

Why do lean and conventional firms operate in the same markets?*

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Abstract

Empirical literature suggests that the adoption of the *lean* management paradigm substantially improves operations performance of manufacturing companies. Nonetheless, conventional producers exist in parallel with lean firms, even in the same markets. Moreover, the empirical literature does not consistently show that the superior operational performance of lean firms, including lower production costs, translates into better financial performance. This paper offers resolutions to both of these apparent paradoxes. In a model with two companies and stochastic demand shocks, it is shown that lean and conventional management approaches can be *strategic substitutes*, i.e., if one firm is lean, its competitor prefers to be conventional, and vice versa. This result implies that in a market with many companies, there will be both lean and conventional companies in equilibrium and the profits of both types of firms will converge.

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1. Introduction

The management paradigm of *lean* has been described as “[using] less of everything – half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering working hours to develop a new product in half the time. Also, it requires keeping far less than half the inventory on site...” (Womack et al., 1990, p. 13). While these promises may appear overblown, it has been confirmed in many empirical studies that production processes restructured under the sway of the lean paradigm really function better. In a sophisticated econometric approach, based on time series data from 52 Japanese automotive companies, Lieberman and Demeester (1999) find that a reduction of inventories by 10% causes¹ labor productivity to rise by 1% on average. Another example is Wu (2003), who analyzes the responses to a 17-pages questionnaire returned by 130 companies from the US automotive supply industry, half of which were lean and the other half non-lean. He finds that unscheduled downtime is 5% among lean companies vs. 8% among conventional companies, and average truck loading time is 41 minutes for lean firms vs. 83 minutes for non-lean firms. In terms of quality, lean firms ship an average of 278 defective parts per one million parts to their customers, while this number stands at 958 for conventional firms. Most importantly, the study affirms that the operational advantages translate into lower costs:² transportation cost accounts for 1.47% of total costs among lean firms and for 1.78% among ordinary firms,³ and lean firms have “emergency shipping costs” of \$330 per one million sales, while for conventional firms this number stands at \$596.

Another example is the study by Hallgren and Olhager (2009), who analyze a sample of 211 manufacturing plants from the electronics, machinery, and automotive industries of various countries and estimate path coefficients for the impact of lean production on operations performance criteria. They report that lean production leads to lower cost, higher quality, higher delivery speed, and higher delivery reliability, with path coefficients for these connec-

¹They test for *Granger causality*.

²Browning and Heath (2009), drawing on an in-depth case study of the production of the F-22 fighter jet by Lockheed Martin, argue that lower costs are an “emergent property” of a holistic lean transformation of a company.

³This finding is based on a subsample of only 11 lean and 9 non-lean firms due to confidentiality concerns of the other companies. Unsurprisingly, given the small sample size, the finding is not statistically significant on a 90%-level.

tions ranging between 0.403 and 0.653, all on a 99% confidence level. The operational advantages of *lean* were confirmed in many other studies, for example in Lawrence and Hottenstein (1995), Nakamura et al. (1998), and Shah and Ward (2003).

Despite this acclaim, *lean* has been adopted only by a subset of the firms in many markets, casually demonstrated by the fact that a great number of academic articles in the operations management literature can compare lean and conventional firms (like some of the aforementioned papers). There is also direct evidence that companies refrain from implementing lean. For each of the lean management techniques covered in a questionnaire by White et al. (1999), up to 50% of the firms reported no implementation. Two of those techniques, *Just-in-Time* and *Total Quality Control*, are explicitly pointed out in Shah and Ward (2003) as methods that can be profitably implemented *independently* of the adoption of any other lean strategies. Nevertheless, White et al. (1999) report that only 66% of small manufacturers and 81% of large manufactures had started implementation of Just-in-Time, while 82% and 91%, respectively, practiced Total Quality Control. Likewise, in a sample of 253 firms from different sectors analyzed in Fullerton and McWatters (2002), 158 (about 62%) had not implemented lean. More recently, Losonci and Demeter (2013) analyzed 453 observations from the *International Manufacturing Strategy Survey*, a database larger than those of similar studies, and discovered great heterogeneity when it comes to the adoption of lean techniques: based on a variety of criteria, they classify 156 firms of their sample as *non-lean*, 191 as *beginner lean*, and 106 as *advanced lean*.

According to common sense, a management paradigm that strongly affects company performance will be adopted either by every firm or by no firm in a market. The *lean* paradigm may be multidimensional and affect multiple components of the production process in different ways, leading to advantages and disadvantages at the same time, but one would still expect a positive or negative net effect. In the former case, all firms should turn lean, while in the latter, all firms should remain conventional.⁴

⁴This is common sense under a classical “industry-based view” as adopted in this paper, where the decisions of companies are primarily determined by the market environment they face, a perspective which permeates the economics and industrial organization literature. If, on the other hand, one adopts a “resource-based view” (Barney, 1991), the argument is less compelling. The resource-based view (RBV) posits that companies’ behaviors and strategies are determined by the resources they have. Proponents of RBV could argue that

This paper offers a resolution to this puzzle. We argue that *lean* and *non-lean* are *strategic substitutes*, i.e., lean firms benefit from their competitors being conventional, while conventional firms are better off when their competitors are lean. This admits the existence of equilibria where lean and conventional firms operate in parallel.

Our argument is based on two crucial assumptions:⁵

Firstly, we acknowledge that lean is a holistic management approach (“lean thinking”) which comprises ideas like scientific management, people involvement, systematic problem solving (cf. Womack and Jones, 1996; Shah and Ward, 2007; Parkes, 2015; Furlan et al., 2019), and may extend to non-production activities like product development (cf. Marodin et al., 2018). Yet, among the undoubtedly many differences between lean and conventional firms, we consider only one, namely that the former tend to hold lower inventories than the latter. While this is by no means the only important distinction of lean (and we do not claim that it is), many authors consider the reduction of inventories, often as a consequence of a reduction of *muda* (Japanese for *waste*), as a signature characteristic of lean production, e.g., O’Neal (1987), Williams et al. (1989), Anyane-Ntow (1991), Williams et al. (1992), Karlsson and Åhlström (1996), and Oliver and Hunter (1998). Narasimhan et al. (2006) include tight buffers even in their definition of lean: “Production is lean if it is accomplished with minimal waste due to unneeded operations, inefficient operations, or excessive buffering in operations.” It was also shown empirically that lean firms really do have smaller inventories, e.g., in Womack et al. (1990), Delbridge and Oliver (1991), Katayama and Bennett (1996), and Oliver and Hunter (1998).⁶

Secondly, our reasoning crucially depends on the assertion that, due to less

lean is in principle advantageous for all firms, but only companies that have the relevant resources (e.g., a sophisticated management and a performance-oriented corporate culture) can go lean. A coexistence of lean and conventional firms in the same market then follows from a heterogeneous resource endowment across the industry. The application of RBV on the question of why companies go lean attributes their decisions to an *exogenous* factor, namely the availability of resources. The model in this paper, on the other hand, explains the decision to go lean *endogenously*.

⁵It was painful to learn that many operations management researchers not only reject these assumptions but also feel strongly about it.

⁶For our argument, it is not important whether the reduction in inventories is considered a defining property of lean or just a consequence of *Just-in-Time* production. Moreover, our argument does not require that lean firms hold *zero* inventory.

inventories and buffers, it is more difficult for lean companies to cope with demand fluctuations. This is affirmed by some of the literature, e.g., Womack et al. (1990) suggest that volatile demand is outright incompatible with lean production, showing in a graph that over the time period from 1947 to 1989 the demand volatility was much higher in the USA than in Japan (p. 247). Katayama and Bennett (1996) endorse this view when they point out that “a particular weakness of lean production is its inability to accommodate the variations or reductions in demand for finished products which have occurred in many Japanese companies.” They report a case study on air conditioner production in Japan (which is highly cyclical) and find that “the plant still has ten large warehouses for stocking finished goods to allow for seasonal demand.” These authors, and the paper at hand, fully acknowledge that lean companies, specifically through the application of *heijunka* principles,⁷ can achieve an astounding degree of flexibility, allowing to quickly react to demand changes. Yet, it seems implausible that a lean company can in the short run react to a demand increase as quickly as a company which can simply sell from the storeroom. One should also bear in mind that a real-time reaction of a lean company to a positive demand shock requires *all firms* in the supply chain to live up to the same high standard of lean implementation and to act in near-perfect synchronization. As we were told by an executive of a large global logistics firm that manages supply chains for manufacturing companies: “If the demand changes for one of our customers in the UK, we have to instantly adjust the entire supply chain back to its origins, which may be in Vietnam.” While this may often work out well, the manager admitted that the adjustment is delicate and glitches may lead to dynamics like the infamous *Bullwhip Effect* (Forrester, 1961). Moreover, even if the supply chain management works virtually frictionless in operationally high-performing companies, it is also clear that not all companies are operationally high-performing, and it seems unlikely that ramping up output by lean firms is *on average* as fast as inventory reduction by conventional firms. What matters for our model is the *average* adjustment speed.

Under the presumption that lean manufacturers cannot cope as well with positive demand shocks as conventional firms due to their reduced inventory, consider an environment where these shocks occur stochastically. If all firms are lean, there is an incentive for an individual firm to switch to conventional

⁷Cf. Helmold (2020), p. 69.

because, in the case of a positive⁸ demand shock, the conventional firm can serve customers instantaneously by reducing its inventories and in this way take over market share from their lean competitors. Yet, if *all* firms turn conventional, this advantage disappears as all firms could then react to a positive demand shock equally fast. On the other hand, it is also no equilibrium if all companies are conventional. In that situation, there is an incentive for a firm to go lean because if the demand shock does *not* materialize, the lean firm can realize lower production costs and prey on the market share of its conventional competitors. The equilibrium market structure has therefore an element of diversification, where one type of company fares better in one scenario and the other type of company does better in the other.

In this paper, we show in a model that there always exists a non-empty interval of shock probabilities in which a conventional competitor is best dealt with by turning lean, and a lean competitor is best dealt with by remaining conventional. This is proved for a situation with two companies, but the result carries over straightforwardly to a market with many companies, where it implies that the *more* lean firms there are, the more profitable it becomes to be conventional, and vice versa. Moreover, the profitability differential between lean and conventional disappears if there are many companies because companies will convert towards the more profitable type until profits have equalized.

The remainder of the paper is organized as follows. Section 2 introduces the model, which represents the output adjustment processes of the firms as a system of differential equations, and states its solution. Section 3 defines the game played by the companies and shows how the shock probabilities determine its equilibrium. Section 4 offers a discussion of the results, and Section 5 concludes. The proofs of all results (except the corollaries) are in the appendix.

2. The model and its solution

Consider a market with two firms which produce and sell a homogeneous good to a great number of customers. Both firms try to maximize their expected equilibrium sales, a simplifying assumption that makes sense when-

⁸The case of a *negative* demand shock is not relevant for us because there is no obvious difference in how fast lean and conventional firms can *reduce* their outputs.

ever the profits grow in sales.⁹ Both firms have to decide whether to be lean or conventional. After they made their decisions, a positive demand shock takes place with probability p . Without demand shock, the joint sales of the companies at the equilibrium price equal D , and if the shock occurs, the market demand jumps to D^{Shock} with $D^{Shock} > D$. There is a parameter δ which stands for the state-dependent advantage/disadvantage of being lean: if the demand shock occurs, a penalty of $\delta > 0$ is deducted from the sales volume of the lean firm, but if the demand shock does not occur, the same value δ is added to its sales.¹⁰ The conventional firm can deliver in both cases equally well and thus does not incur a state-dependent penalty/bonus. For simplicity, we stipulate that if both firms choose the same strategy, they will each get 50% of the market in both states of the world, i.e., if both firms are conventional and there is a shock, they will both have sales of $(1/2) \cdot D^{Shock}$, and without shock $(1/2) \cdot D$. Likewise, if they are both lean, then they will both sell $(1/2) \cdot D^{Shock} - \delta$ with shock and $(1/2) \cdot D + \delta$ without shock.¹¹ With these assumptions, it follows that if both firms are lean, both have the same expected output, which is equal to

$$p \cdot [(1/2) \cdot D^{Shock} - \delta] + (1 - p) \cdot [(1/2) \cdot D + \delta].$$

If both firms are conventional, then the expected output of each firm is

$$p \cdot (1/2) \cdot D^{Shock} + (1 - p) \cdot (1/2) \cdot D.$$

The critical case is the one where one firm is conventional and the other is lean. We assume that the *relative output adjustment speeds*¹² of the conven-

⁹This is the case, for example, if the firm has constant average variable costs. At a given market price, there will be a margin between that price and the average variable costs, and the gross profit of the company will be that margin multiplied by the number of items sold so that the profit is linearly linked to its sales volume.

¹⁰If the *positive* demand shock does not occur, there might be no shock at all or a negative shock. In both cases, it will be advantageous for a firm to be lean. Therefore, we can avoid explicitly modeling the negative demand shock because both cases can be subsumed under the case where there is *no positive demand shock*, and the lean firm gets a sales bonus.

¹¹It was suspected that our result follows because the market volume is exogenously fixed and does not depend on the firms' decisions. This is incorrect. If both firms go lean and there is no shock, the effective market volume is $D + 2\delta$, which is greater than D , the market volume if they are both conventional in that state.

¹²Output adjustment speed in the sense of our model refers to output sold to the customers. While the lean firm is likely to be faster in adjusting its actual production process,

tional and the lean company are constant¹³ and captured in two parameters $\alpha_c, \alpha_l \geq 0$ for which we assume $\alpha_c > \alpha_l$ and $\alpha_c + \alpha_l = 1$.¹⁴ We model the output adjustment processes of the two firms, if a positive demand shock occurs, with a system of differential equations as follows:

$$O'_c(t) = \alpha_c[D^{Shock} - S(t)] \text{ and } O'_l(t) = \alpha_l[D^{Shock} - S(t)] \quad (1)$$

where t is the time variable and $t = 0$ the moment when the shock occurs. $O'_c(t)$ is the derivative of the output of the conventional firm with respect to t , and $O'_l(t)$ is the derivative of the output of the lean firm with respect to t . $S(t)$ is the aggregate supply at time t , given as

$$S(t) = O_c(t) + O_l(t). \quad (2)$$

The primary economic assumption built into the equations (1) is that the firms adjust their output faster if the difference between aggregate supply and aggregate demand is greater.¹⁵ This is based on the intuition that the more drastically the number of incoming orders has increased through the shock, the more quickly a firm will ramp up its production.¹⁶ In addition to the above, we also assume that, as the demand shock is positive, none of the two firms will produce *less* under the new equilibrium than under the old

the conventional firm can faster deliver to the customers because it just reduces its inventories of produced goods.

¹³This is not to be understood in a way that the advantages of going lean accrue to a company constantly over time. That would most likely be incorrect; Netland and Ferdows (2016) provide evidence that the benefits from going lean follow an S-shaped pattern over time.

¹⁴ $\alpha_c + \alpha_l = 1$ is a convenience assumption that does not drive results. In an earlier version of the model, we did not make this assumption and could derive all results with messier expressions.

¹⁵The reader might wonder why there would be a supply-demand gap at all – would this not be prevented by an instantaneous price increase? Possibly yes, but an increase in the market price would lead to the same reactions by the firms as in our model, namely output increases, so that nothing is lost if we do not model prices explicitly. If one wants to address other questions with our model, the price path may be relevant. In Section 5, we briefly outline how prices could be included in the model.

¹⁶The greater the demand increase, the more resources will be made available by the firm to catch up with the demand, leading to a swifter adjustment. This may be, for example, through extra shifts, hires of temporary workers, and emergency purchases of preliminary products abroad or from companies that previously were not suppliers.

equilibrium,¹⁷ i.e., $O_c(0) \leq O_c(t)_{t \rightarrow \infty}$ and $O_l(0) \leq O_l(t)_{t \rightarrow \infty}$. Mathematically, this is of course only meaningful if the values $O_c(t)_{t \rightarrow \infty}$ and $O_l(t)_{t \rightarrow \infty}$ exist, which will be shown in Corollary 1 below.

A *solution* to the system of differential equations given in (1) and (2) specifies functions $O_c(t)$ and $O_l(t)$ which turn (1) and (2) into true statements.

Proposition 1 *The functions*

$$O_c(t) = \alpha_c D^{Shock} + c_1(\alpha_c e^{-t} + \alpha_l) + c_2 \alpha_c (e^{-t} - 1) \quad (3)$$

and

$$O_l(t) = \alpha_l D^{Shock} + c_1 \alpha_l (e^{-t} - 1) + c_2 (\alpha_l e^{-t} + \alpha_c), \quad (4)$$

with $c_1, c_2 \in \mathbb{R}$ being parameters, are the unique solutions to the equations given in (1) and (2).

The following corollary shows that the outputs of the firm approach a finite limit for $t \rightarrow \infty$:

Corollary 1 *The limits of the functions $O_c(t)$ and $O_l(t)$ for $t \rightarrow \infty$ are*

$$O_c(t)_{t \rightarrow \infty} = \alpha_c D^{Shock} + c_1 \alpha_l - c_2 \alpha_c \quad (5)$$

and

$$O_l(t)_{t \rightarrow \infty} = \alpha_l D^{Shock} - c_1 \alpha_l + c_2 \alpha_c, \quad (6)$$

The corollary follows directly from t approaching infinity in the expressions (3) and (4).

If we set the initial conditions for $t = 0$ as $O_c(0) = O_l(0) = 1/2 \cdot D$, we remove all degrees of freedom. Therefore, we can express c_1 and c_2 as functions of D and the other parameters, which yields:

Corollary 2 *The values of c_1 and c_2 are given as*

$$c_1 = (1/2) \cdot D - \alpha_c D^{Shock} \text{ and } c_2 = (1/2) \cdot D - \alpha_l D^{Shock}.$$

¹⁷This assumption was criticized, but it rests on a solid intuition. If a company just ignored the demand shock, it would be odd if it faced difficulties to sell its existing output, given that total demand has increased.

Evaluating the solution (3) at $t = 0$, taking into account $O_c(0) = (1/2) \cdot D$ and $\alpha_l + \alpha_c = 1$, immediately yields the first of the two statements in the corollary. The second can be derived in the same way from (4). From Corollary 1 directly follows:

$$\lim_{t \rightarrow \infty} O_c(t) + \lim_{t \rightarrow \infty} O_l(t) = D^{Shock}. \quad (7)$$

The next result will turn out useful for analysing the equilibria of the game:

Proposition 2 *If the firms choose different strategies and a shock occurs, the equilibrium output is higher for the conventional firm than for the lean firm, i.e.,*

$$\lim_{t \rightarrow \infty} O_c(t) > \lim_{t \rightarrow \infty} O_l(t). \quad (8)$$

3. Strategic analysis

The sales derived in the preceding section lead to the payoff matrix shown in Figure 1. We will refer to the top left outcome as the *symmetric lean outcome* and the bottom right outcome as the *symmetric conventional outcome*. The two other outcomes will be referred to as the *asymmetric outcomes*. If the equilibrium of the game is an asymmetric outcome, lean and conventional are *strategic substitutes*. In this section, we will investigate when this will be the case.

Two instances of the matrix in Figure 1, where the Nash equilibria are the asymmetric outcomes and lean and conventional are strategic substitutes, are shown in Figures 2 and 3. In Figure 2, we have set $D = 1$, $D^{Shock} = 2$, $\alpha_c = 0.9$, $\alpha_l = 0.1$, $\delta = 0.5$ and $p = 0.4$. This means that with probability 0.4, there will be a shock, in the wake of which aggregate demand doubles. The conventional firm can adjust its output nine times as fast as the lean firm, and being lean yields a penalty of -0.5 if there is a shock and a bonus of 0.5 if there is no shock. In Figure 3, we have set $D = 1$, $D^{Shock} = 1.5$, $\alpha_c = 0.6$, $\alpha_l = 0.4$, $\delta = 0.2$ and $p = 0.6$.

How do the equilibria of the game depend on the shock probability p ? Assume that $p = 0$, i.e., it is certain that there will be no demand shock. In that case, the payoff of being lean is higher than the payoff of being conventional irrespective of the competitor's choice, i.e., lean is a strictly dominant strategy. Consequently, both firms are lean in the only equilibrium of the

		Firm 2	
		Lean	Conventional
Firm 1	Lean	both $p \cdot [(1/2) \cdot D^{Shock} - \delta] + (1 - p) \cdot [(1/2) \cdot D + \delta]$	$p \cdot \frac{O_l(t)}{t \rightarrow \infty} + (1 - p) \cdot [(1/2) \cdot D + \delta], p \cdot \frac{O_c(t)}{t \rightarrow \infty} + (1 - p) \cdot (1/2) \cdot D$
	Conv.	$p \cdot \frac{O_c(t)}{t \rightarrow \infty} + (1 - p) \cdot (1/2) \cdot D, p \cdot \frac{O_l(t)}{t \rightarrow \infty} + (1 - p) \cdot [(1/2) \cdot D + \delta]$	both $p \cdot (1/2) \cdot D^{Shock} + (1 - p) \cdot (1/2) \cdot D$

Figure 1: The game played between the two companies. Firm 1 chooses a row, Firm 2 chooses a column of the matrix.

game. Alternatively, assume that $p = 1$. From Proposition (2) and Equation (7) follows that $O_c(t)_{t \rightarrow \infty} > (1/2) \cdot D^{Shock}$ and $O_l(t)_{t \rightarrow \infty} < (1/2) \cdot D^{Shock}$ so that in this case, being conventional is a strictly dominant strategy. Accordingly, there is only one equilibrium where both firms are conventional. What about probabilities that are strictly between 0 and 1? The next result gives a full characterization of the equilibria of the game as a function of the shock probability p :

Proposition 3 *The equilibria of the game of Figure 1 are determined by the value of p in the following way:*

1. *The asymmetric outcomes of the game are the only equilibria if and only if p fulfills the following inequalities:*

$$\frac{\delta}{(1/2) \cdot D^{Shock} - \frac{O_l(t)}{t \rightarrow \infty} + \delta} > p > \frac{\delta}{\frac{O_c(t)}{t \rightarrow \infty} - (1/2) \cdot D^{Shock} + 2\delta} \quad (9)$$

2. *There is always a probability p that fulfills both inequalities (9). This implies that there exists no p that violates both inequalities in (9).*
3. *If p does not fulfill the left inequality of (9), there will be a symmetric equilibrium where both firms are conventional. If p does not fulfill the right inequality of (9), there will be a symmetric equilibrium where both firms are lean.*

		Firm 2	
		Lean	Conventional
Firm 1	Lean	0.8, 0.8	0.84, 0.86
	Conventional	0.86, 0.84	0.7, 0.7

Figure 2: An instance of the game played between the two companies. Firm 1 chooses a row, Firm 2 chooses a column of the matrix. The payoffs result from setting $D = 1$, $D^{Shock} = 2$, $\alpha_c = 0.9$, $\alpha_l = 0.1$, $\delta = 0.5$ and $p = 0.4$.

		Firm 2	
		Lean	Conventional
Firm 1	Lean	0.61, 0.61	0.7, 0.68
	Conventional	0.68, 0.7	0.65, 0.65

Figure 3: An instance of the game played between the two companies. Firm 1 chooses a row, Firm 2 chooses a column of the matrix. The payoffs result from setting $D = 1$, $D^{Shock} = 1.5$, $\alpha_c = 0.6$, $\alpha_l = 0.4$, $\delta = 0.2$ and $p = 0.6$.

The inequalities (9) can be interpreted. $(1/2) \cdot D^{Shock} - O_l(t)_{t \rightarrow \infty}$ in the left denominator is the *disadvantage* of being lean in the asymmetric equilibrium compared to the payoff of the symmetric conventional equilibrium (where both firms obtain $(1/2) \cdot D^{Shock}$). Analogously, $O_c(t)_{t \rightarrow \infty} - (1/2) \cdot D^{Shock}$ in the right denominator is the *advantage* of being conventional in an asymmetric equilibrium compared to the payoff of the symmetric conventional equilibrium. From Equation (7) above it follows that both of these terms are equal, so let us denote the value of this expression by v . The greater v becomes, the smaller is the range of probabilities in which we will have an asymmetric equilibrium. To see that, consider the cases where $v = 0$,¹⁸ $v = \delta$, $v = 2\delta$, and $v = 3\delta$. For these cases, the probability ranges supporting asymmetric equilibria are $(1/2, 1)$, $(1/3, 1/2)$, $(1/4, 1/3)$, and $(1/5, 1/4)$, respectively, i.e., a greater payoff spread in the asymmetric equilibrium leads the probability intervals to become narrower and move closer to 0. This is because a higher v makes being lean in the asymmetric equilibrium less profitable so that only for a tighter range of lower values of p lean is still a best response to a conventional competitor. At the same time, by the dominant strategy argument made above, there is always a probability close enough to 0 such that the only equilibrium will be symmetric lean. Therefore, the lower boundary of the interval supporting asymmetric equilibria will never be equal to 0.

4. Discussion

In the preceding section, we have shown that if the shock probability was 1, it would be a dominant strategy to be conventional. Likewise, if the shock probability was 0, both firms would be lean. So, it is better to be lean in case of surely stable demand and better to be conventional in case of sure demand shocks. This reasoning suggests that also for any value p strictly between 0 and 1, the expected payoff should be better with either lean or conventional, with the exception of one threshold probability $\bar{p} \in (0, 1)$ where the companies perform equally well with both strategies.

Yet, the argument is wrong. If the probability is in the interval specified by the inequalities (9), an “industry-level diversification” of management strategies yields benefits to *both* companies (in terms of expected payoffs). If the

¹⁸This case is actually impossible if $\alpha_c > \alpha_c$, but we ignore this fact here.

shock materialises, there is still one firm that can deliver, but being that firm is only profitable if the other firm can *not* deliver. This effect of lean is reflected in a citation from Oliver and Hunter (1998): “A manager from one of the high-user companies in the study recounted how his company’s destocking programme had led to problems in their ability to meet customer demands. In the face of unpredictable demand and low inventories, the company had lost orders to competitors because of their inability to supply at the right time.” On the other hand, if the shock does *not* materialize, then the lean firm has operational and cost advantages translating into a bigger market share, but only if the other firm is *not* lean.

What about the profits of the firms? There is evidence that lean, despite its better operations performance, does not consistently lead to higher financial performance of a firm, a finding that is puzzling to many authors in the operations management literature and has led to considerable controversy. The debate was triggered by Anyane-Ntow (1991) and Balakrishnan et al. (1996), whose empirical analyses do not show better financial performance of lean firms compared to conventional firms. Supporting these findings, Williams et al. (1995) show that in every year in the time span from 1983 to 1989 the cash flows generated by Toyota (considered by Katayama and Bennett (1996) to be the most advanced lean firm) were below those of GM and Ford.¹⁹ Oliver and Hunter (1998) summarize that “the critique [of lean production] has shifted towards the issue of the financial performance of the Japanese car makers in an attempt to challenge the usually taken-for-granted assumption that Japanese methods, with their apparently enormous superiority in terms of physical conversion, actually translate into superior financial performance.” The authors further add to the evidence: based on a survey of 68 companies in the United Kingdom, they show that between 1984 and 1993, average *sales per employee* (measured in monetary value) are higher for conventional than for lean firms, despite higher labour productivity being one of the signature characteristics of the lean approach.²⁰ At the bottom line, the authors do not find a statistically significant difference in operating profits and return on equity between lean and conventional companies. Analyzing three case studies, Lewis (2000) discovers that the

¹⁹See Table 3 in their paper.

²⁰Womack et al. (1990), p. 92, report that the numbers of man hours required to build a vehicle were 25.1 in the US vs. 16.8 in Japan.

two companies that moved most towards lean were those with the greatest profit losses. Those firms reduced inventory by 60 and 46 percent, and he comments sarcastically that in parallel with their inventories also “profitability has been squeezed (profit -29 per cent and -2 per cent respectively).” Also Jayaram et al. (2008) find “no significant positive or negative effects of lean manufacturing on the overall firm performance”. Losonci and Demeter (2013) compare both the financial and the operations performances of *non-lean*, *beginner lean*, and *advanced lean* companies and find that “significant differences in operational performance of non-lean, beginner and advanced lean companies... are not mirrored in business performance.” They conclude that “excellent internal operations and great operational performance do not warrant great business-level success”, and “operational excellence does not directly lead to better financial and market measures.” Even Rosemary Fullerton, an operations management researcher who adopts an outspokenly positive view on lean production in most of her papers, once admitted that no unambiguously positive connection between the adoption of lean management techniques and firm profitability can be established (Fullerton et al., 2003).²¹

As one can see in Figures 2 and 3, our model does *not* imply that lean production and conventional production are equally profitable. In Figure 2, it is better to be the conventional firm in the asymmetric equilibrium, and in Figure 3, it is better to be the lean firm. Yet, consider a hypothetical process that starts with two companies in an asymmetric equilibrium and

²¹For the sake of a fair presentation, it should be noted that the empirical literature on the financial impact of adopting lean ideas is not unequivocal. Huson and Nanda (1995), based on firm level and industry level data from 1977 to 1992, find that the implementation of lean ideas led to an increase in earnings per share. Likewise, Kinney and Wempe (2002) find a positive impact of lean production on the return on assets but only with companies that have large revenues. The positive effect disappears if they look at the subsample of companies with annual sales revenues of \$108.5 million or lower (39 out of 201 firms in their sample fulfill this criterion). The threshold is the median value of the sales revenues of the firms in the sample of Balakrishnan et al. (1996) and was chosen by Kinney and Wempe (2002) in an attempt to explain the negative performance results of Balakrishnan et al. (1996). Other studies that tend to support a positive impact of lean manufacturing on financial performance are Inman and Mehra (1993), Callen et al. (2000), Fullerton and Wempe (2009), Yang et al. (2011), Galeazzo and Furlan (2018), and, analyzing more holistically the profit impact of sophisticated management, of which the implementation of lean techniques is just one aspect, Sadun et al. (2017).

new firms sequentially entering the market. The profitability differential will lead new firms to choose the more profitable strategy, shrinking the advantage of that strategy because the advantage in the asymmetric equilibrium depends on not all firms choosing the same strategy. In a non-atomic market with infinitely many entrants, the advantage entirely disappeared. The logic of the argument equally applies to the case where one has multiple conventional firms already in the market which can switch to lean. Also here, the switching to lean would continue until the profitabilities of both strategies were equalized.

We think of the equilibration we describe as a “blind”, evolutionary process. Firms start out conventional and engage in asynchronous moves of becoming (more) lean, acting on the immediate feedback they receive. In each stage of the process, the payoffs are determined in a game similar to the one defined in Section 2. We refrain from discussing strategic dynamics that could emerge in repeated play because switching from conventional to lean and back, in response to other firms’ decisions, is not likely to take place in reality, due to the enormous financial and managerial commitments associated with going lean.²²

5. Conclusion

It is no exaggeration to call the rise of the *lean* paradigm one of the most influential developments in operations management in the last 30 years. Already Berggren (1993), alluding to a famous book published at the time, speculates that lean might be “the end of history” in operations management. More recently, Fullerton et al. (2014) calls lean “the most important strategy for achieving world-class performance.” The concept also prominently features in virtually every modern operations management textbook.²³

²²Analyzing repeated play would be relevant if the choice was between *make to order* (MTO) and *make to stock* (MTS) manufacturing approaches. It is much easier to switch between MTO and MTS than it is to move between lean and conventional; many companies choose a “hybrid” approach and move back and forth between MTO and MTS over relatively short periods of time (cf. Peeters and van Ooijen, 2020). It is believed that these switches occur in response to changes of the market environment, and if one could show that MTO and MTS were strategic substitutes, an alternative, strategic explanation could be advanced.

²³For example in Stevenson (2017), Chapter 14, Heizer et al. (2016), Chapter 16, and Slack et al. (2016), Chapter 15.

This paper shows that stochastic demand shocks can give rise to circumstances where lean production is only beneficial to a company if some of the competitors remain conventional. At the same time, remaining conventional is only a best response of a firm if some competitors actually do turn lean. This argument from *strategic substitutability* explains two apparent paradoxes: (a) despite its operational advantages, *lean* is typically not adopted by all firms in a market; (b) the empirical evidence for the financial advantages of lean production is ambiguous.

Our model only looks at equilibrium sales, thought of as a proxy for the firms' profits, but at the cost of increasing the mathematical complexity, it would be possible to include prices in this model and compute the exact profits based on some cost function and the price adjustment path following the shock. To that end, one could posit an aggregate demand function, e.g., the standard linear one $D(p) = a - bp$ (where a is the market volume, b is the slope of the demand curve, and p is the price). The demand shock could then be modeled, most straightforwardly, through an increase in the market volume, i.e., a change from a to a^{shock} with $a < a^{shock}$. For obtaining the price path $p(t)$ of the equilibration process, one could solve the equation $O_1(t) + O_2(t) = a^{new} - bp(t)$ for $p(t)$, where 1 and 2 are the two firms (depending on the model's purpose, not necessarily lean and conventional). The system of differential equations could otherwise remain as is, though D^{Shock} would have to be replaced by the function $D(p)$. While we considered to work this out, we finally decided to create the simplest model sufficient to support our case in point. We leave the more complex model with price path to somebody else interested in modeling firm-level adjustment processes with differential equations, possibly with the aim of answering different questions than the one addressed in this paper.

The question of why some firms go lean and others do not is embedded in the debate on why firms adopt different management practices at all. Based on a very large dataset, Bloom et al. (2019) map out the wide-ranging managerial heterogeneity that is empirically observed and attribute it to the factors "business environment" and "learning spillovers". Their explanatory framework ignores the possibility that heterogeneity is part of a strategic equilibrium. Similarly, Syverson (2011) surveys the extensive empirical evidence on productivity differentials of firms as well as explanations for these differentials. Yet, also his discussion does not cover potential strategic causes of heterogeneity but focuses on "producers' external operating environments"

and “production practices”.²⁴ In view of this debate, it would be interesting to investigate whether strategic substitutionality could be an explanation for other dimensions of firm heterogeneity, not just for the decision to go lean.

Appendix: Proofs

To spare the reader awkward back-and-forth scrolling between the appendix and the main body of the article, we restate the system of differential equations here.

$$O'_c(t) = \alpha_c[D^{Shock} - S(t)] \text{ and } O'_l(t) = \alpha_l[D^{Shock} - S(t)] \quad (\text{A.1})$$

and

$$S(t) = O_c(t) + O_l(t). \quad (\text{A.2})$$

In the proof of Proposition 1, we make use of an important result in the theory of linear differential equations:

Lemma 1 *Given initial conditions for the values $y_1(0)$ and $y_2(0)$, the solution to the system of differential equations*

$$y'_1(t) = a_1[y_1(t) + y_2(t)] \text{ and } y'_2(t) = a_2[y_1(t) + y_2(t)] \quad (\text{A.3})$$

*is unique.*²⁵

The result is contained in the “Fundamental Theorem of the Theory of Linear Equations with Constant Coefficients”. The proof can be found in Arnol’d (1992), p. 164.

Proposition 1 *The functions*

$$O_c(t) = \alpha_c D^{Shock} + c_1(\alpha_c e^{-t} + \alpha_l) + c_2 \alpha_c (e^{-t} - 1) \quad (\text{A.4})$$

and

$$O_l(t) = \alpha_l D^{Shock} + c_1 \alpha_l (e^{-t} - 1) + c_2 (\alpha_l e^{-t} + \alpha_c), \quad (\text{A.5})$$

with $c_1, c_2 \in \mathbb{R}$ being parameters, are the unique solutions to the equations given in (1) and (2).

²⁴The factors identified in both papers could be loosely associated with industry-based and resource-based views on management practices (see Footnote 4 above).

²⁵Uniqueness in this lemma does not mean “unique up to parameter values”. It really means that there is just one function $y_1(t)$ and one function $y_2(t)$, with specific parameter values, solving the system.

Proof. We will first show that the function given in the proposition really solve our system of differential equations. To that end, we will show that the functions (A.4) and (A.5) turn the first equation in (A.1) into a true statement. The solution can be verified for the second equation in (A.1) in the same way.

For the left-hand side of the first expression in (A.1), we take the derivative of (A.4) with respect to t . This yields

$$O'_c(t) = -\alpha_c(c_1 + c_2)e^{-t} \quad (\text{A.6})$$

For the right-hand side of the first expression in (A.1), we obtain $S(t)$ from equation (A.2) by adding the equations (A.4) and (A.5). In this way, we get

$$S(t) = O_c(t) + O_l(t) = D^{Shock} + (c_1 + c_2)e^{-t}. \quad (\text{A.7})$$

From (A.7) directly follows

$$\alpha_c[D^{Shock} - S(t)] = -\alpha_c(c_1 + c_2)e^{-t}. \quad (\text{A.8})$$

The right-hand sides of (A.6) and (A.8) are the same, concluding the proof of sufficiency. For proving uniqueness of the solution, we will prove the more general result that, given the starting conditions, the system admits only one solution. Concretely, we will prove the following: let $\hat{O}_c(t)$ and $\hat{O}_l(t)$ be functions that solve the system of differential equations given by (A.1) and (A.2), and let $\bar{O}_c(t)$ and $\bar{O}_l(t)$ also be functions that solve the system of differential equations given by (A.1) and (A.2), then $\hat{O}_c(t) = \bar{O}_c(t)$ and $\hat{O}_l(t) = \bar{O}_l(t)$ for all t . To show this, define two new functions:

$$U_1(t) := \hat{O}_c(t) - \bar{O}_c(t) \text{ and } U_2(t) := \hat{O}_l(t) - \bar{O}_l(t). \quad (\text{A.9})$$

Taking the derivatives of the functions in (A.9) yields $U'_1(t) = \hat{O}'_c(t) - \bar{O}'_c(t)$ and $U'_2(t) = \hat{O}'_l(t) - \bar{O}'_l(t)$, and, using (A.1) and (A.2), these derivatives are equal to

$$U'_1(t) = -\alpha_c[(\hat{O}_c(t) - \bar{O}_c(t)) + (\hat{O}_l(t) - \bar{O}_l(t))] \quad (\text{A.10})$$

and

$$U'_2(t) = -\alpha_l[(\hat{O}_c(t) - \bar{O}_c(t)) + (\hat{O}_l(t) - \bar{O}_l(t))]. \quad (\text{A.11})$$

Using (A.9) again, (A.10) and (A.11) can be written as

$$U'_1(t) = -\alpha_c[U_1(t) + U_2(t)] \text{ and } U'_2(t) = -\alpha_l[U_1(t) + U_2(t)]. \quad (\text{A.12})$$

(A.12) is itself a system of differential equations, which, by Lemma 1, has a unique solution. The unique solution to the system is given by

$$U_1(t) = (\alpha_c e^{-t} + \alpha_l)U_1(0) + \alpha_c(e^{-t} - 1)U_2(0) \quad (\text{A.13})$$

and

$$U_2(t) = \alpha_l(e^{-t} - 1)U_1(0) + (\alpha_l e^{-t} + \alpha_c)U_2(0). \quad (\text{A.14})$$

The fact that (A.13) and (A.14) are solutions for the system (A.12) can be quickly verified. Taking the derivatives of (A.13) and (A.14) with respect to t yields

$$-\alpha_c e^{-t}(U_1(0) + U_2(0)) \text{ and } -\alpha_l e^{-t}(U_1(0) + U_2(0)). \quad (\text{A.15})$$

These we can plug in on the left-hand sides of the equations in (A.12). For the right-hand sides of (A.12), we add up the equations (A.13) and (A.14). This yields $e^{-t}(U_1(0) + U_2(0))$. Multiplying this term by $-\alpha_c$ and $-\alpha_l$, respectively, also yields the expressions in (A.15). Therefore, the left-hand and right-hand sides of the equations in (A.12) are equal if the functions $U_1(t)$ and $U_2(t)$ are those stated in (A.13) and (A.14).

By assumption, we have $\hat{O}_c(0) = \hat{O}_l(0) = \bar{O}_c(0) = \bar{O}_l(0) = D/2$. Therefore, from (A.9) follows $U_1(0) = 0$ and $U_2(0) = 0$. Because the unique solutions for $U_1(t)$ and $U_2(t)$ are given by (A.13) and (A.14), it follows that $U_1(t) = 0$ and $U_2(t) = 0$ for all t . This implies, by the definition of $U_1(t)$ and $U_2(t)$, that $\hat{O}_c(t) = \bar{O}_c(t)$ for all t and $\hat{O}_l(t) = \bar{O}_l(t)$ for all t , which means that the function $\hat{O}_c(t)$ is the same as the function $\bar{O}_c(t)$ and the function $\hat{O}_l(t)$ is the same as the function $\bar{O}_l(t)$. $\square$

For proving Proposition 2, we need the following lemma:

Lemma 2 *For the parameters c_1 and c_2 of the solution of the system holds $c_1 + c_2 \leq 0$.*

Proof. From (A.4) and (A.5) follows that the outputs of the firms at $t = 0$ are

$$O_c(0) = \alpha_c D^{Shock} + c_1 \text{ and } O_l(0) = \alpha_l D^{Shock} + c_2. \quad (\text{A.16})$$

By assumption,

$$\lim_{t \rightarrow \infty} O_c(t) + \lim_{t \rightarrow \infty} O_l(t) \geq O_c(0) + O_l(0). \quad (\text{A.17})$$

Because of Equation (7), the left hand-side of (A.17) is equal to D^{Shock} . On the right-hand side of (A.17), we can plug in the expressions given for $O_c(0)$

and $O_l(0)$ in (A.16) to obtain $D^{Shock} + c_1 + c_2$. Thus, (A.17) turns into $D^{Shock} \geq D^{Shock} + c_1 + c_2$, and subtracting D^{Shock} on both sides yields the result. $\square$

Proposition 2 *If the firms choose different strategies and a shock occurs, the equilibrium output is higher for the conventional firm than for the lean firm, i.e.,*

$$O_c(t) > O_l(t). \quad (A.18)$$

Proof. Using equations (5) and (6) from Corollary 1, the statement to be proved can be written as

$$\alpha_c D^{Shock} + c_1 \alpha_l - c_2 \alpha_c > \alpha_l D^{Shock} - c_1 \alpha_l + c_2 \alpha_c.$$

On the left-hand side, we add c_1 and deduct c_1 , and on the right-hand side we add c_2 and deduct c_2 . This leads to:

$$\alpha_c D^{Shock} + c_1 - c_1 + c_1 \alpha_l - c_2 \alpha_c > \alpha_l D^{Shock} + c_2 - c_2 - c_1 \alpha_l + c_2 \alpha_c. \quad (A.19)$$

Considering (A.16), we note that $O_c(0)$ and $O_l(0)$ are included in the left and right hand sides of (A.19) so that the expression turns into:

$$O_c(0) - c_1 + c_1 \alpha_l - c_2 \alpha_c > O_l(0) - c_2 - c_1 \alpha_l + c_2 \alpha_c.$$

Because of $O_c(0) = O_l(0)$, we can remove these terms from both sides of the inequality. After rearrangement, this yields

$$c_2 - c_1 + 2(c_1 \alpha_l - c_2 \alpha_c) > 0 \Leftrightarrow \underbrace{(\alpha_l - \alpha_c)}_{<0} \underbrace{(c_1 + c_2)}_{\leq 0} > 0. \quad (A.20)$$

On the right-hand side of (A.20), the first factor is negative because of $\alpha_l < \alpha_c$, and the second factor is non-positive because Lemma 2 states that $c_1 + c_2 \leq 0$. Therefore, the inequality is fulfilled, and as we applied only equivalent transformations, this verifies inequality (A.18). $\square$

Proposition 3 *The equilibria of the game of Figure 1 are determined by the value of p in the following way:*

1. *The asymmetric outcomes of the game are the only equilibria if and only if p fulfills the following inequalities:*

$$\frac{\delta}{(1/2) \cdot D^{Shock} - O_l(t) + \delta} \Big|_{t \rightarrow \infty} > p > \frac{\delta}{O_c(t) - (1/2) \cdot D^{Shock} + 2\delta} \Big|_{t \rightarrow \infty} \quad (A.21)$$

		Firm 2	
		Lean	Conventional
Firm 1	Lean	a, a	c, b
	Conventional	b, c	d, d

Figure 4: The general form of the game in Figure 1.

2. *There is always a probability p that fulfills both inequalities (A.21). This implies that there exists no p that violates both inequalities in (A.21).*
3. *If p does not fulfill the left inequality of (A.21), there will be a symmetric equilibrium where both firms are conventional. If p does not fulfill the right inequality of (A.21), there will be a symmetric equilibrium where both firms are lean.*

Proof. We start with the first statement of the proposition. The matrix in Figure 1 has the form as the matrix shown in Figure 4. The equilibria of the game represented by Figure 4 are asymmetric if $b > a$ and $c > d$. Substituting the expressions of Figure 1, $b > a$ is

$$p \cdot O_c(t) + (1 - p) \cdot (1/2) \cdot D \underset{t \rightarrow \infty}{>} p \cdot [(1/2) \cdot D^{Shock} - \delta] + (1 - p) \cdot [(1/2) \cdot D + \delta]$$

and $c > d$ is

$$p \cdot O_l(t) + (1 - p) \cdot [(1/2) \cdot D + \delta] \underset{t \rightarrow \infty}{>} p \cdot (1/2) \cdot D^{Shock} + (1 - p) \cdot (1/2) \cdot D.$$

Applying equivalent manipulations to the second inequality yields

$$\delta > p \cdot (1/2) \cdot D^{Shock} - p \cdot O_l(t) + p\delta \underset{t \rightarrow \infty}{} \quad (\text{A.22})$$

We divide both the right-hand and the left-hand sides by

$$(1/2) \cdot D^{Shock} - O_l(t) + \delta. \quad (A.23)$$

$t \rightarrow \infty$

From Proposition 2 and Equation (7) follows $(1/2) \cdot D^{Shock} > O_l(t)_{t \rightarrow \infty}$. Therefore, expression (A.23) is unambiguously and strictly positive, and inequality (A.22) turns into

$$\frac{\delta}{(1/2) \cdot D^{Shock} - O_l(t) + \delta} > p,$$

$t \rightarrow \infty$

which is the first inequality in (A.21). The second inequality in (A.21) can be verified in the same way by transforming the inequality that corresponds to $b > a$. As all transformations were equivalent, the proposition is stated as *if and only if*.

The second statement is true iff

$$\frac{\delta}{(1/2) \cdot D^{Shock} - O_l(t) + \delta} > \frac{\delta}{O_c(t) + 2\delta - (1/2) \cdot D^{Shock}}. \quad (A.24)$$

$t \rightarrow \infty$ $t \rightarrow \infty$

Applying straightforward equivalent transformations to (A.24) and using Equation (7) leads to $2\delta > \delta$, which is true whenever $\delta > 0$.

The third statement follows from the fact that a situation where a value p fulfills the left but not the right inequality in (A.21) corresponds to the situation $d \geq c$ and $b > a$ in Figure 4. With those payoffs, it is an equilibrium if both firms are conventional. Likewise, if the right inequality in (A.21) is fulfilled and the left inequality is not fulfilled, this corresponds to the situation $a \geq b$ and $c > d$ in Figure 4, when it is an equilibrium if both firms are lean. □

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