

# Manufacturing Management in Process Industries: The Impact of Market Conditions and Capital Expenditure on Firm Performance

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**Abstract**—Process industries operate in commodity markets with low product variety, little product differentiation, and highly capital-intensive manufacturing. Because prices are volatile and demand is uncertain, manufacturing capabilities become the main strategic competitive lever. The purpose of this paper is to evaluate the interplay between market conditions, capital expenditure, manufacturing flexibility, and production capacity to effectively analyze the consequences of manufacturing investments in both the short and the long terms. In order to achieve this, we developed an econometric model linking market conditions and operational decisions. We tested the model on a sample of 480 firms from the mining sector and 1053 firms from the oil and gas sector. The results show that firms in process industries follow the market with their investments, which impacts their operations in the short term as well as their capacity growth in the long term. Additionally, from our findings, we propose a *firm value driver model* that managers could consider when deciding on capital expenditures. Finally, our results indicate that the managers of financially healthy companies should resist the stock market's short-term pressure to reduce fixed costs and instead play the long game.

**Index Terms**—Capital expenditure, commodity markets, manufacturing flexibility, process industry, production capacity.

## I. INTRODUCTION

**F**IRMS in process industries, such as oil and gas, steel mining, and chemical, have unique production requirements [1]. Unlike consumer industries, process industries operate with less product differentiation and low variety; they compete in commodity markets with high fixed costs combined with little or no pricing power. As a result, manufacturing capabilities become the main strategic competitive levers. However, since process industries operate with highly asset-intensive manufacturing, they face a crucial tradeoff when balancing short-term and long-term interests [2], [3].

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The literature on manufacturing has long recognized the need for volume flexibility in dealing with dimensions such as demand uncertainty, short product life cycles, and overcoming disruptions [4]–[7], yet it has paid little attention to how managers in process industries align their capital expenditure (CAPEX) to strike a balance between long- and short-term production [8]. Understanding the drivers and consequences of CAPEX is particularly important, since process industries operate in a business environment with unique characteristics.

First, process industries, in contrast to consumer industries, operate with little possibility of product differentiation and fewer market strategies for creating value [9]. Ultimately, price setting becomes market based and volatile compared with consumer products.

Second, limitations in predicting commodity prices and demand uncertainties shape the market. Due to unpredictable market conditions [10], process industries turn to manufacturing costs as the main competitive lever, especially in long-term production [11]. Additionally, for traditional consumer markets, there are several frameworks designed to forecast demand, and hence price [12]; in process industries, however, these frameworks may not be appropriate [13]. Unanticipated changes in demand or supply can result in unstable price trends, since pricing dynamics are directly dependent on the supply–demand balance. Therefore, it is important to evaluate the interplay between CAPEX, manufacturing flexibility, and production capacity to effectively handle price volatility in the short term and improve production capacity in the long term.

Third, CAPEX has a strong impact on manufacturing capabilities [14]–[16] since process industries operate with capital-intensive technologies. Moreover, CAPEX on manufacturing assets is sensitive to cash flow swings [17], [18]. High fixed costs combined with little or no pricing power make companies' cash flow highly sensitive to volatile market prices. In turn, any changes in investments impact manufacturing volume flexibility [5], [19] and capacity expansions [20].

Although the effects of price trends and demand uncertainties on CAPEX investments are known, little is known about how they interact, which could provide a framework for managers in process industries, especially on how to allocate CAPEX for short- and long-term gains. In order to investigate this, we seek to answer the following research question: *How do market conditions impact CAPEX and manufacturing capabilities and*

*what are the consequences for firm performance in the short and long terms?*

The remainder of this paper is organized as follows. In Section II, we present the theoretical underpinnings and develop the hypotheses. In Section III, we develop an empirical model using financial accounting, spot market price, and stock market data for the mining and oil and gas sectors that establishes a link between CAPEX and manufacturing management. We selected the oil and gas and mining industries as they represent 31% and 40% of sales in the commodity market, respectively. In Section IV we present our results, and Section V concludes this paper.

## II. THEORY DEVELOPMENT AND HYPOTHESES

To articulate our theoretical relationships, we adopted the approach explained by Whetten *et al.* [21]. This approach suggests borrowing theory from other fields and adapting it to the focal context. Being motivated by this approach, we then considered two streams of literature that are particularly relevant for our paper.

First, we started with established theoretical concepts from the manufacturing literature, namely manufacturing flexibility and production capacity. Second, we borrowed the theoretical concept of price and asset development from the financial literature to base our work on the determinants of the value of investment decisions at the firm level. We present our theoretical approach in detail below with the two streams that are inextricably related.

### A. Price Trend and Demand Uncertainty

Investments in the development and maintenance of fixed assets represent the main competitive edge for firms in industries with undifferentiated products. The development of manufacturing assets in process industries requires high investments and cash outflows, which can be financed from external or internal sources.

However, internally financed investments are particularly sensitive to cash flow volatility and financial liquidity, as modeled under different assumptions [22]. For example, there is a multiplier effect of tangible assets and investments, which increases an investment's cash flow sensitivity and particularly exposes the process industries under consideration [23]. Evidence suggests that even the least financially constrained firms are sensitive to cash flow volatility. The vast majority of evidence from the literature suggests that commodity markets are sensitive to cash flow volatility and require high investments. These investments are primarily financed from internal sources [24], [25]. The cash flow generated depends directly on market prices. Therefore, CAPEX is not only particularly high compared with other industries but also a core competency of firms in commodity markets. For example, petrol companies largely decreased their CAPEX in response to the 1986 drop in oil prices because of reduced cash inflows [26], suggesting that CAPEX depends on market price trends. The current finance literature has mainly focused on firms' financial liquidity constraints and access to external financing. We add to this stream of literature by introducing an

operational aspect, focusing on investments in fixed assets by manufacturing industries. Further, we focus on internally generated cash flows as they play a crucial role in determining the short-term and long-term development of a firm [24]. Based on these arguments, we propose the following hypothesis:

*H1: CAPEX from internally generated cash flows is positively correlated with long-term price trends*

Furthermore, investments and cash flows are highly interdependent. Investments are associated with projected future cash flow volumes, and anticipated sales positively impact investment volumes [15]. In addition, investments are sensitive to the availability of internal funding. Furthermore, cash inflows become more volatile (and uncertain) as prices become more volatile, and this negatively impacts CAPEX.

*H2: CAPEX from internally generated cash flows is negatively correlated with demand uncertainty*

### B. Short-Term Production and Manufacturing Volume Flexibility

Manufacturing flexibility is the ability to change or react to environmental uncertainty with little penalty in time, effort, cost, or performance. Manufacturing flexibility is vital for companies in times of price volatility and competitive pressure [27]–[29]. It has two aspects: range and time. Range describes the variations in a system along dimensions such as volume, product type, and material handling. Time measures the duration until a system attains a new stage. The theoretical basis was laid down by Gerwin [30], who developed a conceptual framework for operational flexibility. He combined sources of uncertainty such as demand, machine downtime, and life-cycle duration, with strategic objectives. This theoretical work was further structured to address six different aspects.

- 1) Definition of flexibility.
- 2) Request for flexibility.
- 3) Classification according to dimensions of flexibility.
- 4) Measurement of flexibility.
- 5) Choices for flexibility.
- 6) Interpretation of flexibility.

In the context of process industries and commodity markets, not all sources of uncertainty and dimensions of flexibility are applicable to the same extent. For example, volume flexibility is particularly valuable in cases of high demand uncertainty, low demand correlation over time, and low total market size [31]. The importance of short-term volume adjustments in commodity markets increases with higher price volatility in the market. Therefore, in the 1980s, companies started using the sales and operations planning (S&OP) mechanism, a cross-functional process to guarantee a "... medium to long-term stable production plan" [32, p. 3]. In recent years, the purpose has shifted more toward a "... dynamic business performance process." The objective is to make production and sales refinements [33] and quickly react to changing market and operational conditions [11]. The liquid spot markets that exist for many commodities make the S&OP process particularly valuable. These markets permit firms to flexibly adjust their sales volumes [34] and

capture favorable price peaks. S&OP includes sales, operations, and finance and is used to decide on production, inventory, and sales adaptations from the forecasts [35], [36]. These variables are interdependent [11], [31] and based on external factors (e.g., market price, supply-demand balance) and internal factors (e.g., contracted sales, idle production capacity).

Measuring the magnitude and value of flexibility is crucial [37]–[39]. The ability of commodity markets to react to unpredictable price swings is fundamentally different to traditional cost reduction strategies. Empirical evidence from across 83 industries illustrates the competitive advantage that manufacturing flexibility can bring [40]. The literature presents two distinct approaches to quantifying the value of flexibility: looking at the impact flexibility has on a firm’s market valuation or testing the amount of avoided costs or marginal performance [41]. Graves and Tomlin [42] showed that process flexibility in supply chains may prevent inefficiencies and improves the likelihood of meeting demand.

Our paper focuses on a firm’s ability to increase production volumes flexibly in the face of variable market prices. However, flexibility comes at a cost [43]–[44], particularly in relation to dedicated equipment [45]. Flexibility in sales volumes requires significant investment in manufacturing-related fixed assets, which puts financial pressure on the company and incentivizes constantly high utilization rates [46]. Therefore, CAPEX from internally generated cash flows can act as a production driver in the short term.

*H3: Short-term production is positively correlated with CAPEX*

However, investments in manufacturing assets puts pressure on high asset utilization and limits a company’s freedom to adapt supply volumes flexibly in the short term.

*H4: Manufacturing volume flexibility is negatively correlated with CAPEX*

### C. Long-Term Capacity Expansion

Capacity planning in manufacturing industries involves deciding on the amount, type, and timing of capacity adjustments [47] and can be described as a sizing problem [11]. Capacity adjustments—how much capacity to add or reduce—are particularly important in process industries operating in commodity markets, since these industries are characterized by undifferentiated products and high fixed costs. Capacity planning is a crucial determinant of the growth of companies in manufacturing industries and has a significant impact on their market valuation [41]. It is strategically important for process industries because: 1) new investments require considerable resources, and payback times are long; 2) manufacturing equipment has low scrap value; and 3) important economies of scale can be achieved. Geng and Jiang [49] demonstrated the importance of capacity planning to mitigate industry-specific difficulties in the semiconductor manufacturing industry, such as long lead times and high capacity increment costs.

Goyal and Netessine [31] modeled the relationship between investments in technology and capacity under demand uncertainty. They showed that the cost of capacity for a com-

petitor is negatively associated with a firm’s willingness to pay for volume flexibility. Similarly, sequential decisions on capacity, production, and pricing show optimal investment strategies under different scenarios of competition, uncertainty, and timing of operational decisions [50]. Finally, the long payback times for manufacturing equipment in process industries make these investments risky, particularly in times of high demand uncertainty. Price competition is fierce and economies of scale are essential. Therefore, investments in fixed assets translate, to a great extent, into additional capacity and production in commodity markets. Capacity increases are discrete [11], and this is particularly true in the two industries considered—mining and oil and gas. In these industries, projects exploring new resources are often in remote locations and require complex and extensive infrastructure investments.

We contribute to the mainly modeling-based literature with this empirical work on capacity planning and asset development by looking at an industry setup in which demand and prices are exogenous. This is in contrast with most of the established literature, which models two-stage cases in which companies first decide on capacity, then on pricing.

*H5: Long-term capacity growth is positively correlated with CAPEX*

### D. Firm Performance as a Function of CAPEX

CAPEX decisions have a short-term and a long-term impact on the value of a firm. Extensive evidence suggests that long-term CAPEX decisions are viewed favorably by stock markets [51]–[54]; that is, the stock market generally rewards the long-term decisions of firms. McConnell and Muscarella [51] reported that increases (or decreases) in CAPEXs lead to significant positive (or negative) stock returns for industrial firms. Consistent with these findings, Woolridge and Snow [55] showed positive stock market reactions to four different public announcements of corporate strategic decisions on CAPEX, joint ventures, research and development projects, and product or market diversification. Stock price reactions to long-term investment decisions can provide useful insights into improving capital budgeting decisions. Further, it becomes easier for managers to tap the capital markets to finance value-enhancing projects, especially in manufacturing-intensive process industries.

*H6: CAPEX negatively impacts a firm’s market valuation in the short term, but has a positive impact in the long term*

## III. MODEL DEVELOPMENT AND DATA

In this section, econometric models are developed to test the hypotheses, and potential sources of endogeneity are addressed. As detailed above, CAPEX from internally generated cash flows is associated with price trends and demand uncertainty. Additionally, short-term production, manufacturing flexibility, and long-term capacity growth are also affected by CAPEX. The modeling framework is thus based on relationships between CAPEX and long-term price trends (*H1*), demand uncertainty (*H2*), short-term production (*H3*), manufacturing flexibility (*H4*), long-term capacity growth (*H5*), and firm

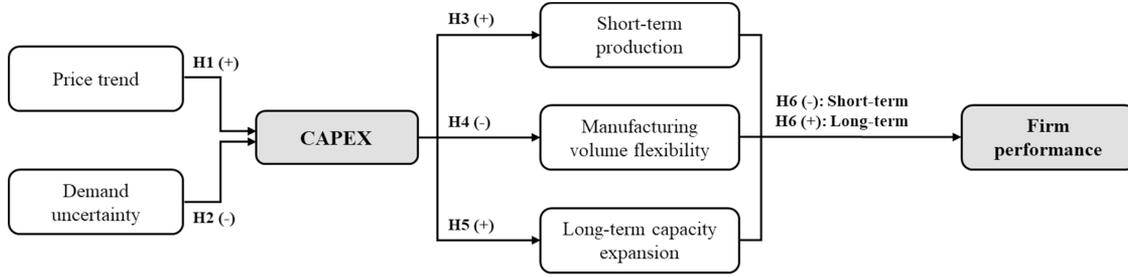


Fig. 1. Impact of market conditions on investment, operations and firm performance.

TABLE I  
DATABASE OF MINING AND OIL AND GAS INDUSTRIES AND SUBSECTORS BY SIC CODE

Mining Industry	SIC	Sample Firms	# Firms	# Obs
Metal mining	10	Barrick Gold Corp., Freeport–McMoran Inc., Anglo American plc, Rio Tinto	395	6,999
Bituminous coal and lignite mining	12	Yanzhou Coal Mining Co. Ltd., Consol Energy Inc., Peabody Energy Corp.	42	812
Mining and quarrying of nonmetallic minerals, except fuels	14	Martin Marietta Materials, Compass Minerals Intl. Inc., Athabasca Minerals Inc.	43	1,055
Oil and gas extraction	13	Baker Hughes Inc., Weatherford Intl Plc, Halliburton Co., ConocoPhillips, Schlumberger Ltd.	955	21,306
Petroleum refining and related industries	29	Hess Corp., BP plc, Chevron Corp., Exxon Mobil, Husky Energy Inc., Suncor Energy Inc.	98	2,542

performance ( $H6$ ). Fig. 1 shows the hypotheses and the modeling framework.

Ketokivi and McIntosh [56] discuss techniques that can be used to deal with issues of endogeneity. We followed their advice and went through the following steps to alleviate potential econometric concerns. First, we attempted to specify every model according to best practice in the literature. The details and rationale for each model are discussed in detail in Section III-C. Second, we conducted several sensitivity analyses that demonstrate the robustness of our findings to alternative specifications. These are presented in Section IV-E. Third, we used panel data and a corresponding regression model, which mitigates unobserved heterogeneity and removes potential endogeneity arising from omitted variables. Last, and importantly, we grounded our hypotheses in theory.

#### A. Data Sources

Our research was based on the mining and oil and gas industries as process industries operating in commodity markets. The database was created by sourcing and matching data from Compustat North America (quarterly and annual financial accounting data), Bloomberg (stock market), and the International Monetary Fund (historical monthly spot price data) by Standard Industrial Classification (SIC) Code using unique identifiers (see Table I).

#### B. Variable Definitions

Wherever possible, we operationalized the variables used as established in the literature.

*Capital intensity* is measured based on expenditures for fixed assets on an annual basis. Since the typical CAPEX planning cycle generally comprises the entire fiscal year, companies do not publish lead time information. Rumyantsev and Netessine [57] developed a proxy based on accounts payable. The basic idea is that “financial transactions should be correlated with times of shipment and delivery of inputs and therefore should be correlated with the lag a company has to respond . . .” [57, p. 16]. Therefore, we use days of accounts payable outstanding as a proxy for lead time

$$\begin{aligned} \text{Lead Time}_{itn} &= \text{Days Payables Outstanding}_{itn} \\ &= \frac{365}{\left(4 * \frac{\text{COGS}_{itn}}{\text{Accounts Payables}_{itn}}\right)}. \end{aligned}$$

where indices  $i$ ,  $t$ , and  $n$  are the firm, yearly and quarterly indices, respectively. The gross margin (GM) is defined as

$$\text{Gross Margin}_{itn} = \frac{\text{Sales}_{itn} - \text{COGS}_{itn}}{\text{Sales}_{itn}}.$$

Firms set inventory targets and they try to limit deviations from this level [58]. Since companies do not systematically reveal these objectives, we used the average inventory measure

among peer companies outlined by Chen *et al.* [59]. Therefore, we calculated the delta target inventory as the difference between the average inventories of firms with the same SIC code and the current inventory level of the firm

$$\begin{aligned}\Delta\text{Target Inventory}_{itn} &= \text{Target Inventory}_{it} - \text{Inventory}_{itn} \\ &= \frac{1}{m} \sum_m \left( \frac{\text{Inventory}_{itm}}{\text{COGS}_{itm}} \right) - \frac{\text{Inventory}_{itn}}{\text{COGS}_{itn}}.\end{aligned}$$

The *price trend* variable is calculated as the difference the current price and the closing price in the two prior quarters

$$\text{Price Trend}_{itn} = \frac{\text{Price}_{itn} - \text{Price}_{i,t,n-2}}{\text{Price}_{i,t,n-2}}.$$

*Demand uncertainty* is measured as the relative difference between the sales forecast and actual sales

$$\begin{aligned}\text{Demand Uncertainty}_{itn} &= \frac{\text{Sales Forecast}_{itn} - \text{Sales}_{itn}}{\text{Sales}_{itn}} \\ &= \frac{(a_{itn} + b_{itn}) - \text{Sales}_{itn}}{\text{Sales}_{itn}}\end{aligned}$$

where  $a_{itn} = \alpha * \text{Sales}_{i,t,n-1} + (1 - \alpha)(a_{i,t,n-1} + b_{i,t,n-1})$  and  $b_{itn} = \beta(a_{itn} - a_{i,t,n-1}) + (1 - \beta)$  and  $\alpha$  and  $\beta$  are coefficients between 0 and 1.

The optimum values for the coefficients, where the mean square error is minimized, were obtained for ( $\alpha = 0.5; \beta = 0.5$ ). Sales are represented as reported in the income statements. Since firms do not systematically report their sales forecasts, the Holt forecasting [60] method was used to create sales forecast figures based on previous sales performance [61], [62]. *Production* is measured by adjusting the cost of goods sold (COGS) with the delta of inventory at the end and beginning of the period [63]

$$\text{Production}_{itn} = \text{COGS}_{itn} + \text{Inventory}_{itn} - \text{Inventory}_{i,t,n-1}$$

where inventory is measured as average inventory at the end and beginning of the quarter

$$\text{Inventory}_{itn} = \frac{\text{Inventory}_{itn} + \text{Inventory}_{i,t,n-1}}{2}.$$

*Manufacturing flexibility* in this paper describes volume flexibility [31], a firm's ability to adapt production volumes at short notice as a reaction to external disruptions. The literature does not offer an empirical measure for volume flexibility, a gap we aim to fill as follows: if a company decides in the S&OP process to increase/decrease sales volumes because of higher/lower than expected market prices, this sales volume difference compared to forecasts has to be come from an adjustment in production volume and/or adjustments in inventory. Manufacturing flexibility indicates the degree to which such sales adjustments are

met by production adjustments and is calculated as

$$\begin{aligned}\text{Manufacturing Flexibility}_{itn} &= \Delta\text{Sales}_{itn} + \text{Planned Inventory Change}_{itn} \\ &= -\text{Actual Inventory Change}_{itn} (\text{Sales}_{itn} - \text{Sales Forecast}_{itn}) \\ &\quad + (\text{Average Inventory}_{itn} - \text{Inventory}_{i,t,n-1}) \\ &\quad - (\text{Inventory}_{itn} - \text{Inventory}_{i,t,n-1}).\end{aligned}$$

Here, sales adjustment ( $\Delta\text{Sales}$ ) is calculated as the difference between actual sales and forecaste sales. The inventory adjustment (*Planned Inventory Change* – *Actual Inventory Change*) is proxied by the difference between actual inventory sales and planned inventory sales. Companies do not systematically publish the figures for planned inventory sales. Yet, they generally have inventory level targets, and we assume these targets have been met over the previous four quarters. Therefore,

$$\begin{aligned}\text{Planned inventory sales}_{itn} &= \text{Current inventory level}_{itn} \\ &\quad - \text{Average inventory level}_{i,t,n-1}.\end{aligned}$$

We also tested the scale-dependent variables—production (PROD), capital intensity (CAP), sales (SALES), and inventory (INV)—as intensities by dividing them by the market value of equity [62], which did not change our results.

### C. Econometric Specifications

In order to test the hypotheses, we developed empirical models in accordance with the established finance and operations management literature. The models are in log-multiplicative form, as in comparable operations management research [57], [61]. All models include firm-specific terms ( $A_i, B_i, C_i, D_i, E_i$ ) controlling for unobserved firm-specific characteristics, yearly/quarterly dummies ( $a_t, b_t, c_t, d_t, e_t$ ) accounting for time-dependent macro effects, and idiosyncratic firm-time specific error terms ( $\alpha_{itn}, \beta_{itn}, \gamma_{itn}, \delta_{itn}, \varepsilon_{itn}$ ).

1) *Price Trend and Demand Uncertainty*: We developed a dynamic panel model to examine the impact of market prices and demand uncertainty on CAPEX volumes (H1 and H2). Since CAPEX is a crucial cost item in financial planning, the CAPEX planning process to decide on investment volumes follows the fiscal year cycle. The magnitude of investments in commodity markets is impacted by market prices, particularly price volatility and price trends. CAPEX covers investments in both new capacity and maintenance of the current fixed-asset base. Therefore, current investments are directly linked to past investments, so we include CAPEX from the previous year. A classic fixed-effects estimator would be biased, as shown by Nickell [64], so instead we implemented the Arellano–Bond estimator [65] with robust standard errors and adapted for dynamic panel data with “small T, large N” panels. The CAPEX planning is modeled as follows:

$$\begin{aligned}\log \text{CAPEX}_{it} &= A_i + \alpha_1 \log \text{Price Trend} \\ &\quad + \alpha_2 \log \text{Demand Uncertainty}_{it} + \alpha_3 \log \text{CAP}_{i,t-1} \\ &\quad + \alpha_4 \log \text{Sales}_{it} + a_t + \alpha_{it}.\end{aligned}$$

2) *Short-Term Production and Manufacturing Volume Flexibility*: We developed a simultaneous equation model (SEM) to reflect the impact of CAPEX on production (**H3**) and a dynamic panel model to examine the relationship between CAPEX and manufacturing flexibility (**H4**). The S&OP process determines adaptations from forecasts of sales, inventory, and production for the upcoming sales period. They depend directly on one another: the higher the planned sales, the more the company has to produce and/or sell from its inventory. Sales are constrained by idle production capacity and inventory. Additional production is a potential substitute for inventory and is directly related to sales levels. The simultaneous interdependence of these dependent variables can lead to inconsistent estimates. We controlled for this by setting up the following SEM—as done before in operations management literature [62], [66]—for the three dependent variables production, inventory, and sales:

$$\begin{aligned} \log \text{Production}_{itn} = & B_i + \beta_1 \log \text{Inventory}_{itn} + \beta_2 \log \text{Sales}_{itn} \\ & + \beta_3 \log \text{Production}_{i,t,n-1} + \beta_4 \log \text{CAPEX}_{it} \\ & + \beta_5 \log \text{Lead Time}_{itn} + b_t + \beta_{itn} \end{aligned}$$

$$\begin{aligned} \log \text{Inventory}_{itn} = & C_i + \gamma_1 \log \text{Production}_{itn} + \gamma_2 \log \text{Sales}_{itn} \\ & + \gamma_3 \log \text{Inventory}_{i,t,n-1} + \gamma_4 \log \text{TargetInventory}_{itn} \\ & + \gamma_5 \log \text{Gross Margin}_{itn} + \gamma_6 \log \text{Demand Uncertainty}_{itn} \\ & + d_t + \delta_{itn} \end{aligned}$$

$$\begin{aligned} \log \text{Sales}_{itn} = & D_i + \delta_1 \log \text{Production}_{itn} + \delta_2 \log \text{Inventory}_{itn} \\ & + \delta_3 \log \text{Sales}_{i,t,n-1} + \delta_4 \log \text{Gross Margin}_{itn} + d_t + \delta_{itn}. \end{aligned}$$

The current performance of the dependent variables depends on past performance, the so-called halo effect, and is modeled by introducing the lagged dependent variables [67], which satisfy the conditions for instruments [66]. Besides reflecting the interactions of the dependent variables, each equation is completed by a number of exogenous terms and control variables. CAPEX on fixed assets is particularly high in process industries and accounts for a high share of fixed costs. It is amortized by producing large volumes at constantly high utilization rates. Therefore, CAPEX is positively correlated with production [61]. Sales refers to the sum of production and inventory sold. Similarly, the sales delta defined in the S&OP either has to be produced or be taken from stock. The extent to which a company can handle additional sales defined in the short-term S&OP through increased production depends inversely on the lead time. Supply chain managers pursue inventory targets, among others. The more the current level deviates from this target, the more they are incentivized to correct (sell or hold back) the inventory level toward achieving the target. The literature has established the positive effect of the GM and demand uncertainty on inventory [61] and of the GM on sales [66]. We implemented a fixed-effect model to test how CAPEX manufacturing volume

flexibility

$$\begin{aligned} \log \text{Manufacturing Flexibility}_{itn} = & E_i + \varepsilon_1 \log \text{CAPEX}_{itn} \\ & + e_t + \varepsilon_{itn}. \end{aligned}$$

3) *Long-Term Capacity Expansion*: We developed a panel vector autoregressive model (VAR) to identify implementation times of investments (**H5**). There is a time lag between the moment the cash outflow for a project is accounted for and the moment the corresponding production capacity becomes operational. Companies generally invest each year in a portfolio of projects for the maintenance and expansion of fixed assets. These investments translate into production capacity after varying time periods, depending on the type and size of the project. Therefore, current production potentially depends on various lagged investments. In order to determine the dynamic intertemporal relationship between investments in manufacturing assets and production, we applied an autoregressive model to our panel dataset, as done before in the operations management and finance literature [68], [69]. We applied a least square dummy variable (LSDV) estimator, which fits both variables, to lags of itself and the other variable [70]. The LSDV estimator can be more efficient than the generalized method of moments estimator [65], which can be generalized for models with higher order lags [71]. We used the annual growth in production and CAPEX as dependent and independent variables, respectively. Love and Zicchino [68] used a similar model to examine the relationship between companies' financial conditions and investment. CAPEX includes one-off exploration and development costs incurred in the lifetime of a new production site [72]. The number of time lags included in our model depended on the project type. Having reviewed the documentation of several greenfield projects across commodities, we found that capacity planning periods generally last up to six years [11], [73]

$$\begin{aligned} & \frac{\text{Production}_{it} - \text{Production}_{i,t-1}}{\text{Production}_{i,t-1}} \\ = & F_i + \sum_{g=0}^6 \zeta_f * \frac{\text{CAPEX}_{i,t-g} - \text{CAPEX}_{i,t-g-1}}{\text{CAPEX}_{i,t-g-1}} + f_t + \zeta_{it}. \end{aligned}$$

4) *Firm Performance as a Function of CAPEX*: Capacity growth is crucial to secure a company's market position, earn higher profits, and further increase investments in capacity [74]. In the finance literature, the role of investments is as a predictor of stock returns [48], [75]. We believe the crucial importance of CAPEX in process industries and the complex interaction effects between the described operational aspects requires a holistic short- and long-term assessment of the relationship between CAPEX and stock performance. This has not been addressed in the literature to date. To close this gap and test **H6**, we implemented a fixed-effect model as used in the corresponding finance literature to test the impact of investments on stock performance [48]. Investment plans have substantial forecasting power with respect to annual stock returns and contain information not captured by other forecasting variables [76]. Therefore,

TABLE II  
DESCRIPTIVE STATISTICS FOR THE MINING AND OIL AND GAS INDUSTRIES FOR 2000–2015

Variable	Mining (N = 8,866)		Oil & Gas (N = 23,848)	
	Mean	S.D.	Mean	S.D.
Sales, \$ million	473.0	2,485	1,794.1	9,410.1
Sales forecast, \$ million	475.2	2,542.3	1,779.6	9,426.8
Production, \$ million	306.2	1,543.7	1,403.0	7,890.0
Inventory, \$ million	170.7	623.3	419.6	2,442.5
Target inventory, \$ million	163.6	602.1	415.7	2,395.8
CAPEX, \$ million	190.7	973.5	559.9	2,433.6
Gross margin, %	5.11	116.4	21.4	163.4
Demand uncertainty, %	45.5	118.6	34.0	51.5
Price trend, %	-0.2	7.5	5.6	22.4
Lead time, days	192.4	1,414.6	312.5	627.8

TABLE III  
ESTIMATES FROM THE DYNAMIC PANEL MODEL FOR PRICE TREND AND DEMAND UNCERTAINTY

CAPEX	Mining	Oil & Gas
Price trend	0.272** (0.106)	0.164*** (0.0212)
Demand uncertainty	-0.0877* (0.0391)	-0.0891** (0.0319)
Lagged CAPEX	0.643*** (0.0404)	0.651*** (0.0265)
Sales	0.0655** (0.0209)	0.00864 (0.0186)
N observations	8,866	23,848
N firms	480	1,053

Standard errors in parentheses \* p < 0.05, \*\* p < 0.01, \*\*\* p < 0.001

our econometric model specifies

$$\frac{\text{Stock Price}_{i,t} - \text{Stock Price}_{i,t-1}}{\text{Stock Price}_{i,t-1}} = G_i + \sum_{h=0}^6 \eta_h * \frac{\text{CAPEX}_{i,t-h} - \text{CAPEX}_{i,t-h-1}}{\text{CAPEX}_{i,t-h-1}} + g_t + \eta_{it}$$

#### D. Descriptive Statistics

Table II provides the descriptive statistics for 2000–2015. We collected the data for 1997–1999 to calculate sales forecasts for the first year. We excluded companies with missing or negative values for COGS, CAPEX, inventory, and sales. In the oil and gas and mining industries, respectively, on average, CAPEX was approximately \$560 billion and \$191 billion, and demand uncertainty was 34.0% and 45.5%. The price trend was higher for oil and gas, at 5.6%, than for mining, at -0.2%. Similarly, lead time was longer for oil and gas than for mining.

## IV. RESULTS

### A. Price Trend and Demand Uncertainty

Table III provides estimates from the dynamic panel model. As anticipated, the relationship between price trend and CAPEX (mining:  $\alpha_1 = 0.272$ ; oil and gas:  $\alpha_1 = 0.164$ ) and that between

demand uncertainty and CAPEX are significant and in the predicted direction (mining:  $\alpha_2 = -0.0877$ ; oil and gas:  $\alpha_2 = -0.0891$ ). An increase in price trends and a decrease in demand uncertainty significantly increases CAPEX. As predicted, companies increase their investments in fixed assets at times when prices have risen over the previous two quarters (price trend variables). The reason for this positive association might be that companies have earned higher cash inflows and therefore have more resources available and/or that they expect prices to increase further and will therefore continue to invest to capture higher earnings in future.

### B. Short-Term Production and Manufacturing Volume Flexibility

Table IV provides estimates from the SEM that models S&OP dynamics and indicates the positive impact CAPEX has on short-term production volumes. We note that CAPEX is indeed a highly significant production driver (mining:  $\beta_4 = 0.0722$ ; oil and gas:  $\beta_4 = 0.151$ ) for both industries under consideration, as stated in hypothesis H3. This confirms that cash outflows for CAPEX impact the daily operations of firms in these sectors and incentivize them to sweat their assets and constantly produce at high utilization rates. This limits their room for maneuver to adapt production volumes without slashing spending on fixed

TABLE IV  
ESTIMATES FROM THE SEM FOR IMPACT OF CAPEX ON PRODUCTION

Production	Mining	Oil & Gas
CAPEX	0.0722*** (0.00551)	0.151*** (0.0206)
Year Dummies	Yes	Yes
N observations	7,312	17,405
N firms	436	994
Overall R <sup>2</sup>	97.43%	99.10%

Standard errors in parentheses \* p < 0.05, \*\* p < 0.01, \*\*\* p < 0.001

TABLE V  
ESTIMATES FROM THE DYNAMIC PANEL MODEL FOR CAPEX AND MANUFACTURING FLEXIBILITY

Manufacturing Flexibility	Mining	Oil & Gas
CAPEX	-0.0835*** (0.0121)	-0.0555*** (0.00825)
Lagged manufacturing flexibility	0.297*** (0.0275)	0.351*** (0.0233)
N observations	8,866	23,848
N firms	480	1'053

Standard errors in parentheses \* p < 0.05, \*\* p < 0.01, \*\*\* p < 0.001

assets. The explicative power of the SEM model is very high with strong overall  $R^2$  values.

The driving effect CAPEX has on production levels is directly linked to its effect on manufacturing volume flexibility. Since companies are incentivized to boost production and increase capacity utilization with increasing investment volumes, this intuitively reduces their willingness and ability to flexibly decrease and increase production levels. In line with **H4**, this explains the negative impact CAPEX has on manufacturing flexibility (Table V; mining:  $\varepsilon_1 = -0.0835$ ; oil and gas:  $\varepsilon_1 = -0.0555$ ) and why companies do not reduce production even in times of structural oversupply.

### C. Long-Term Capacity Expansion

The estimates from the panel VAR are shown in Table VI, which indicates that a relative increase in CAPEX impacts the long-term future production capacity growth, supporting **H5**. The significant impact of investments dating back six years indicates the long planning and implementation horizon of these industries (mining:  $\zeta_1 = 0.0802$  to  $\zeta_6 = 0.164$ ; oil and gas:  $\zeta_1 = 0.398$  to  $\zeta_6 = 0.472$ ). In the mining industry, we observe peaks of impact after years three and six, which could indicate that it has fewer, but bigger, projects. In the oil and gas industry, the impact is more smoothly spread out, particularly over years two to five (i.e.,  $\zeta_2, \zeta_3, \zeta_4, \zeta_5$ ). We applied the Granger causality tests [77] on the VAR estimates. The null hypothesis that the six lagged terms of CAPEX growth do not forecast production growth is rejected at significance level  $p$ -value < 0.001.

### D. Firm Performance as a Function of CAPEX

As predicted in **H6**, we find that although recent spending reductions boost the market valuation (mining:  $\eta_1 = -0.100$ ,  $\eta_2 = -0.0874$ ,  $\eta_3 = -0.0513$ ; oil and gas:  $\eta_1 = -0.0495$ ,  $\eta_2 = -0.0357$ ), the effect in the longer run (mining:  $\eta_4 = 0.0125$ ,

$\eta_5 = 0.0127$ ,  $\eta_6 = 0.00698$ ; oil and gas:  $\eta_3 = 0.0786$ ,  $\eta_6 = 7.9e-08$ ) is the opposite (see Table VII). The model explains 13.3% for mining and 12.4% for oil and gas of within variation in the data. This indicates that CAPEX management is highly important in such industries, where prices are dictated by the markets and commercial levers are limited. The overall  $R^2$  is 4.03% for mining and 4.48% for oil and gas, which is consistent with the values in the literature [75].

### E. Robustness Tests

We tested the robustness of the presented results by altering the econometric models. Across a vast series of robustness tests, we continued to find very strong results, which further supported our results and confirmed our hypotheses. The detailed results and tables are available from the authors upon request.

We used the Arellano–Bond estimator to model the impact of market prices on CAPEX volumes while accounting for the dynamic nature of the model. We also applied the Anderson–Hsiao estimator and an individual fixed-effect model including lagged CAPEX. As we did with price trend and demand uncertainty, we applied different estimators (two-stage least square (OLS), single equation fixed effects, single equation random effects) to model the dynamics of the S&OP process. The relationship between CAPEX and manufacturing flexibility was originally tested with a single-equation fixed-effect model. The original findings from the fixed-effect model are consistent with the random- and between-effect model. For long-term capacity expansion, we find that fixed-effect and random-effect models were consistent with the original panel VAR model for the mining industry. However, for the oil and gas industry, the findings were not significant in the fixed-effect model and there was a relative decrease in long-term future production capacity growth in the random-effect model.

TABLE VI  
ESTIMATES FOR PANEL VAR FOR CAPEX ON CAPACITY EXPANSION

Response to	Response of Production Growth	
	Mining	Oil & Gas
CAPEX Growth 1-Year Lagged	0.0802*** (0.0154)	0.398*** (0.0763)
CAPEX Growth 2-Year Lagged	0.0515** (0.0180)	0.846*** (0.0784)
CAPEX Growth 3-Year Lagged	0.168*** (0.0220)	1.048*** (0.104)
CAPEX Growth 4-Year Lagged	0.0740*** (0.0211)	1.161*** (0.0898)
CAPEX Growth 5-Year Lagged	0.0303 (0.0228)	0.820*** (0.129)
CAPEX Growth 6-Year Lagged	0.164*** (0.0199)	0.472*** (0.122)
N observations	705	945
N firms	141	189
Overall R <sup>2</sup>	72.27%	73.81%

Standard errors in parentheses \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

TABLE VII  
RESPONSE OF STOCK PRICE TO CAPEX OVER TIME

Stock Price Growth	Mining	Oil & Gas
CAPEX Growth 1-Year Lagged	-0.100** (0.0323)	-0.0495*** (0.0101)
CAPEX Growth 2-Year Lagged	-0.0874** (0.0297)	-0.0357* (0.0181)
CAPEX Growth 3-Year Lagged	-0.0513** (0.0195)	0.0786*** (0.0111)
CAPEX Growth 4-Year Lagged	0.0125** (0.00431)	0.0479 (0.0332)
CAPEX Growth 5-Year Lagged	0.0127*** (0.00364)	0.0293 (0.0299)
CAPEX Growth 6-Year Lagged	0.00698*** (0.00130)	7.90e-08*** (9.41e-09)
N observations	377	987
N firms	116	270

Standard errors in parentheses \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

## V. CONCLUSION

Fig. 2 shows the results of the initially hypothesized relationships for (A) the mining industry and (B) the oil and gas industry. Previous research shows that commodity price variations can be separated into long-term dynamics and short-term variations [78], [79]. Our empirical support for *H1* means that CAPEX increases as long-term price trends increase. This implies that both price and asset development play a crucial role in determining the competitive edge for commodity markets in the short and long terms. Additionally, the literature emphasizes firms' financial liquidity constraints and access to external financing [24], while overlooking the value of operational aspects of investments in fixed assets for manufacturing industries. Our findings are consistent with the current financial literature wherein price trends determine CAPEX for short-term future investments: companies increase their investments in fixed assets when prices increase in the prior quarters. Similarly, our empirical support for *H2* means that companies are reluctant to spend in times of demand uncertainty, since the projected future return on investments must be discounted by higher risks. De-

spite demand uncertainty, there are potential opportunities for companies that have the advantage of flexibility when making their capital planning decisions.

In the context of process industries and commodity markets, volume flexibility is important during high demand uncertainty. With more adjustable fixed costs, capital could become companies' biggest lever for more responsive production and more flexible CAPEX. Therefore, measuring the magnitude and value of flexibility is important when reacting to unpredictable price swings [19], [38], [80], [81]. Accordingly, the empirical support for *H4* means that investment decisions for manufacturing systems often neglect the manufacturing flexibility that allows a company to adapt to long-term production requirements and structures. Concurrently, our empirical support for *H3* suggests that CAPEX is a significant driver of short-term production volume.

Capacity planning is a determinant of growth in manufacturing industries, especially for process industries, and represents a sizing problem [11]. Our results indicate that the relative increase in CAPEX positively impacts the long-term production capacity growth (*H5*). In the mining industry, our results indicate

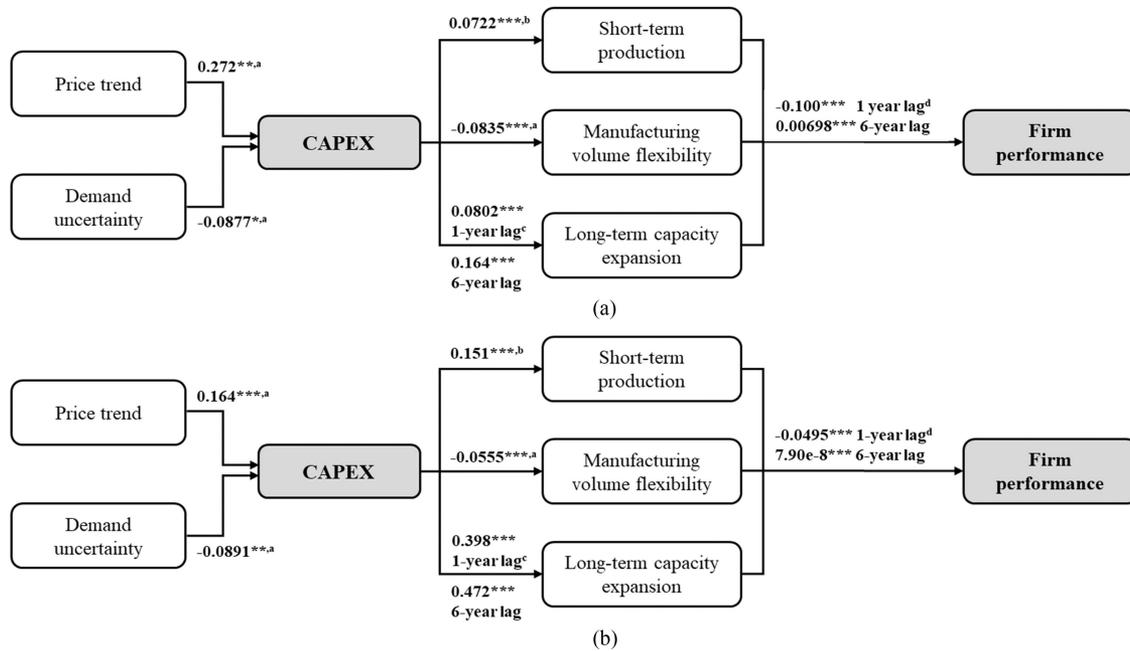


Fig. 2. Modeling results with standardized estimated parameters for (a) mining industry and (b) oil and gas industry. <sup>a</sup>Dynamic panel model. <sup>b</sup>Simultaneous equation model. <sup>c</sup>Panel VAR. <sup>d</sup>Fixed-effects model. \* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$ .

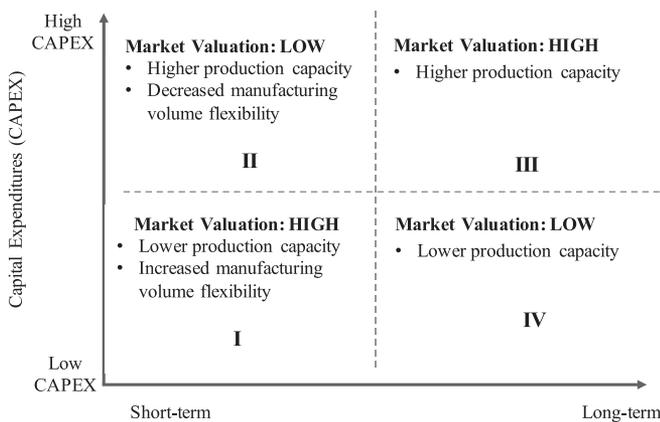


Fig. 3. Firm value driver model: CAPEX in the short and long terms.

the discrete impact of CAPEX on capacity planning, suggesting fewer and larger projects. However, for the oil and gas industry, the impact is more evenly spread out, suggesting continuous CAPEX and consistent production levels. Therefore, in process industries, projects exploring new resources are in many cases in remote locations and require complex and extensive infrastructure investments.

### A. Conceptual Framework

Rocco and Plakhotnik [82, p. 128] define a conceptual framework as one that “relates concepts, empirical research, and relevant theories to advance and systematize knowledge about related issues.” To show the impact of CAPEX in relation to short- and long-term periods, as suggested from our empirical results, we developed a conceptual framework (illustrated in Fig. 3) that could help explain the impact of price volatility

and demand uncertainty on CAPEX. The conceptual framework was based on the main dimensions from our theoretical model and refined using researcher triangulation to discern patterns and differences. The conceptual framework is described next. The model has four main quadrants:

*Quadrant I:* in the short term, reducing CAPEX reduces production capacity for process industries, allowing for increased manufacturing volume flexibility in response to market trends and resulting in a higher market valuation.

*Quadrant II:* increasing CAPEX in the short term commits process industries to higher production capacity with decreased volume flexibility. However, the additional CAPEX investment relative to market trends may have a negative short term impact on a firm performance.

*Quadrant III:* increased CAPEX in the long term may allow process industries to better manage price volatility and demand uncertainty. It allows higher production capacity in the long term, which would positively affect firm performance.

*Quadrant IV:* low CAPEX investments in the long run reduce production capacity. This is an undesirable strategy, as it dramatically reduces a firm performance in the long run.

Revenue growth can come from either 1) higher average sales prices or 2) higher production volumes. Although our results indicate that price trend is positively correlated with CAPEX, demand uncertainty increases the risks associated with investments. Both components are impacted by CAPEX adjustments—operating margin increases because of lower depreciation and capital turnover increases because of lower amount of fixed assets. Cutting CAPEX potentially has effects in the short and long terms. In the short term, companies gain volume flexibility, which allows them to strategically position products on the market to capture favorable price peaks and potentially increase their average sales price. In the long term,

by contrast, production growth is negatively impacted. Flexible companies are more profitable and can invest more in capacity expansion, and thus improve their performance. CAPEX decisions are important, complex, and long term in nature. Therefore, managers have to evaluate various factors to determine how much internally generated cash should go to funding manufacturing, while responding to market price volatility. This necessitates the evaluation of existing measures and the development of new ones for flexibility, especially in manufacturing-intensive process industries.

### B. Theoretical Implications

This paper contributed to the operations management and finance literature. We followed the guidelines on theory building described by Corley and Gioia [83] and Whited [84]. With this approach, we present four main contributions.

1) *Short-Term Manufacturing and Investment*: From the operations management literature, previous research shows how volume flexibility is particularly valuable during demand uncertainty [19]. This research has documented various types of flexibilities, such as machine setup, process, transfer, system setup, and routing flexibilities [2], which are crucial in defining short-term manufacturing flexibility. All these types are firm specific and accumulate as bottom-up operational activities that inform top-down strategies. However, previous research rarely mentions how investments impact volume flexibility—a feature that has been asked for, but is scarce in the literature [17], [39]. In this paper, we largely focused on volume flexibility. We specifically contribute to the literature by adding a proxy for manufacturing volume flexibility and modeling the interaction of important S&OP dimensions such as sales, operations, and finance.

Our results also show that price trends, and volatility have a direct impact on firm-level investments, leading companies to follow the market. Combining this with the insights above, our results suggest that managers of financially healthy companies should resist the stock market's short-term pressure to reduce fixed costs and instead play the long game. This means that, in the context of process industries, the impact of short-term manufacturing volume flexibility on investment when internally generated cash flows are sensitive becomes very crucial.

2) *Long-Term Capacity Expansion*: From the operations management point of view, capacity planning in manufacturing industries usually faces an important decision regarding how to select the optimal quantity and portfolio of product-dedicated and flexible capacities [11], [85]. While some operations are mostly concerned with changes in demand [86], [87], we focused more on modeling-based capacity expansion by looking at an industry setup in which demand and prices are exogenous. This runs contrary to most of the established literature, which models two-stage cases in which companies first decide on capacity, then pricing.

3) *CAPEX as a Predictor of Stock Returns*: In the finance literature, the role of investments as a predictor of stock returns has been discussed, but has less often been empirically tested [48], [75]. In this paper, we implemented a fixed-effect model—similar to the corresponding finance literature—in or-

der to test the impact of investments on stock performance. Our results from (H6) indicate that a firm's stock price negatively correlates with CAPEX in the short term, while it has a positive impact in the long term. In spite of the short-term effect, our findings suggest that managers in process industries still need to consider the long-term impact of CAPEX decisions on a firm's market valuation. Thus, it is now evident that CAPEX can be a viable predictor of stock returns, which is one of the theoretical implications of our paper.

4) *Internally Generated Cash Flows*: The finance literature has mainly focused on firms' financial liquidity constraints and access to external financing [24], [88]. The literature confirms that firms across industries have different financing structures, both internal and external. These structures, however, can be determined both by firm-specific characteristics, such as investment and employment, and by institutional environment factors, such as financial crises [89]. When it comes to process industries, as we have seen, the cash flow generated depends directly on market prices. Internally generated cash flows are generally the dominant source of finance for investment. However, in our empirical study, we focused on the crucial role of internally generated cash flows by introducing an operational aspect. Our results show that internally generated cash flows play a crucial role in determining short- and long-term development. Therefore, CAPEX from internally generated cash flows can act as a production driver in the short term.

### C. Managerial and Policy Implications

Our results offer managers in process industries several insights. The role of every manager is to create long-term value for stakeholders. The principle of value creation has stood the test of time, dating back to the notion of the difference between the return on capital invested (ROIC) and the cost of capital. In their highly regarded book, Koller *et al.* [90] describe two major ingredients for long-term value creation: revenue growth and ROIC. The combination of the two generates cash flow which, if it exceeds the cost of capital, leads to value creation. In process industries, the role of managers is highly complex, since their decisions are affected by a complex system of interlinked operational and financial variables, as well as unpredictable market conditions. First, our results indicate that internally generated cash flows play a crucial role in determining short-term manufacturing flexibility. Second, our results give managers an understanding of steady long-term asset development and how it is beneficial from an operational point of view. Practitioners should now take advantage of long-term growth, which is positively correlated with past CAPEX. Another contribution of this work is the model presented in Fig. 3, which describes four quadrants. Our paper used a conceptual framework developed from the literature review. The framework posits that prices and asset development are associated with CAPEX, which affects manufacturing flexibility and production capacity. Therefore, determining the production capacity and manufacturing flexibility is an important consideration for managers in process industries.

#### D. Future Research Directions

Our insights raise further questions which could be addressed through future research. In terms of the average impact that investment decisions have on stock performance, it would be valuable to segment the market by financial indicators and test how these effects are altered or moderated. Second, in our paper, CAPEX on manufacturing assets is considered at an aggregate level, since public data do not specify the type of investment. It would be interesting to study the effect of investments in upgrading current assets compared with investments in new equipment. Third, future research could focus on conducting an event study, wherein companies announce the additional production volume, the assets invested, and the timeline, and then check how the stock markets react in the days, months, and years thereafter. Fourth, the conceptual model we developed only considers the aforementioned variables, while future research could include inventory holdings, the role of technological advancements, seasonal demand, and several other supply chain inefficiencies that may affect CAPEX. We hope that future research could also benefit from other similar studies in understanding the major differences between process industries and consumer industries in the context of operations management, such as capacity and manufacturing flexibility.

#### E. Conclusion

This paper evaluated the impact of price trends and demand uncertainty on CAPEX from internally generated cash flows. It examined how CAPEX was associated with manufacturing flexibility, short-term production, and long-term production capacity. A major contribution of this paper was the contextual consideration of how the aforementioned factors jointly interact to affect a firm's short-term volume flexibility and long-term capacity expansion in asset-intensive manufacturing process industries. This approach was essential, as it provided managers and investors with novel insights into the implications of manufacturing asset investment decisions over the complete market cycle, and allowed them to gain a competitive edge in the commodity market. Furthermore, this paper establishes empirical evidence for the short- and long-term operational impact of adjustments to investments in manufacturing assets and links this to stock returns.

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