Modelling Production Capacity Ramp-Downs: "Reverting" the Market Growth Model

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1. Introduction

In Forrester's (1968) Market Growth model, capacity adjustments, both expansion and contraction, are driven by a firm's delivery delays. However, firms often rely on different information when making these opposite decisions. While expansion mostly responds to perceived market opportunities or customer-related pressure (e.g., delivery delay), ramp-downs are often triggered by internal performance indicators, such as excess, obsolete, or underutilized capacity (Di Fan et al., 2020; Morrison, 1985). This paper extends Forrester (1968)'s Market Growth model (resp. Sterman's [2000] update) to separate the information triggers for expansion and reduction of production capacity (capacity adjustments refer specifically to production capacity, while salesforce capacity is modelled separately, following the structure of the original model). While a delivery delay remains the trigger for capacity expansions, capacity underutilization triggers reductions.

This work extends classical growth-oriented System Dynamics models to account for production capacity ramp-downs and limited markets, providing a tool to investigate their effects and associated uncertainties. The relevance of the topic lies in the strategic importance of capacity reduction decisions for companies operating in constrained markets. In managerial practice, companies are increasingly faced with decisions to reduce production capacity, with recent examples including Volkswagen and ThyssenKrupp (Volkswagen Group, 2024; ThyssenKrupp, 2024). Furthermore, from a sustainable perspective, ramp-downs may become a strategic alternative to unsustainable growth (Reichel and Seeberg, 2010). Despite its relevance, the topic has received little attention in the literature (Di Fan et al., 2020; Akkermans et al., 2019).

The rest of this paper is structured as follows. The second section presents an overview of the capacity strategy in an organization, the role of decision-makers, and the use of System Dynamics as a tool to investigate their relations. In the third section, a description of the acquisition unit of the Market Growth model and its extension is provided. The fourth section presents the simulation results, followed by their discussion in section 5. The final section summarizes the main findings and concludes the paper.

2. Capacity Strategy and Bounded Rationality

A firm's operations are closely dependent on its capacity strategy. For this reason, decisions related to capacity are extremely important. Too much capacity can lead to underutilization and higher costs, while too little capacity may result in an inability to properly satisfy customer demand and, consequently, lower revenues (Slack and Lewis, 2017). This trade-off also emerges when companies make decisions about capacity adjustments. The company not only has to decide whether to increase/decrease capacity or not, but also when and by how much. Thus, firms must balance the benefits of maintaining sufficient capacity, including economies of scale, against the risk of excess capacity, while limiting capacity may reduce excess capacity but increase the risk of shortages. Capacity lead times further complicate these decisions by delaying the effects of capacity adjustments.

These decisions involve substantial information and trade-offs, making them extremely complex. The managers making them operate under bounded rationality (Simon, 1955). This means that their decisions are the outcome of the amount of information they can use and their ability to derive meaningful insights from this information (Morecroft, 1983). Thus, capacity change decisions, even though intendedly rational, may reveal limitations due to factored decision making, rules of thumb, and partial information (Morecroft, 1983).

Using Forrester (1968)'s system dynamics Market Growth Model, Sterman (2000) and Morecroft (1983) investigated bounded rationality in an organization facing capacity adjustment decisions. System Dynamics represents the perfect methodology for illustrating the challenges decision-makers face in complex environments and for showing how well-intentioned decisions can generate unintended outcomes when managers lack full information or cannot process the overall system structure (Bendoly et al., 2015).

Other authors, instead, used the Forrester model to optimize the decisions embedded in it. Vierhaus et al. (2014) identified parameter trajectories using an optimization framework that reduces oscillations in production capacity. White and Censlive (2016) introduced a controlled, engineering-based model for the capacity policy that enables the elimination of the system's bust-and-boom cycles.

While the original model and subsequent work focus on growth and capacity expansion, the model also allows for capacity reductions. Although expansion and ramp-down are opposite decisions, they are modelled as being triggered by the same information: delivery delay. When delivery delay is far from the company's goal, pressure to expand increases, while in the opposite scenario, a reduction is initiated. However, ramp-downs are usually triggered by excess, obsolete, or underutilized production capacity (Di Fan et al., 2020; Morrison, 1985). This work includes this distinction in Sterman (2000)'s version of the Market Growth model and investigates how this distinction in capacity adjustment triggers influences the system. The next section describes part of the original model and this paper's extended version.

3. Model Structure

3.1 Market Growth Model

The Market Growth model was developed by Forrester in 1986 to illustrate a contemporary phenomenon: new companies fail even when demand could (seemingly) grow forever. In the model, an inadequate capacity level constrains the company's ability to exploit the full potential of the market. This inadequacy is determined by the company's own policies, which suggest decisions based on limited information and bounded rationality (Forrester, 1968; Morecroft, 1983; Sterman, 2000).

The model is structured into three major loops, corresponding to different organizational units: sales, order fulfilment, and capacity acquisition. Since the extension introduced in this paper concerns the capacity acquisition sector, only this part of the original model is described below.

The capacity acquisition sector is governed by a balancing loop, the capacity expansion one, and a reinforcing loop, the capacity goal (Figure 1). The company adjusts its current capacity in response to the expansion pressure generated by a mismatch between the current delivery delay and the firm's own goal.

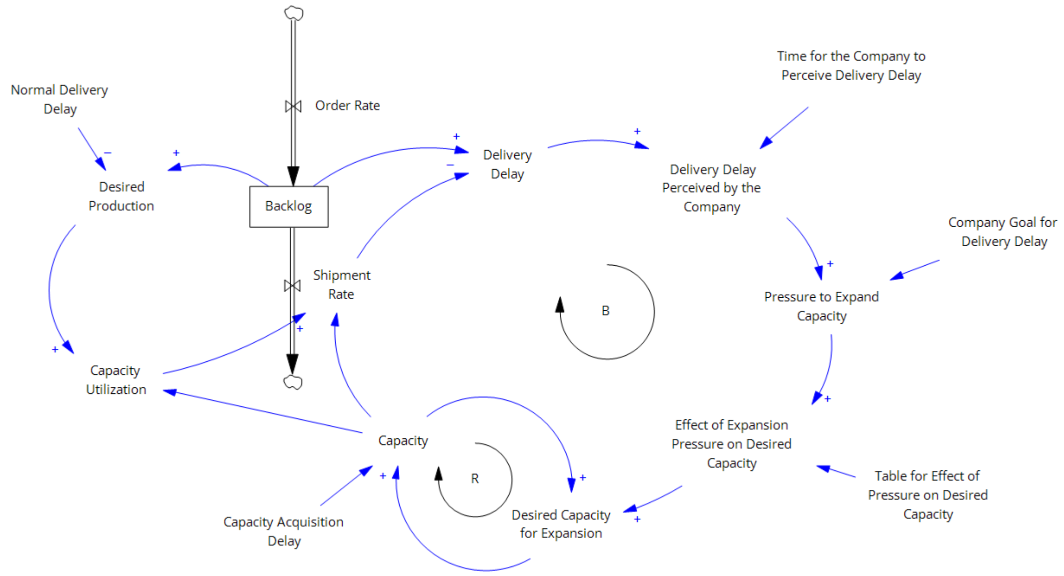

Figure 1: Stock and Flow Structure of the Capacity Acquisition Unit in the Market Growth Model

3.2 Model Extension (capacity adaptation)

In the extended model, capacity addition and reduction are governed by distinct decision rules and are triggered by different information. First, Capacity is represented as a stock with *Increase Capacity Rate* and *Decrease Capacity Rate*, as inflow and outflow, respectively. This separates the two capacity-adjustment policies and their inputs. For the expansion mechanism, as in the original model, the decision is triggered by the delay in the firm's delivery capability relative to its goal. A larger gap between the actual and desired delivery delay generates expansion pressure, which activates the adjustment-reinforcing loop. The reduction mechanism is instead triggered by Capacity Utilization. When *Capacity Utilization* is below the company's goal, it generates pressure to reduce capacity. Both capacity adjustment mechanisms are subject to the same 18-month implementation delay, retained from Sterman (2000)'s formulation. Furthermore, the adjustment structure follows the conservative behavioural logic of the original Market Growth model. Increases in expansion pressure translate into less than proportional increases in desired capacity, with the effect eventually saturating at a maximum value (Sterman, 2000). Capacity reductions are triggered only when utilization falls substantially below the company's target, reflecting a conservative approach to both capacity adjustments. This conservative behaviour reflects managers' resistance towards decisions that involve uncertainty regarding future demand, sunk costs, and irreversibility. Figure 2 depicts the stock-and-flow structure of the extended capacity acquisition unit.

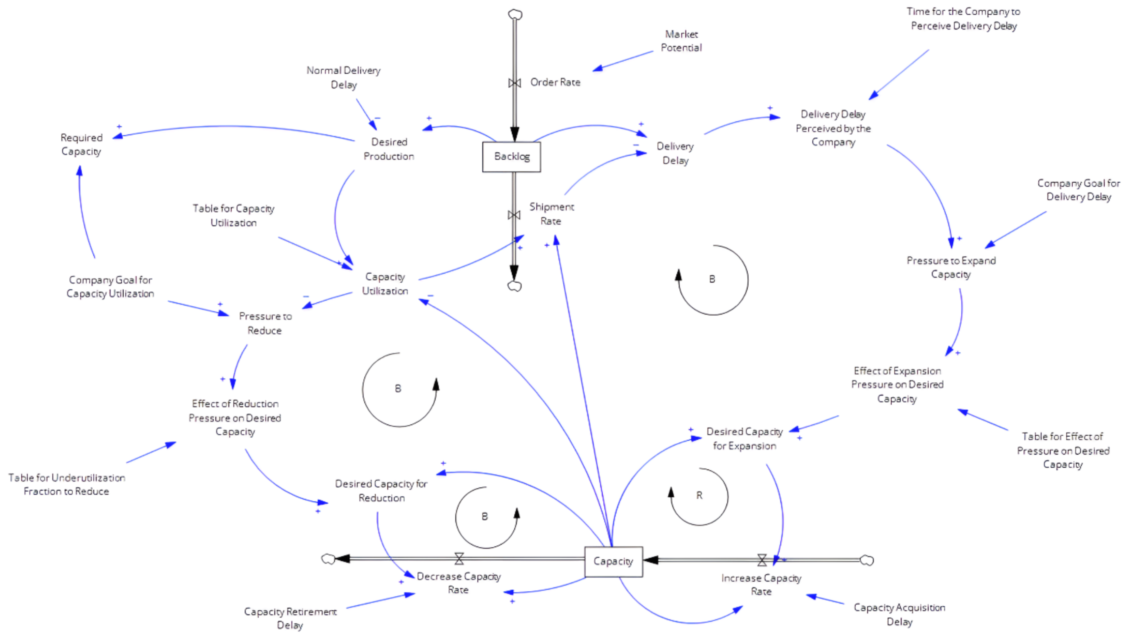

Figure 2: Stock and Flow Structure of the Capacity Extension in the Market Growth Model

One of Forrester's simplifying assumptions in his model was an unlimited market, which was well aligned with his purpose of illustrating growth dynamics in an unconstrained market. However, most markets are limited or even declining. As this work aims to investigate the impact of these market constraints on the firm's capacity policy, an additional extension to the original Market Growth model is made. The added variable *Market Potential* influences *Order Rate* and works as an upper bound on the number of orders that can be generated, regardless of *Sales Force* and *Sales Effectiveness*.

The four scenarios chosen for investigation represent different market trajectories: an unlimited market as in the original model, a limited market, a market with a one-time reduction, and a continuously decreasing market.

4. Simulation Results

The simulations are conducted in Vensim over a time horizon of 130 periods (months), and with a starting capacity of 500 units/month, as in the original Market Growth model.

4.1 Comparison of Original and Extended Model under Unlimited Market Conditions

The extended model is first simulated under the Unlimited Market scenario and compared to the original Market Growth version. As Figure 3 shows, Capacity in both models presents a similar pattern with minor differences. During the first month, the extended model capacity exhibits a steeper initial decline, followed by a smoother decline until around month 35. This initial drop results from the simulation's initial conditions, in both models, capacity has the same initial value, and capacity utilization begins at 0. In the original model, this initial steep decline does not appear, as capacity utilization does not affect Capacity's reductions. However, also in the original model, at the beginning of the simulated period, Capacity is characterized by a moderate decline that lasts slightly longer than in the extended version, until around month 40. The reduction in this scenario is determined by a low level of *Delivery Delay*, which determines *Desired Capacity* to be adjusted down based on the firm's recognized pressure for expansion. After the initial decline, capacity in both models follows a growth trajectory characterized by moderate oscillations, which are more pronounced in the original model. Towards the end of the simulations, capacity reaches higher levels in the extended model.

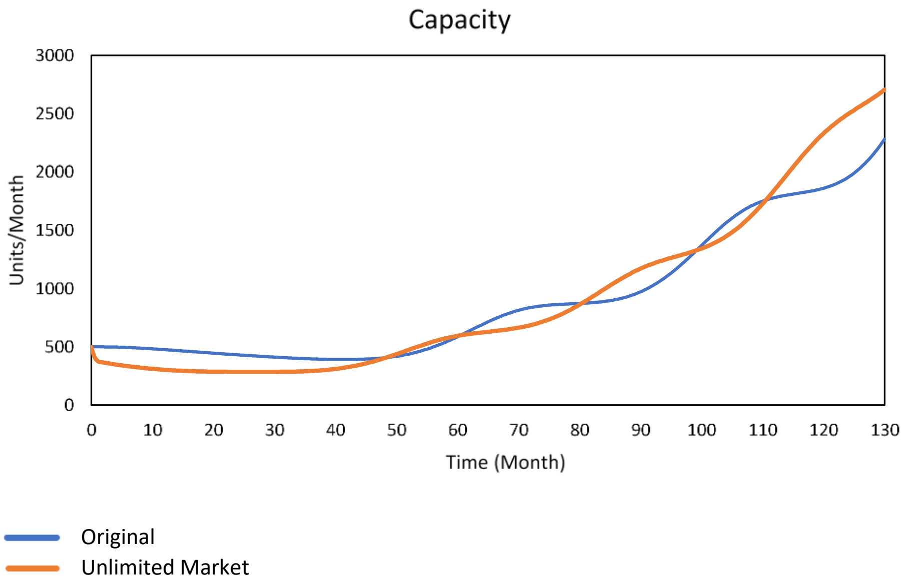

Figure 3: Capacity Dynamics in the Original and Extended Market Growth Models (Unlimited Market Scenario)

4.2 Results across Market Scenarios in the Extended Capacity Model

Across the four scenarios, capacity accumulates very differently. In the first two scenarios, Unlimited and Limited Market, *Capacity* follows the same pattern until month 100, which corresponds to the month in which the company reaches 2000 units/month ordered (Limited Market scenario constraint). Thus, the Limited Market reaches its maximum order level, while capacity continues to increase until the end of the simulation due to the implementation delay. Nevertheless, capacity remains below that of the Unlimited market, where orders continue to increase. In the last two scenarios, capacity accumulation varies well before month 100, reflecting the different market constraints.

While minor reductions occur in the One-Time Reduction scenario (capacity falls from 628 to 606 units/month over months 69-130), significant ones happen in the Continuously Decreasing Market scenario. This result is consistent with the model's representation of capacity reduction as a delayed and conservative managerial response to underutilization. Across the first three scenarios, capacity utilization remains close to or above the firm's 0.8 goal for most of the simulated period, generating limited pressure for capacity reduction. In the Continuously Decreasing Market scenario, *Capacity Utilization* drops below the company's goal around month 65. However, substantial capacity reduction occurs only after month 110. This delay results from both the 18-month implementation period and the conservative reduction rule, under which pressure on *Desired Capacity for Reduction* is significant as the utilization gap increases. Consequently, only large gaps trigger significant ramp-downs. Overall, the simulations suggest that under conservative and delayed reduction policies, firms may tolerate substantial excess capacity before initiating significant ramp-downs. As a result, meaningful capacity reductions emerge only under conditions of persistent market decline.

In a constrained or decreasing market, companies are challenged with excess capacity and its related costs. To investigate this in the model, a new variable *Required Capacity* has been created, which represents the capacity required to meet demand while maintaining the firm's target capacity utilization and normal delivery delay. It reflects the capacity level that allows the company to operate at its intended performance level.

Comparing *Required Capacity* with the actual one provides a direct indication of capacity misalignment (Figure 4). In the Unlimited and Limited market scenarios, after approximately 20-30 months, required capacity consistently exceeds actual capacity. This indicates that the company cannot promptly react to demand changes, reflecting adjustment delays and boundedly rational capacity-planning policies. While the gap narrows towards the end of the simulation due to orders' stabilization in the Limited market scenario, it continues to widen in the Unlimited Market scenario. This suggests a persistent difficulty in adjusting toward the intended performance level despite continued growth.

In the One-Time Market Reduction and Continuously Decreasing Market scenarios, the dynamics differ substantially. Around the middle of the simulation, the required capacity initially increases, while the actual capacity responds only weakly and with a delay. As market constraints take effect, required capacity declines sharply, eventually falling below actual capacity. At this point, the company shifts from a situation of capacity shortage to one of excess capacity. In the One-Time Reduction scenario, required capacity stabilizes at a level that corresponds to a capacity utilization close to the company's goal (approximately 0.8). For this reason, the pressure to reduce capacity does not increase, and the reduction policy is not triggered. As a result, the company stabilizes at a capacity utilization level slightly below its goal and at a capacity level that is slightly above the required level.

In contrast, in the Continuously Decreasing Market, required capacity decreases steadily toward zero, while actual capacity adjusts only gradually due to implementation delays and conservative decision rules. This determines a prolonged period of significant excess capacity. Although the model does not explicitly represent capacity-related costs, prolonged excess capacity may imply additional costs and reduced profitability (Morrison, 1985; Pindyck, 1990).

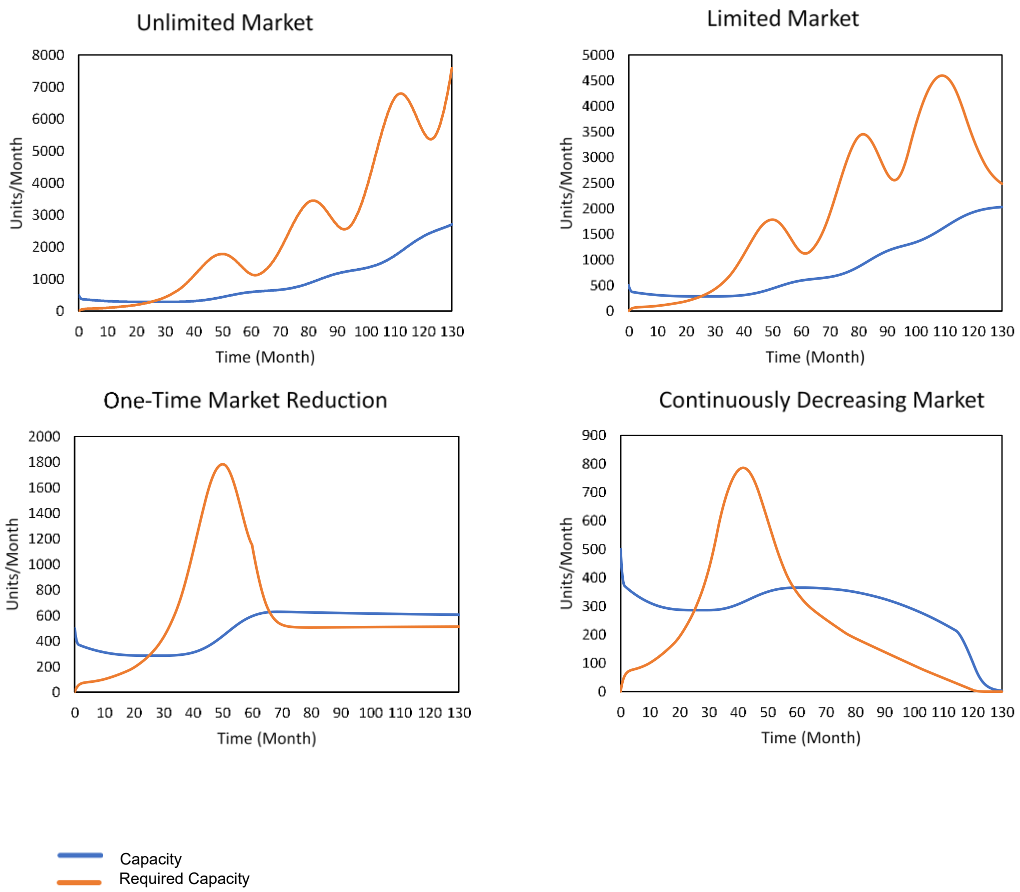

Figure 4: Comparison of Actual and Required Capacity across Scenarios

5. Discussion

This paper extends the classical Market Growth model to distinguish the information triggers for capacity expansion and reduction, and to represent constrained and declining markets. The results show that separating these triggers slightly stabilizes the capacity dynamics in the original settings (Unlimited Market). In the extended model, capacity reductions are triggered by capacity utilization, rather than delivery delay. Because capacity utilization remains closer to the company's goal, it generates less pressure for capacity reductions. As a result, Capacity remains at higher levels for longer, increasing product availability and contributing to shorter delivery delays. As *Delivery Delay* remain closer to the firm's goal, pressure to expand capacity is reduced, limiting capacity additions and contributing to more stable capacity dynamics.

However, in constrained markets, depending on market conditions and behavioural parameters, the extended structure can lead to persistent capacity underutilization and delayed ramp-downs. Beyond the effects on capacity dynamics, market constraints propagate through the sales force and sales effectiveness. Reductions in *Market Potential* directly limit the *Order Rate* and, consequently, *Shipment Rate* and *Revenue*. Lower revenues reduce the *Sales Budget* and *Sales Force*, further limiting the firm's ability to generate orders. At the same time, lower order volumes reduce *Delivery Delay* and increase *Sales Effectiveness*. However, this improvement does not increase *Order Rate*, *as Market Potential* represents the limiting factor in these scenarios. The firm may have sufficient *Sales Force* and *Sales Effectiveness* to generate additional orders, but the *Order Rate* is constrained by *Market Potential*. Thus, improvements in product availability cannot translate into additional orders in a shrinking or limited market.

These market constraints determine the conditions under which the capacity reduction mechanism is activated. In the first three scenarios, the reduction policy remains largely inactive. Consistent with the conservative reduction rule embedded in the model, moderate underutilization generates insufficient pressure to trigger substantial capacity reductions. This pattern is consistent with the literature suggesting that capacity reduction policies are often delayed (Di Fan et al., 2020).

In contrast, in the Continuously Decreasing Market, capacity utilisation falls below the goal relatively early, but reductions in capacity occur substantially only at the end of the simulated period. Only when capacity utilization falls significantly below the company's goal does the pressure to reduce capacity activate a steep ramp-down. This behaviour reflects theoretical insights suggesting that reductions are perceived as a painful decision due to sunk costs or a mistake of previous investments (Pindyck, 1990). Thus, managers prefer to deal with excess or underutilized capacity rather than reduce it (Di Fan et al., 2020; Trivella et al., 2020). In the model, this is captured by the conservative parameterisation of the effect of capacity utilization on *Desired Capacity for Reduction* and the implementation delay. In the One-Time Market Reduction scenario and more generally when the market stabilizes, this behaviour may reflect a capacity cushion that the company maintains as a buffer against uncertainty. In contrast, in the other scenarios, the gap between required and actual capacity becomes more pronounced. This results either in excess capacity and underutilization or in insufficient capacity, limiting the firm's ability to satisfy customers. This suggests a trade-off between maintaining a safety cushion and avoiding prolonged inefficiencies, which underscores the complexity of capacity reduction decisions. This highlights the need for further research on how firms can effectively manage capacity reduction in constrained and declining markets.

6. Conclusion

This paper extends Forrester's (1968) Market Growth model, in the updated version of Sterman (2000), by separating the information triggers for capacity expansion (delivery delay) and reduction (capacity underutilization), and by introducing market constraints to represent limited and declining markets. The comparison between the original and the extended model under the original settings shows that separating the capacity adjustment triggers slightly stabilizes capacity dynamics.

The simulations of the four different market scenarios demonstrate how, under conservative and delayed capacity-reduction policies, firms tolerate substantial levels of excess capacity before initiating significant ramp-downs. In the Unlimited, Limited, and One-Time Market Reduction scenarios, capacity reductions remain limited despite periods of underutilization. Only in the Continuously Decreasing Market scenario substantial capacity reductions occur, and only after a prolonged delay. These results indicate how conservative ramp-down policies contribute to persistent mismatches between actual and required capacity, both in declining and growing markets.

The study contributes to the system dynamics literature by extending the classical Market Growth model to explicitly represent capacity-reduction decisions, a topic that has received limited attention in previous research (Akkermans et al., 2019; Di Fan et al., 2020). From a sustainable standpoint, understanding capacity reductions becomes particularly relevant when firms need to move beyond continuous growth and deliberately reducing production capacity may become a sustainable alternative (Reichel and Seeberg, 2010) or the only alternative to comply with capital decommissioning policies (Zwetsloot et al., 2026). Future directions should, therefore, further explore capacity reduction strategies and provide managers with guidance on successfully ramping down capacity when required by changing market conditions or broader sustainability objectives.

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