the value of intangible assets, an association that was strengthened by higher inventory efficiency. However, we also found that the flow of capital assets is negatively related to the value of intangible assets, an association that is further exacerbated by high production efficiency. Our findings explain how operations management could play an important role in influencing the intangible asset value of manufacturing firms.

1. Introduction

Intangible assets are increasingly forming the basis of competitive advantage for a large number of firms (Bianchi, 2017; Haskel & Westlake, 2018). Because these assets have become a major portion of corporate assets in US and European firms, they have received considerable interest from scholars and policymakers (Shin, Kraemer, & Dedrick, 2017). According to Itami (1987), “invisible [intangible] assets are often the only real source of competitive edge that can be sustained over time” (page 1). Intangible assets refer to “...a particular technology, accumulated consumer information, brand name, reputation and corporate culture” (page 1). Despite this growing interest in understanding the drivers of intangible capital, the operations management literature has paid scant attention to explaining the vital role operations management can play in enhancing the value of intangible assets. To address this gap in our understanding of the nature and dynamics of capital assets in influencing the value of intangible assets, we draw on the classical dynamic resource accumulation framework by Dierickx and Cool (1989). They highlighted that managers must make decisions about expenditures (flow) to acquire assets in factor markets to accumulate (stock) non-tradable resources that lead to competitive advantage. The authors' bathtub analogy focuses on investing and building assets over time, and illustrates that the flow of assets and accumulation of the stock of resources is a dynamic process:

“[...] at any moment in time, the stock of water is indicated by the level of water in the tub; it is the cumulative result of flows of water into the tub (through the tap) and out of it (through a leak). In the example of R&D, the amount of water in the tub represents the stock of know-how at a particular point in time, whereas current R&D spending is represented by the water flowing in through the tap; the fact that know-how depreciates over time is represented by the flow of water leaking through the hole in the tub”

(Dierickx & Cool, 1989, page 1506)

Extending this metaphor to the critical, yet less explored, process of accumulating capital assets during the process of operations could increase a firm's intangible asset value by maintaining the stock and flow of capital assets. Focusing on both stock and flow is necessary, because “while flows can be adjusted instantaneously, stocks cannot. It takes a consistent pattern of resource flows to accumulate a desired change in strategic asset stocks” (Dierickx & Cool, 1989, page 1506). Capital assets include machine, warehouse, and inventory capacities. The dynamic accumulation of capital stock provides firms with the necessary bandwidth to support operational activities that drive a firm's intangible asset value. Current stock constitutes a combination of older and newer capital assets, whereas older capital assets help maintain continuity and interconnectedness with operational and non-operational capabilities. Because current asset interconnectedness is already

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accounted for in a firm's stock price, newer avenues of interconnectedness increase the value of intangible assets (i.e., market capitalization minus the firm's book value) (e.g., Villalonga, 2004). A higher flow of capital assets, or a higher allocation of capital assets relative to their depreciation, signals greater commitment toward renewing the capital asset base. Based on the limited understanding of how the stock and flow of capital assets contribute to the value of intangibles and the relevance of operational performance characteristics, our first research question is: *Does the stock of younger capital assets or the flow of capital assets influence the value of a firm's intangible assets?*

Furthermore, operational characteristics—inventory efficiency and production efficiency—could further influence the strength of these proposed associations. Higher inventory efficiency could act as a pipeline for the interconnectedness of the stock of younger capital assets within a firm and in the supply chain. Firms with higher inventory efficiency could be construed as being better able to manage the stock of younger capital assets to improve the value of intangible assets. However, firms with a higher flow of capital assets and higher production efficiency would be construed as being less capable of integrating the flow of capital assets with broader resources and capabilities, leading to a lower value of intangible assets.

To test for the proposed framework, based on a sample of 1390 manufacturing firms representing 8255 firm-years, and using Arellano-Bond dynamic panel regression, firms with stock of younger capital assets realize a higher value of intangible assets; however, firms with a higher flow of capital assets realize a lower value of intangible assets. For firms with stock of younger capital assets, higher inventory efficiency was positively associated with the value of intangible assets; however, for firms with a higher flow of capital assets, production efficiency was negatively associated with the value of intangible assets. The findings are robust to alternate specifications.

The findings provide theoretical contributions to the operations management literature. First, past work in operations management has focused on aligning strategic objectives with operations objectives (Joshi, Kathuria, & Porth, 2003), or has asked whether operations contribute to a firm's competitive advantage (Flynn, Schroeder, & Sakakibara, 1995). Other work has focused on the contribution of learning and knowledge exchange between operations functions and other functional areas (Kim, 2006; Luo, Slotegraaf, & Pan, 2006) and among supply chain partners (Dyer & Singh, 1998; Li, Ragu-Nathan, Ragu-Nathan, & Rao, 2006). Still yet others have focused on the effects of lean production (Eroglu & Hofer, 2011) or practices that integrate the operations function with organizational factors, such as Total Quality Management (Douglas & Judge, 2001) or quality management practices (Flynn et al., 1995), on competitive advantage. Capital assets form the building block of operational and nonoperational capabilities, and yet, the ways in which a firm dynamically manages its capital assets have received limited attention in the operations management literature.

Second, by focusing on the stock and flow of capital assets we extend Dierickx and Cool (1989) framework. Deeds and Decarolis (1999) focused on the flow of knowledge assets in the context of geographic spillovers and alliances. Knott, Bryce, and Posen (2003) concluded that Dierickx and Cool's model is supported for asset erosion (related to asset stocks), but is not more important than asset flows. Recently, Erden, Klang, Sydler, and von Krogh (2014), in a sample of public biopharmaceutical firms, found that knowledge flows² have a nonlinear impact on firm performance. To our knowledge, this is the first study to test the stock and flow of capital assets and extend Dierickx and Cool's (1989) framework to operations management.

Third, although the operations function forms the core of a firm, in the broader business literature its impact on competitive advantage has

received limited attention (Adam & Swamidass, 1989; Demeester, De Meyer, & Grahovac, 2014). Whereas marketing assets (Wernerfelt, 2014), knowledge stocks (Grant, 1996), information systems capabilities (Clemons, 1986), and even executive talent (Bartlett & Ghoshal, 2013) are associated with the intangible asset value of a firm, the dynamic accumulation of capital assets also seems to play an important role in increasing the intangible value of a firm's assets. Work in operations management has focused on the resource-based view (RBV) of the firm to explain the value of operational resources and capabilities (Barratt & Oke, 2007; Coates & McDermott, 2002; Paiva, Roth, & Fensterseifer, 2008). A firm's resources are a function of type, magnitude, and the nature of the resources (Amit & Schoemaker, 1993). Past work on operations has focused on the type of resources (relational capital and operational capabilities), but the nature (tangible or intangible) and magnitude (stock and flow) of resources remain less explored. The current framework explores the nature and magnitude of capital assets (stock and flow) in a dynamic panel framework to explain how firms, through dynamic capital asset management, increase the value of intangible assets through a “cumulative result of adhering to a consistent set of [capital asset stock and flow] policies over a period of time” (Dierickx & Cool, 1989, page 1506).

2. Theoretical background

According to the RBV, valuable, rare, inimitable, and non-substitutable resources lead to sustainable competitive advantage (Barney, 1986). Reflecting the rent-generating potential of resources, the RBV highlights the efficacy of resources in developing competitive advantage, especially when they are intangible (Taylor, 1999). Because intangible assets are less mobile, difficult to imitate, and embedded in a complex web of human and technological assets, they are the key to competitive advantage.

The market value of a firm is attributed to both the value of intangible assets and the value of tangible assets. The tangible value of assets is measured by the replacement costs of assets such as plant, equipment, inventory, and short-term assets. The remaining component of market value is the intangible asset value of the firm, which constitutes value attributed to brand, knowledge, culture, employee relations, patents, and copyrights, among other items that lead to firm value over and above the replacement value of a firm's tangible assets. Tacit and difficult to codify, intangible resources are less likely to be traded in factor markets and increasingly exhibit complementarities with knowledge and skills within and outside the firm.

Capital assets form the core of the organizational activities of a manufacturing firm and influence a multitude of organizational resources to form a complex combination of resource bundles that increase the intangible asset value of firms. Yet, capital assets, including machines, equipment, and immovable assets, which can be construed as tangible assets, form complex interconnections with resources, activities, and stakeholders to indirectly increase the intangible asset value of the firm. In operations management, a complex combination of tangible capital assets within the firm and in the supply chain leads to stronger interconnectedness of intangible resources. Stock and the flow of tangible capital assets provide the task, tool, and process infrastructure to facilitate knowledge exchange among employees (Dyer & Nobeoka, 2000; Linderman, Schroeder, Zaheer, Liedtke, & Choo, 2004) across functional areas (Malhotra & Sharma, 2002) and within the supply chain (Cousins & Menguc, 2006; Ketchen & Giunipero, 2004). Combinations and recombinations facilitated by tangible capital assets increase value, rarity, and non-substitutability of such bundled operational resources (Rungtusanatham, Salvador, Forza, & Choi, 2003).

2.1. Dynamic asset accumulation model

Dierickx and Cool (1989) proposed that assets must be accumulated over time to develop a bundle of strategic assets. Resources, or “stocks

² Proxied as R&D expenditures, density of firms in the geographic area of the firm, alliances, and personnel growth.

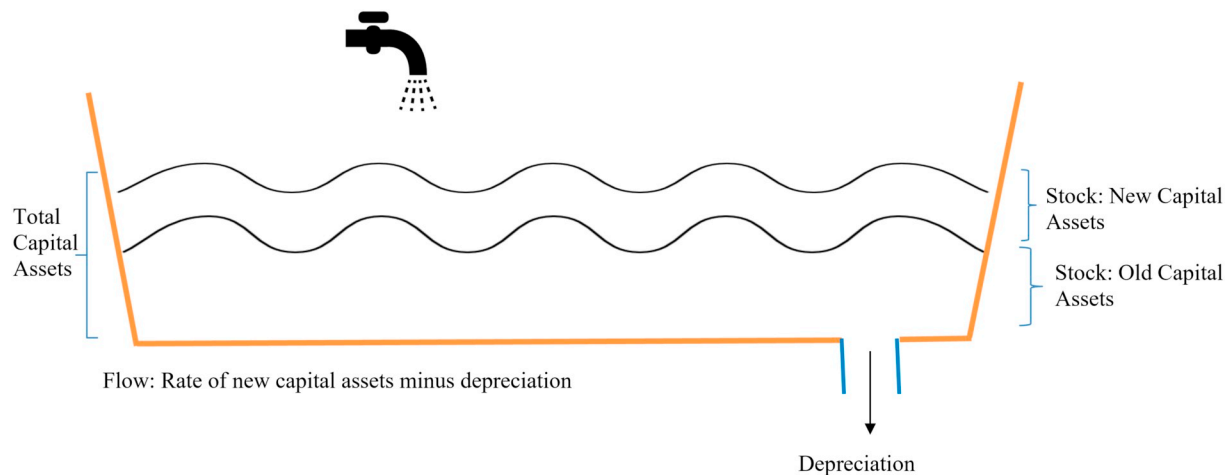


Fig. 1. Dynamic capital asset accumulation model.

of available [tangible or intangible] factors that are owned or controlled by a firm” (Amit & Schoemaker, 1993, page 33), must be acquired from the strategic factor markets and integrated with existing resources and capabilities to configure valuable, rare, inimitable, and non-substitutable resources. Unless a firm deliberately commits the time and effort to upgrading assets, asset erosion will reduce competitive advantage. To prevent the erosion of assets and maintain the value of a bundle of assets it is crucial to manage capital assets dynamically.

Two factors influence the rate of dynamic asset accumulation: 1) the flow of assets into the firm, and 2) accumulation time (Adamides & Voutsina, 2006; Denrell, 2004). The flow of new assets refers to the rate at which new assets are added and existing ones depreciate. The flow of capital assets helps close strategic gaps identified between strategic goals and the capacity of existing strategic assets. However, assets are added in increments, and strategic gaps cannot be filled instantaneously by acquiring capital assets from the factor markets; instead, they are accumulated over time.

Based on this discussion, we draw on the bathtub analogy proposed by Dierickx and Cool (1989) (Fig. 1). The water level in the tub represents the total stock of assets. Total stock of capital assets is the sum of older capital assets and newer capital assets. The lower water layer represents the older accumulated stock of assets, which exits the tub through depreciation of the assets. The stock of accumulated older assets is more deeply interconnected and forms the basis of maintaining ongoing operational activities. However, over time, these assets erode and the stock must be replenished with newer assets. The upper layer represents the stock of new capital assets. The relative ratio of new to old capital assets is the value of net property plant and equipment divided by gross property plant and equipment, or the newness of the stock of capital assets. Firms with stock of younger capital assets are able to close competitive gaps and improve performance.

Due to longer accumulation times for new capital assets, the flow of new capital assets (through the tap illustrated in Fig. 1) is essential to ensure the acquisition of capital assets from factor markets, because “maintaining a given rate of investments in flows over a particular time interval produces a larger increment to the asset stock than maintaining twice these investments in flows over half the time interval” (Erden et al., 2014, page 2778). The flow of capital assets, measured as the ratio of the difference between capital assets minus depreciation to the replacement value of assets, is necessary to maintain a pipeline of newer assets to be integrated into existing capital assets (cf., Swink & Nair, 2007; Whyte, 1994). Because asset acquisition and accumulation times vary, flow helps maintain the vitality of capital assets, which is central to sustaining competitive advantage.

To summarize, because capital assets form the core operational infrastructure of a firm, the dynamic accumulation of these assets is

central to maintaining their competitiveness. Because capital assets are deeply interconnected with resources within and outside the firm, the stock of younger capital assets and flow of capital assets are both critical. The stock of younger assets ensures that the firm is positioned to close strategic gaps and meet competitive demands. The ageing stock of capital assets signals a firm's reduced ability to meet competitive challenges, increases threat-rigidity, and reduces a firm's ability to update interconnectedness with other resources within and outside the firm. Because a critical mass of assets is not created instantaneously, a sustained flow of capital assets ensures that the firm continues to focus on competitiveness. Next, we propose that the stock of younger capital assets and the flow of capital assets increase the value of intangible assets.

3. Hypotheses development

A stock of younger capital assets can be a double-edged sword for manufacturing firms. On the one hand, older capital assets can be beneficial, because routines and processes can be better refined over time on the same set of tangible resources than for younger capital assets. Older assets are embedded with supply chain partners' competencies, and interface with the functional areas of the firm. A unique bundle of interconnected, older tangible resources provides necessary stability, whereas the stock of younger assets is related to the firm's future growth potential. On the other hand, however, firms with older tangible assets are unable to provide the necessary infrastructure of assets to create novel interconnections among bundles of resources within and outside the firm. Older assets may also signal a firm's limited ability to renew capital assets and meet emerging realities in competitive market domains. While the stock of older capital assets reassures stakeholders of a firm's ability to meet ongoing operational challenges, the stock of younger assets increases the fidelity of signals that the firm has a modernized operational asset base to be more competitive.

On the net, drawing on Penrose (1959), older assets may increase the imitation of capabilities over time, as the causal ambiguity of older assets is likely to be lower. A newer asset base forces the firm to reassess, realign, and reinvigorate relationships among resources and capabilities within and outside the firm to increase intangible asset value. Younger assets force firms to focus on managing the efficacy of older assets, and to ensure the inclusion of newer assets in a complex network of operational and nonoperational resources. Firms with younger capital assets can improve information gathering and processing mechanisms to develop valuable recombinations of capital assets with broader resource bundles in the firm and in the supply chain. Because the value of intangible assets relates to skills and knowledge, it is strengthened by the newness of firm assets; as such, we expect that

firms with a stock of younger assets are positively related to the value of intangible assets:

Hypothesis 1. The stock of younger capital assets is positively associated with a firm's intangible asset value.

Based on the literature encompassing asset economics, a firm incurs two types of capital expenditures—growth versus maintenance capital expenditures (Gort & Wall, 1998; Mullen & Williams, 2004; Sweeney, 1930). Maintenance-based capital expenditures are depreciation expenses. If a firm's capital expenditures are equal to or below maintenance expenditures, competitive advantage may deteriorate in the long term, because the firm is not making capital expenditures aimed at building plants or upgrading machinery. Flow of capital assets is the degree to which a firm makes capital investments relative to depreciation expenditures for every dollar of the replacement cost of assets, or $\left[\frac{\text{Capital Expenditure}}{\text{Replacement value of assets}} - \frac{\text{Depreciation}}{\text{Replacement value of assets}} \right]$ (Konar & Cohen, 2001; Sweeney, 1930). If the value is positive, the firm allocates more funds toward new capital when making decisions on replacing assets. In contrast, if the value is negative, the firm allocates more operational expenditures toward depreciation in replacing existing assets. A negative value indicates that the firm is allocating more funds to depreciation than it is for new capital investments for every dollar of the firm's replacement value. A negative value thus indicates the “dying firm effect” (Konar & Cohen, 2001), where the firm aims to maintain its older assets through an increased focus on depreciation.

Due to longer lags in accumulation time, flow rate is an important determinant of the long-term vitality of a bundle of resources. The flow of capital ensures continuous recombination and alignments with other bundles of resources. The refreshment rate or vitality resulting from flow provides resources from factor markets to close strategic gaps and pursue newer competencies. A slower flow of capital assets may limit the necessary recombinant uncertainty (Fleming, 2001) to increase the tacit nature of knowledge and skills among operations assets and broader resource bundles in the firm and supply chain. We can thus propose our second hypothesis:

Hypothesis 2. Flow of capital assets is positively associated with a firm's intangible asset value.

Next, we identify the role of operational characteristics that could impact the efficacy of stock and the flow of capital assets. For firms with younger assets, inventory efficiency could be an additional signal of the firm's ability to increase the value of intangible assets. With a higher flow of capital assets, higher production efficiency could further reduce the value of intangible assets. Inventory efficiency, or the degree to which a firm's inventory turnover is higher than its competitors, is an important operational capability. Different functional areas, such as marketing, in an effort to increase market responsiveness, require the operations function to have higher coordination and communication, with inventory efficiency being a proxy for how well internal and external demand management capabilities are coordinated (Balakrishnan & Geunes, 2004; Hill & Scudder, 2002; Sahin & Robinson, 2005). Higher inventory efficiency relative to competitors not only indicates a firm's ability to forecast and manage materials more effectively, but also reflects a firm's ability to manage the flow of materials. Inventory efficiency through improved information flow, information sharing, and resource management indicates improved sharing of information among supply chain partners (Netessine & Zhang, 2005). Inventory efficiency complements younger assets to increase the efficacy of IT assets (e.g., electronic data interchange) through improved accuracy and data transfer. Furthermore, higher inventory efficiency creates conduits for exchanging information and knowledge that span both internal and external stakeholders. Inventory efficiency can be regarded as a “plumbing” system that connects the stock of younger capital assets with resources and capabilities (Coe, Dicken, & Hess, 2008; Pagell, 2004).

Younger capital resources flow through circuitry composed of knowledge, skills, materials, and products to increase the overall value of intangible assets. For example, younger capital assets, along with inventory efficiency, allow the marketing function to strengthen its relationship with customers and improve brand recognition. Smoother product flow resulting from higher inventory efficiency in firms and a supply chain with stock of younger assets also indicate the firms' ability to develop collaborative forecasting techniques (Wagner, 1980) and inventory management routines to reduce waste and stockouts (Heydari, 2014). More importantly, younger assets facilitate the convergence of inter- and intra-organizational efforts to improve the synthesis of accumulated bundles of capital resources. Higher inventory efficiency indicates leanness, and firms with younger capital assets coupled with higher inventory efficiency is a clear signal of a firm's ability to improve material flow (Davies & Joglekar, 2013; Dehning, Richardson, & Zmud, 2007), productivity (Eroglu & Hofer, 2011), and lower output variability (Michalski, 2009). Also, because inventory can tie up firm capital (Modi & Mishra, 2011), increasing inventory efficiency of firms with younger assets signals that the firm could use working capital to further leverage younger capital assets.

With a higher stock of younger capital assets, firms with higher levels of inventory efficiency provide an additional signal to stakeholders that they can manage a younger operational asset base to increase the value of intangible assets. We therefore posit:

Hypothesis 3. At higher levels of inventory efficiency, a firm with younger capital asset stock has a stronger positive association with the value of its intangible assets.

Production efficiency entails higher relative efficiency in transforming raw materials to finished products (Jeong & Phillips, 2001; Modi & Mishra, 2011). Increasingly newer methods are implemented (e.g., just in time, flexible manufacturing, cycle time reduction, mistake proofing, and maintenance management) to improve production efficiency. Production improvement methods aim to streamline the production process to reduce waste, increase speed, and improve set up times. Production efficiency is a result of a complex and coordinated set of organizational resources and knowledge (Fugate, Stank, & Mentzer, 2009; Kortmann, Gelhard, Zimmermann, & Piller, 2014; Ross & Droge, 2004), but it only hones efficiency-oriented capabilities, and may not prepare a firm to close strategic gaps. Developed through strong path dependence, production efficiency represents deeply embedded capabilities that may not fully help develop higher intangible asset value by increasing the flow of capital assets.

For firms with a higher flow of capital assets or a greater focus on growth-based capital expenditures relative to maintenance-based capital expenditures, higher production efficiency could signal a limited ability to leverage new capital investments toward increasing adaptation (cf. Flynn & Flynn, 2004; Narasimhan, Talluri, & Das, 2004; Plambeck & Taylor, 2013). Production efficiency signals efficiency in maintaining performance but not in promoting growth; in fact, higher production efficiency could be a liability for firms with a higher flow of capital assets. Production efficiency, despite an increasing escalation of capital expenditures, signals that a firm is continuing to focus on path-dependent knowledge and skills that may not create additional value, possibly indicating that the firm aims to pursue tried and tested approaches with existing capital assets and aims to increase efficiency at the expense of upgrading capital assets.

Overall, higher levels of production efficiency under a higher flow of a firm's capital assets (newer, higher-vitality assets) signal that the firm may be less able to meet changing market or competitive demands. This, in turn, lowers the intangible asset value of firm assets and leads to:

Hypothesis 4. At higher levels of production efficiency, a firm with a higher flow of capital asset stock has a negative association with the value of its intangible assets.

Overall, our proposed theoretical framework draws on the dynamic asset accumulation framework, and proposes the benefits to intangible asset value under high levels of stock of younger capital assets (H1) and flow of capital assets (H2). Complementing these hypotheses, inventory efficiency strengthens the association in H1, and production efficiency negates the association in H2.

4. Data and methods

To test the proposed hypotheses on the relationship between stock and flow of a firm's capital assets and the value of its intangible assets, we draw from COMPUSTAT data. To lower sampling bias, we did not apply any filters³ and included all publicly traded manufacturing firms (two-digit SIC codes 20 to 39) from 1980 to 2018 (the last full year of data available at the time of this study). Based on case wise deletion, the dataset includes 8255 firm-year observations from 1390 manufacturing firms. The fewer number of firm-year observations is due to case wise deletions resulting from a large number of firms not reporting the value of their intangible assets.

Table 1 describes the variable operationalizations and Table 2 summarizes the variables at the industry level. In the right-most column of Table 1, for replication we include the variable in names in COMPUSTAT for all the variables in the analysis, along with applicable formula for each variable.

4.1. Dependent variable: value of the firm's intangible assets

The value of intangible assets is operationalized as the natural log of the value of intangible assets (in millions) (Konar & Cohen, 2001; Villalonga, 2004).

4.2. Predictor variables

4.2.1. Inventory efficiency

Based on Modi and Mishra (2011), inventory efficiency is measured relative to competitors' inventory; that is, for firm i at time t (year):

$$IE_{it} = \frac{\left(\frac{Sales_{it}}{Inventory_{it}}\right) - \mu\left(\frac{Sales_t}{Inventory_t}\right)}{\sigma\left(\frac{Sales_t}{Inventory_t}\right)}$$

where μ is the industry (at SIC2) mean sales to inventory ratio at time t (year), and σ is the standard deviation in sales to inventory for the industry (at SIC2) at time t . The intuition is as follows: The numerator measures the degree to which firm i 's inventory efficiency deviates from mean industry inventory efficiency. Because inventory efficiency varies from industry to industry, the difference in the numerator is normalized by the standard deviation of inventory efficiency in an industry. This allows for a standardized measure of inventory efficiency comparable across industries.

4.2.2. Production efficiency

Production efficiency is the sales generated for every dollar invested in net property, plant, and equipment (PPE), and is adjusted for the mean industry (at SIC2) ratio of sales to net PPE. The difference is divided by the standard deviation of sales to net PPE in the industry (Modi & Mishra, 2011) in year t :

$$PE_{it} = \frac{\left(\frac{Sales_{it}}{NetPPE_{it}}\right) - \mu\left(\frac{Sales_t}{NetPPE_t}\right)}{\sigma\left(\frac{Sales_t}{NetPPE_t}\right)}$$

Similar to the measure of inventory efficiency, production efficiency is a standardized measure comparable across industries.

4.2.3. Stock of younger capital assets

Based on Konar and Cohen (2001), the stock of younger capital assets is the ratio of net PPE to gross PPE (cf. Sweeney, 1930; Warren, 2005). As Konar and Cohen (2001) note, higher values indicate increasingly younger assets.

4.2.4. Flow of capital assets

Flow of capital refers to the extent to which firms invest in growth-oriented capital expenditures relative to maintenance-oriented capital expenditures for each dollar in the replacement value of assets (Konar & Cohen, 2001; Sweeney, 1930; Warren, 2005). Higher values indicate greater focus on investments in growth-oriented capital expenditures, and lower values indicate greater orientation toward maintenance-oriented capital expenditures.

4.3. Control variables

To control for additional factors that may influence a firm's value of intangible assets we included the following controls.

4.3.1. Revenue

Natural log of revenue controls for firm size, which has been shown to have a significant impact on intangible assets (Connolly & Hirschey, 2005; Villalonga, 2004).

4.3.2. Advertising expenses

Because advertising expenses are strongly correlated with product differentiation and consumer loyalty, which in turn increase the value of intangible assets (Hirschey & Weygandt, 1985), we include advertising expenses measured as a percent of the replacement costs of assets. Adjusting advertising costs for the replacement cost of tangible assets allows for an assessment of the degree to which firms allocate funds toward advertising, given the stock of capital assets.

4.3.3. Research and development

R&D expenses are positively related to the intangible asset value of firm assets (Hirschey & Weygandt, 1985). For our measure of R&D intensity, we use the natural log of a firm's research and development expenses. As we control for firm revenue and revenue growth, we do not adjust R&D expenses by sales.

4.3.4. Revenue growth

To control for past performance, we include the three-year revenue growth in firm sales. Because sales growth leads to a higher value of intangible assets, revenue growth captures several unobservable controls that drive the value of intangible assets (Bolton, Chen, & Wang, 2011). We measure percentage growth in revenue over a three-year period.

4.3.5. Number of employees

The number of employees also proxies for firm size. We use the natural log of the number of employees for this control.

4.4. Results

Table 3 presents correlations. We used a dynamic panel specification, *xtabond2* in STATA 15.0, and all predictor variables at $t - 2$ as instruments (Roodman, 2006). In Table 4, we present the results. We first present estimates of the null model (Model 1), and then introduce our control variables (Model 2), independent variables (Model 3), interaction terms (models 4 and 5), and finally the full model (Model 6).

Hypothesis 1 proposed that the stock of younger capital assets is positively associated with the value of intangible assets. We found support for this hypothesis (Model 3: $\beta = 0.323$, $p < 0.01$). Hypothesis 2 proposed that higher flow of capital assets is positively associated with the value of intangible assets. Hypothesis 2 is not supported

³ The main effects are robust to winsorizing at 1%.

Table 1
Description of variables.

Variable	Description	COMPUSTAT variable fields
Value of intangible assets	Natural log of intangibles in millions for year $t + 1$.	$\ln(intan)$
Inventory efficiency	Ratio of the firm's net sales to average total inventory (inv_t), normalized by the industry mean and standard deviation of sales ($sale$) to average total inventory at 2-digit SIC code.	$inv_t, sale$
Production efficiency	Ratio of the firm's sales to average net property plant and equipment ($ppent$), normalized by the industry mean and standard deviation of average net property plant and equipment, with industry defined at the 2-digit SIC code.	$ppent, sale$
Stock of younger capital assets	The newness of assets calculated as the net property plant and equipment divided by gross property plant and equipment (Konar & Cohen, 2001).	$(ppent/ppegt)$
Flow of capital assets	Measure of capital expenditure dollars relative to depreciation per dollar of replace cost of tangible assets (Konar & Cohen, 2001).	$(capx - dp)/(at - intan)$
Revenue	Natural log of revenue in millions.	$\ln(revt)$
Advertising expense	Advertising expense divided by tangible assets. Tangible assets are total assets minus intangible assets (Konar & Cohen, 2001).	$(xad/(at - intan))$
R&D	Natural log of research and development expenditures	$\ln(xrd)$
Revenue growth %	Revenue growth defined as the percent change in growth year to year.	$(rev_{t-1} - rev_{t-5})/rev_{t-5}$
Number of employees	Natural log of the number of employees	$\ln(emp)$

Notes: the labels in the parentheses in the second column are the labels in COMPUSTAT and are listed to facilitate replication.

because the effects are significant in the opposite direction (Model 3: $\beta = -0.625, p < 0.01$).

In Hypothesis 3, we proposed that higher inventory efficiency strengthens the positive association between the stock of younger capital assets and the value of intangible assets (Model 4: $\beta = 0.261, p < 0.01$). Fig. 2(a) shows that the decline in value of intangible assets is not significant at low levels of inventory efficiency; however, at higher levels of inventory efficiency, the increasing stock of younger capital assets is positively associated with intangible asset value. Perhaps newer capital assets, along with high inventory efficiency, may help enhance the speed, quality, cost, flexibility, and reliability dimensions of operational performance. Higher inventory efficiency may complement newer stock of capital assets to improve the overall perception of operational performance, which may have indirect spillovers in the resource web of a firm to influence the value of intangible assets.

Hypothesis 4 proposed that at higher production efficiency, a higher flow of capital assets lowers the value of intangible assets (Model 5: $\beta = -0.956, p < 0.01$). Fig. 2(b) shows that at higher production efficiency, the intangible assets of firms with a higher flow of capital assets have a lower value. Consistent with the arguments leading to H4, higher production efficiency lowers the value of intangible assets with an increasing flow of capital assets. However, of interest is also the left side of Fig. 2(b). When the flow of capital assets is slower, higher production efficiency results in higher value of intangible assets. The combination of slow flow of capital with high and low production efficiency could represent a different firm configuration (e.g., food manufacturers), where production efficiency may increase operational performance for an inherently more intransient capital base (i.e., slow to flow capital assets in food manufacturing). It is plausible that focusing on manufacturing flexibility, which could be better measured from primary data, may increase the value of intangibles with higher asset flow and production efficiency. Drawing on change-stability logic (Farjoun, 2010), a stable capital asset base coupled with higher production efficiency may provide the necessary stability to enhance aspects such as branding and stakeholder relationships in certain types of industries.

The estimates were consistent in the full model (Model 6). Overall, Hypotheses 1, 3, and 4 are supported.

4.5. Robustness checks

4.5.1. Contemporaneous endogeneity

Given the dynamic panel specification controls for autocorrelation among stock and the flow of capital assets and value of intangibles, there is likely to be mutual causality in a contemporaneous time period. The value of intangibles is incorporated in the stock price, and lags in

reporting accounting performance could bias the estimates.

Using data from the Bureau of Economic Analysis (BEA), we identify three instruments based on fixed assets and consumer durables industries in the US economy for each firm-year: 1) aggregate chain indices of the net stock of fixed assets and consumer durables; 2) aggregate chain indices of the depreciation of fixed assets and consumer durables; and 3) aggregate chain index of investments in fixed assets and consumer durables. The aggregate chain indices represent the quantity of assets in upstream, downstream, and focal industries for consumer durables.⁴ For each product, BEA calculates inflation and dollar-adjusted values and aggregates them for all products in a sector. The three instruments are on net stock of fixed assets, value of depreciated assets, and total investments in each set of durables. The three identified instruments are based on variations in the US economy and represent asset makeup in a given firm year. As consumer durables are precursors of future economic demand, they may not have a direct impact on the value of intangible assets in the firm.

Using the firm-year, time-varying instruments in the *xtivreg2* routine in STATA 15.0, we find consistent estimates with the main results (Table 5, Model 7), except for 1. Related to the strength of the instruments, the Cragg-Donald Wald F statistic (=4.295) was below the Stock-Yogo value at 10% (=13.43) and at 25% (=5.45) of the maximum value of IV size, indicating that the null hypotheses that instruments are weak cannot be rejected.

Overall, due to weak instruments, we are unable to rule out endogeneity in our estimates.

4.5.2. Mixed model specification

As firms are nested in the industry, and industries and firms are nested in time, we tested whether inferences are robust to a mixed model specification (Table 5, Model 8). The inferences are consistent with the main inferences.

⁴ The industries and their buyers and suppliers included by the BEA are: autos, light trucks, motor vehicle parts and accessories; furniture, clocks, lamps, lighting fixtures and other; carpets and other floor coverings; window coverings; household appliances, glassware, tableware, and household utensils; tools and equipment for house and garden; video and audio equipment; photographic equipment; personal computers and peripheral equipment; computer software and accessories; calculators, typewriters, and other information equipment; sporting equipment, supplies, guns, and ammunition; motorcycles, bicycles, and accessories; pleasure boats; pleasure aircraft; other recreational vehicles; recreational books; musical instruments; jewelry and watches; therapeutic appliances and equipment; educational books; luggage and similar personal items; telephone and facsimile equipment.

Table 2
Descriptive statistics.

SIC	Industry name	Number of observations	Ln intangibles (t + 1)	Revenue (t)	Advertising expense	Ln R&D	Revenue growth %	Number of employees	Inv. eff.	Prod. eff.	Stock of younger capital assets	Flow of capital assets
2000–2099	Food and kindred products	491	5.656	7.6806	0.0874	2.5615	0.1669	2.1516	-0.1554	-0.1824	0.5416	0.0158
2100–2199	Tobacco products	17	4.6904	7.0273	0.0563	2.1042	0.108	1.1968	0.2958	0.3395	0.5525	0.0057
2200–2299	Textile mills products	39	0.7137	4.9634	0.0084	0.6881	0.1558	0.3421	-0.1588	-0.3064	0.5032	0.0023
2300–2399	Apparel and other finished products made from fabrics	49	4.8856	7.1838	0.0453	2.816	1.5139	2.3688	-0.1755	-0.2237	0.516	0.0053
2400–2499	Lumber and wood products	32	3.1776	5.9542	0.066	1.3535	0.2874	0.4453	-0.3429	-0.2451	0.5514	0.0053
2500–2599	Furniture and fixtures	114	3.946	6.7336	0.1085	2.224	0.1118	1.3963	0.4137	-0.0534	0.4266	0.001
2600–2699	Paper and allied products	96	4.9541	7.2659	0.0897	2.9158	0.2094	1.9021	0.5412	0.3338	0.5233	0.0112
2700–2799	Printing, publishing and allied industries	46	5.0403	6.6193	0.0655	2.8887	0.5566	1.1213	1.3797	-0.2412	0.4384	-0.0128
2800–2899	Chemicals and allied products	1636	3.5242	5.4787	0.0828	2.5469	1.0285	0.0982	-0.086	0.0487	0.5186	-0.0047
2900–2999	Petroleum refining and related products	11	2.8361	3.3272	0.0376	0.2316	6.8535	-2.369	-0.5482	1.184	0.5325	-0.0202
3000–3099	Rubber and miscellaneous plastics products	152	3.5393	6.2419	0.0331	1.9666	0.4081	1.0314	-0.3662	-0.0176	0.4161	-0.0006
3100–3199	Leather and leather products	48	1.52	5.631	0.0751	1.2663	0.3283	0.2485	-0.364	-0.3162	0.4398	0.0037
3200–3299	Stone, clay, glass and concrete products	91	1.9563	5.3914	0.0279	0.3911	0.1688	-0.0812	-0.113	0.6322	0.5023	0.0122
3300–3399	Primary metal industries	72	2.9434	5.1235	0.0134	1.2726	0.2056	-0.1016	0.0119	0.1738	0.5112	-0.0013
3400–3499	Fabricated metal products, except machinery and transportation equip.	357	3.4488	5.755	0.0322	1.277	0.1827	0.661	-0.1501	-0.058	0.4731	0.0028
3500–3599	Industrial and commercial machinery and computer equipment	1334	3.661	5.8885	0.0193	2.7073	0.2809	0.5712	-0.0538	-0.0884	0.444	-0.0124
3600–3699	Electronic and electrical equipment and components, except computer	1798	2.9023	5.2053	0.0156	2.4773	0.4422	-0.0045	-0.0644	-0.0946	0.4265	-0.0106
3700–3799	Transportation equipment	253	2.7253	6.4612	0.0196	2.604	0.3407	1.109	-0.0778	0.168	0.4811	0.0049
3800–3899	Measuring, analyzing and controlling instruments	1619	2.4792	4.4955	0.0199	2.0332	0.526	-0.6143	-0.0294	-0.0404	0.459	-0.0098
2000–3899	All industries	8255	3.8423	6.6871	0.0537	2.1606	0.8253	0.6824	-0.0026	0.0602	0.5506	-0.0001

Table 3
Correlations and descriptive statistics.

	Mean	Std dev	Ln intangibles (t + 1)	Lagged revenue	Advertising expense	R&D	Revenue growth (%)	Number of employees	Inventory efficiency	Production efficiency	Stock of younger capital assets	Flow of capital assets
Ln intangibles (t + 1)	3.2971	3.0248	1.0000									
Lagged revenue	5.5308	2.3189	0.8237*	1.0000								
Advertising expense	0.0391	0.0816	0.0836*	0.1001*	1.0000							
R&D	2.3375	2.2944	0.7411*	0.7947*	-0.0017	1.0000						
Revenue growth (%)	0.5173	4.0094	-0.0625*	-0.0870*	0.0006	-0.0459*	1.0000					
Number of employees	0.2639	2.1278	0.7708*	0.9405*	0.0761*	0.7492*	-0.0757*	1.0000				
Inventory efficiency	-0.0572	0.6005	0.0479*	0.0422*	0.0440*	0.0723*	0.0036	0.0061	1.0000			
Production efficiency	-0.0347	0.6963	-0.1769*	-0.1926*	0.1428*	-0.1927*	0.0176	-0.2656*	0.0307*	1.0000		
Stock of younger capital assets	0.4690	0.1697	0.1286*	0.1158*	0.0396*	0.0299*	0.0791*	0.2038*	-0.0325*	-0.2847*	1.0000	
Flow of capital assets	-0.0057	0.0610	-0.0162	0.1327*	0.0044	0.0450*	-0.0074	0.1931*	-0.0795*	-0.0964*	0.3107*	1.0000

Notes: 1390 firms representing 8255 firm-year observations from 1980 to 2018. All correlations with * are significant at 0.05 or below.

4.5.3. Alternate moderation effects

We further assessed the relationship between the alternate specifications of moderators. The interactions between the stock of younger assets and production efficiency was ($\beta = 0.0829, p > 0.10$) and between the flow of capital assets and inventory efficiency it was ($\beta = 2.837, p > 0.10$). The results are available from the authors.

5. Discussion

The results show that firms with stock of younger capital assets do realize gains in the value of intangible assets (supporting H1); however, firms with a higher flow of capital assets realize a lower value of intangible assets (not supporting H2). Firms with a stock of younger capital assets coupled with higher inventory efficiency realize a higher value of intangible assets (supporting H3). Supporting H4, for firms with a higher flow of capital assets, the value of intangible assets is lower when production efficiency is higher.

Lack of support for H2 can be explained by accumulation time lags for capital assets. As firms allocate available budgets for strategic expenditures among R&D, advertising, and capital expenditures, the flow of capital assets may take longer to translate directly to valuable resources. Traditionally, the stock market reacts strongly to R&D expenditures compared to other forms of strategic expenditures (Woolridge & Snow, 1990). The stock market may construe the flow of capital assets as lagging a signal of assets reaching critical mass before the flow of capital assets can contribute to the intangible asset value of the firm, thus potentially discounting higher capital asset flows.

The findings make several contributions to the literature. First, the stock and flow of capital assets is a seldom-explored concept in operations management. The findings show that a younger capital base is directly related to a higher intangible asset value (cf. Armstrong & Shimizu, 2007; Coates & McDermott, 2002). Capital assets form the scaffolding of an operational base, and its stock (age of capital assets) and flow (relative orientation toward growth and maintenance of capital assets) remain important aspects of dynamically managing capital asset accumulation in operations.

Second, the contrasting effects in H1 and H2 indicate the value of stock overflow of capital asset accumulation; that is, maintaining stock of a younger capital base seems more valuable than a faster flow of capital expenditures. Capital assets are absorbed into the firm at a much slower rate than other resources. Relationships among tools, tasks, and processes require deliberate and reciprocal exchanges, and increasing flow could pose absorption and integration challenges. The results also suggest that higher flow (higher stock of younger assets) coupled with higher production (inventory) efficiency is detrimental (beneficial) to improving intangible asset value.

Third, work in marketing and information systems over the years has highlighted the value of such resources in increasing the intangible asset value of a firm (Villalonga, 2004), thereby increasing competitive advantage. Efforts in operations management, however, are limited, despite the fact that operations management is a core function of an organization. The nature and rate of accumulation of capital assets seem to signal the preparedness of firms in driving their intangible asset value (cf. Rungtusanatham et al., 2003).

Fourth, by examining the relationship between stock and the flow of capital assets, we contribute to Dierickx and Cool's (1989) seminal work. Whereas studies on resource accumulation have focused on knowledge assets, we show that the stock and flow of capital assets could also impact the value of intangible assets. A significant body of work has focused on dynamic capabilities, or the ability to reconfigure capabilities, from the perspective of knowledge stocks. The results show that previously less considered capital stocks are central to increasing the value of intangible assets. The work of Dierickx and Cool (1989) is the cornerstone of the strategy literature, yet only three empirical studies have focused on testing this framework (Deeds & Decarolis, 1999; Erden et al., 2014; Knott et al., 2003), and all three studies have focused

Table 4
Regression estimates for Arellano-Bond regression panel data models.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Null model	Controls model	IV model	Moderator	Moderator	Full
	Ln intangibles t + 1	Ln intangibles t + 1	Ln intangibles t + 1	Ln intangibles t + 1	Ln intangibles t + 1	Ln intangibles t + 1
Revenue		0.137*** (0.0212)	0.229** (0.0190)	0.216*** (0.0194)	0.194*** (0.0193)	0.266*** (0.0181)
Advertising		−0.361** (0.177)	−0.543*** (0.167)	−0.537*** (0.168)	−0.730*** (0.173)	−0.639** (0.168)
R&D		0.197*** (0.0197)	0.195** (0.0163)	0.208*** (0.0169)	0.196*** (0.0168)	0.205*** (0.0154)
Revenue growth % (3-year)		0.00206* (0.00123)	0.00187 (0.00121)	0.00175 (0.00122)	0.00223* (0.00121)	0.00180 (0.00120)
Number of employees		0.542*** (0.0330)	0.573*** (0.0280)	0.582*** (0.0295)	0.578*** (0.0282)	0.585*** (0.0262)
Inventory efficiency			0.0586*** (0.0169)	−0.0709* (0.0363)		−0.109*** (0.0352)
Production efficiency			−0.0264* (0.0155)		−0.0602*** (0.0157)	−0.0461*** (0.0155)
Stock of younger capital assets [H1: +]			0.323*** (0.0879)	0.270*** (0.0865)		0.426*** (0.0820)
Flow of capital assets [H2: +]			−0.625*** (0.147)		−0.664*** (0.146)	−0.944** (0.146)
Stock of younger capital assets × inventory efficiency [H3: +]				0.261*** (0.0683)		0.329*** (0.0649)
Flow of capital assets × production efficiency [H4: −]					−0.956*** (0.215)	−0.984*** (0.208)
Constant	3.297*** (0.0365)					
F-stat	35.07***	14.38***	13.23***	14.20***	13.68***	13.25***
Observations	8255	8255	8255	8255	8255	8255
Number of firms	1390	1390	1390	1390	1390	1390

Notes: standard errors in parentheses.

*** $p < 0.01$.

** $p < 0.05$.

* $p < 0.1$.

on knowledge stocks. As far as we know, this is the first study to examine the role of the dynamic accumulation of capital assets in driving the value of intangible assets.

However, in addition to the three studies listed above, [Lin and Wu \(2014\)](#) draw on a survey-based measure of dynamic capabilities from the top 1000 Taiwanese companies. Their findings show that dynamic capabilities mediate a firm's valuable, rare, inimitable, and non-substitutable (VRIN) resources to improve performance; however, non-VRIN resources do not have a mediating effect. Among three types of dynamic learning capabilities—integration, learning, and reconfiguration—learning capabilities had the strongest mediation effect in their study. In the context of our study, we could not measure dynamic capability; however, it is of both theoretical and practical interest to assess whether dynamic capabilities drive the capital asset stock and flow. Dynamic capabilities could be an important theoretical precursor to dynamic resource accumulation.

Furthermore, [Hall and Andriani \(2000, 2003\)](#) highlight the importance of intangible assets in the supply chain. Our framework complements their work by focusing on how the flow of capital assets, a phenomenon rooted in the dynamic capabilities framework, explains the overall increase in the value of intangibles. While intangibles at the firm level may also influence operations and supply chain outcomes, we lowered these reverse effects by using dynamic panel regression.

5.1. Managerial implications

The findings highlight multiple managerial implications. Interconnected with other resources and capabilities, the stock and flow of capital assets are the backbone of a firm's operational efforts. Acquiring, accumulating, and enhancing capital assets reduce asset erosion and develop asset mass efficiencies because the stock market values the stock of younger capital assets over the flow of capital assets. Developing a stronger understanding on how flow translates into the stock of resources is crucial ([Sterman, 2001](#)). At high capital asset flow, focusing on higher production efficiency seems counterproductive, because it signals intentions to integrate such stocks into improving current production but not pursuing growth strategies. Capital assets must be managed actively by maintaining a stock of younger capital assets, and the stock market values capital assets based on their youth, especially when inventory efficiency is high. [Warren \(2005\)](#) proposed tools such as time-chart thinking to identify time scales and time paths of resource accumulation. Simpler tools such as opening balance, additions, losses (to depreciation), and closing balance ([Warren, 2005](#)) could also help assess the stock and flow of capital assets.

5.2. Limitations and directions for future research

This study is not without limitations. We focus on accumulation patterns of capital assets in manufacturing firms using yearly data from

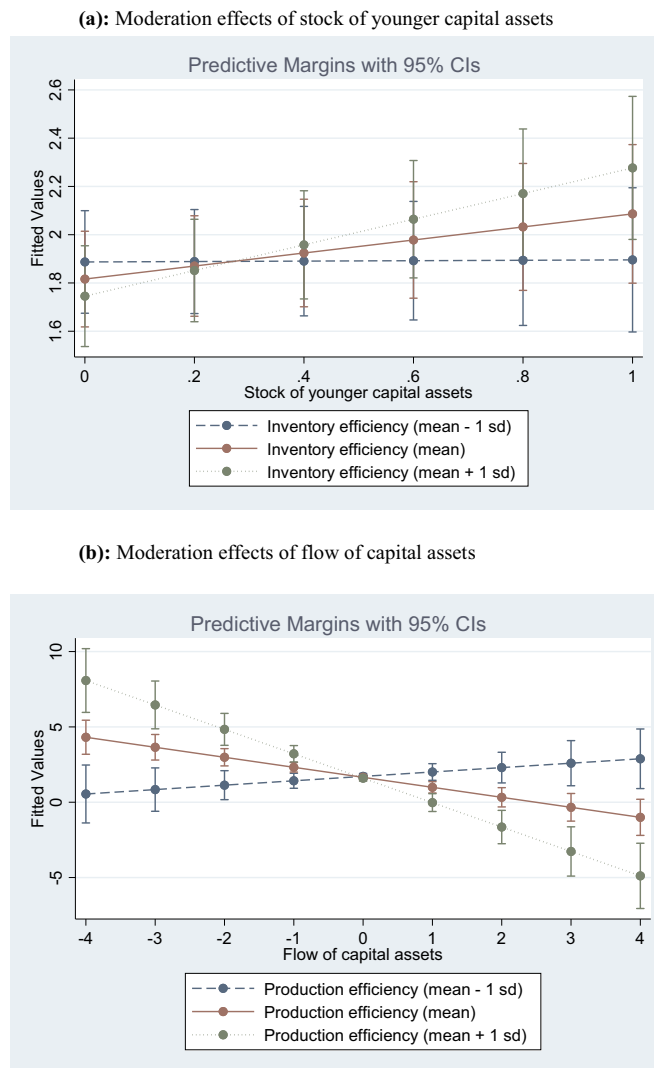


Fig. 2. Two-way interaction plots (± 1 SD).

annual reports. These patterns are not readily discernible from accounting performance data, but are inferred based on the makeup of capital assets. We call on future studies to draw on qualitative data to identify patterns of accumulating, integrating, and reconfiguring capital assets. The inferences are also limited by the tradeoff between generalizability across a large number of manufacturing firms versus collecting primary data to develop a finer-grained understanding of a firm's dynamic capital asset accumulation approaches. In service firms, the challenges of dynamically accumulating human capital may be more unique than in the manufacturing context explored here. Finally, we cannot rule out endogeneity in our inferences that imply correlation and not causation.

The findings also provide directions for future research. Understanding the stock and flow of capital assets is important for operational strategy. The present study is an early finding on the value of managing stocks and flows of assets in the context of the broader dynamic resource management framework. As operational capabilities could be built on the stock and flow of capital assets, stock and flow are important characteristics to consider for future research. Possibly, the stock of younger capital assets could support manufacturing flexibility, and the stock of older capital stock could improve returns from lean production. Lean production requires stronger coordination and relies on pre-established routines, which may not be amenable to the faster flow of capital assets. Alternatively, balance in the stock of younger and

Table 5
Robustness tests.

	(7)	(8)
	IV/GMM estimation of the fixed-effects and first-differences	Mixed-effects regression
Stata 15.0 routine→	<i>xtivreg2</i>	<i>xtmixed</i>
Variables	Ln intangibles $t + 1$	Ln intangibles $t + 1$
Revenue	0.498*** (0.0323)	0.878*** (0.0254)*
Advertising	-0.600** (0.291)	0.549** (0.225)
R&D	0.412*** (0.0251)	0.305*** (0.0130)
Revenue growth % (3 year)	-0.0120*** (0.00330)	-0.00279 (0.00444)
Number of employees	0.353*** (0.0404)	-0.0392 (0.0263)
Inventory efficiency	-0.178*** (0.0654)	-0.236*** (0.0716)
Production efficiency	-0.0849*** (0.0275)	-0.0132 (0.0295)
Stock of younger capital assets	0.213 (0.131)	1.679*** (0.117)
Flow of capital assets	-1.912*** (0.269)	-7.062** (0.313)
Stock of younger capital assets \times inventory efficiency	0.392*** (0.124)	0.460*** (0.146)
Flow of capital assets \times production efficiency	-1.167*** (0.380)	-0.657 (0.459)
Constant	-0.603*** (0.185)	-3.113*** (0.144)
Chi2	109,459.41***	21,183.61***
Observations	8255	8255
Number of firms	1390	1390

Notes: standard errors in parentheses.

*** $p < 0.01$.

** $p < 0.05$.

* $p < 0.1$.

older resources could also help a manufacturing firm pursue operational and supply chain ambidexterity by ensuring the continuity of old routines while acquiring newer capital assets.

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