MIXUPS IN THE WAREHOUSE: CENTRALIZED AND DECENTRALIZED MULTI-PLANT FIRMS

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Single-plant firms choose quantity/quality levels to maximize profits. Multi-plant firms face this decision and must also choose how many decision makers to have. This article presents two case studies and a model of a multi-plant firm in which overhead costs are lower with one decision maker (centralization), but the mass of information and the need for timely decisions make occasional mixups unavoidable. Multiple decision makers (decentralization) solves the mixup problem. Standardization—treating different outlets similarly in response to costly mixups—appears in the case studies, and is demonstrated as a result in the model. (*JEL* D21, L23)

I. INTRODUCTION

All firms receive information and use it to make decisions. Multi-plant firms receive information at scattered locations and must choose how this knowledge will flow and how decisions will be made. The firm might have a single decision maker, which I call centralization, or it might allow each location to make decisions based on any information available to them, a situation I call decentralization.

This article considers issues affecting the choice between one and several decision makers, first through a simple model of a multi-plant firm and then through two case studies that illustrate many of the model's conclusions. The model assumes, and the case studies show, that a single decision maker often has trouble handling all information available from widely scattered locations. Mixups (shipping the wrong bundle to an outlet) are an unavoidable consequence of having a single "boss."[1] When the firm has more than one decision maker, mixups are avoided, but overhead costs are larger. One of the model's key results, which is confirmed by the case studies, is that the centralized firm often "standardizes" as a way to simplify the problem it faces. That is, it ships similar (and less-than-optimal) bundles to all outlets, even though resizing or reforming bundles could increase the profitability of any one outlet.

There is a large literature in which delay (and its minimization) is the driving force behind organizational form. Radner (1993), Van Zandt and Radner (1995), and Van Zandt (1999) analyze the time required to process a batch of information under different organizational structures. Bolton and Dewatripont (1994) extend Radner (1993) by explicitly including both processing and communication delay, and differentiating between the two types. The firm minimizes delay when agents specialize in processing particular types of information. Specialization also occurs in the model of Geanakoplos and Milgrom (1991), in which the firm may dictate which bits of information managers attend to. The firm's problem then is to coordinate the different bits of information its managers hold. Communication delay is at issue in Marschak and Reichelstein (1998), who relate organizational structure to the size

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1. *Centralization* will be used interchangeably with "single decision maker" throughout this paper. *Decentralization* indicates that every plant is empowered to make decisions for itself.

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of communication costs and message complexity. The issue of time to transmit information is also considered in Govindarajan (1986), who notes that communication delay in a rapidly changing environment or in a firm where coordination is crucial may favor centralization. A key assumption of these models is that no worker below the top of the hierarchy is empowered to act without direction from above.

A second function of organizational form is to prevent the firm from undertaking substandard projects. Sah and Stiglitz (1986; 1991) show that when overall project quality is low, hierarchy is preferred, as it is more profitable when individual managers hold potential projects to high standards. This work was extended by Koh (1992), who showed that the firm minimizes its costs if managers undertaking the first review of a project reject it when they work in a hierarchy and accept it when they work in a polyarchy. Thus, managers working in a hierarchy should have a higher standard for acceptance than those working a polyarchy. Sah (1991) describes managerial ability as also affecting the choice of organizational form, since a single manager's influence is larger in a centralized organization than under decentralization. When the manager is not able, centralization may lead to markedly lower profits than a decentralized firm would achieve.

Discovery and implementation of optimal policies may also be affected by the organization's structure. A single location may search for the optimal policy to be implemented everywhere (centralization), or all units may search and may or may not adopt policies selected by others (decentralization). Better policies are discovered when the organization employs multiple searchers, and/or when the single searcher becomes more sophisticated. Kollman, Miller, and Page (2000) demonstrate that for moderately difficult problems, multiple searchers (decentralization) improves the organizational outcome more than a more sophisticated headquarters, but very easy or very difficult problems are better solved by improving headquarters' sophistication. As in Aoki (1986), decentralization is preferred for problems of moderate difficulty because response time is faster and miscoordination is unlikely; centralization is preferred when (1) local conditions change little (centralization is less expensive) or (2) local conditions are extremely variable (decentralized units may settle on suboptimal policies).

Organizational form also affects the firm's rate of innovation through knowledge spillovers between outlets. Chang and Harrington, Jr. (1998; 2000) show that a firm should centralize when knowledge spillovers between outlets outweigh the benefits of procedures tailored to each local market. When innovation opportunities are rich, the firm should free outlets to search for innovations on their own (i.e., decentralize), but if innovations are complex, the firm is more profitable when headquarters searches for innovations to be implemented by all outlets.

In contrast to the articles in which delay drives the choice of organizational form, and those in which undertaking quality projects is the firm's objective, this article allows for both centralized and decentralized decision making.[2] The first group of articles does not consider decentralized decisions, while the second does not allow for centralized decisions. Additionally, standardization is a result in this model, not an assumption as in the optimal policy and rate of innovation literatures.[3] In the model presented below, the centralized firm does not require all outlets to be identical. I show that as a result of errors, it is optimal for headquarters to treat outlets similarly, although not identically.

This article considers the effect of mixups on total production. I show that the "error-free" centralized firm produces more and enjoys higher profits than the decentralized firm. Because the cost of errors depends in part on differences in markets, the more similar the markets in which the firm operates, the more likely it is that the firm is centralized. I also show that as mistakes become less likely, the centralized firm becomes more profitable. This suggests that improvements in inventory tracking and handling technology should lead firms to centralize decision making.[4]

2. The model of Van Zandt (1998) allows for decentralized decision making, which leads to more timely actions. Here, decentralized decision making avoids costly mistakes.

3. In fact, the model presented below shows that complete standardization (treating all outlets equally), as happens in both the optimal policy and rate of innovation papers listed above, is *never* an optimal strategy.

4. In a related article, Baiman, Larcker, and Rajan (1995) present a model in which centralization is a

A model of a firm choosing whether to have a single decision maker or to decentralize decision making is presented in section II. Following that, two case studies are discussed and I show how the predictions of the model parallel developments within each firm. Conclusions and suggestions for further research appear in the final section.

II. THE MODEL

The model describes a firm in which production/warehousing decisions can be made at a single location for the entire firm, with bundles packed and shipped to various outlets (centralized) or they can be made by each outlet for itself (decentralized). Intermediate forms, in which decision making is split among several levels are not considered.[5] I model the firm as a team rather than a collection of self-interested players. This allows me to abstract from strategic behavior by outlets.[6]

The firm is assumed to have some activity, which I will call "sales," that cannot be centralized. If production decisions are made at a single location for the entire firm, information overload causes the decision maker to occasionally ship a location's optimal bundle incorrectly.[7] These mixups do not occur when each outlet makes its own production decisions, so that a decentralized firm does not make mistakes. On the other hand, the centralized firm obtains economies of scale not available to the decentralized firm. This tradeoff between lower overhead costs and inevitable mixups with centralization motivates the firm's choice to have one or many decision makers.

The firm has n outlets, each of which earns revenue $R_i(q)$ (an increasing and strictly concave function). We may think of q as quantity of a single good, in which case outlets are assumed to be operating in different sized markets. The model's main results continue to hold if q is taken to represent other characteristics such as color mix, size, or special features. The key assumption is that for each location there is some optimal bundle, based on characteristics of its revenue function. Total revenue for the firm is given by $\sum_j R_j(q_i)$, where q_i may vary across outlets. When the firm is centralized, outlet j receives some bundle q_i that is optimal for one of the firm's n locations. When $i = j$, the central warehouse has shipped correctly; when $i \neq j$, the central warehouse has made a mistake, which occurs with probability ε.[8]

It is most convenient to think of n as a large number so that some outlets may receive their own optimal bundle while others do not. In this case, ε represents the probability that an outlet receives the wrong bundle and smaller ε implies fewer mistakes. It is also possible, however, that n could be as small as two, if we think of ε as the likelihood that the central warehouse ships bundles randomly rather than ensuring that the correct shipment goes to each outlet. We would then interpret ε as the likelihood of random shipment by the warehouse.

In order to generate economies of scale, I assume increasing concave costs, which implies that the cost of producing at each location separately exceeds the cost of producing the same quantity at a single location: $\sum_i c(q_i) > c(\sum_i q_i)$. Concave cost may represent actual increasing returns to scale, or the elimination of duplicated services that centralized warehousing/production makes possible.

function of the costliness of potential errors made by business units. They show that as errors are more costly, the firm's headquarters delegates fewer tasks to the unit, so that the firm becomes more centralized as the costliness of errors rises. Here, headquarters makes the errors, so that more likely (costly) mistakes favor decentralization.

5. The problem that arises is in defining "centralization." If a two-layer hierarchy is possible, we may see a centralized group of centralized regions (complete centralization), a decentralized group of centralized regions (regional centralization), or a decentralized group of decentralized regions (complete decentralization). The analysis of such a system involves extensive algebra, but generates no additional insights. It can be shown that regional centralization mirrors general centralization.

6. Strategic behavior within teams has been extensively studied. I ignore it in order to highlight other issues pertinent to the centralization-decentralization choice.

7. Every outlet receives some bundle in the model.

8. It is important to emphasize that every outlet receives an "optimal" bundle. In the decentralized firm, each outlet receives its own optimal bundle for sure. In the centralized firm, each outlet receives its own optimal bundle with probability $1 - \varepsilon$.

The centralized firm's profits are given by:

$$(1) \qquad \Pi_c = (1-\varepsilon)\sum_i R_i(q_{ic}) + \varepsilon \sum_i \overline{R}(q_{ic}) - c(Q)$$

where $\overline{R}(q_{ic}) = (1/n)\sum_j R_j(q_{ic})$ and $Q = \sum_i q_{ic}$. When a bundle is misshipped (probability ε), I assume that it is sent to any of the outlets with equal probability.[9]

Because the firm's cost function is concave its profit function might be convex, so that a finite profit-maximizing set of bundles may not exist. In order to guarantee existence of a finite solution, the revenue function must be more concave than the cost function. Standard second-order conditions for profit maximization (which are assumed to hold here) support this conclusion.

The decentralized firm's profit function is

$$(2) \qquad \Pi_d = \sum_i [R_i(q_{id}) - c(q_{id})]$$

The firm no longer obtains economies of scale, but mixups are never made.

It is possible that $\max_q n\overline{R}(q) - c(nq) \geq \max_{\{q_i\}} \sum_i [R_i(q_i) - c(q_i)]$. This implies that even when a centralized firm ships the same bundle to every outlet, it earns more profit than the decentralized firm. Proposition 2 below shows that completely random shipping ($\varepsilon = 1$) causes the centralized firm to send the same bundle to all outlets. Thus, if the inequality listed above holds, the centralized firm that makes only errors will be more profitable than the decentralized firm, so that the firm will always choose to centralize. The more interesting case occurs when this inequality is reversed, which will be assumed. In effect, by assuming that decentralization is preferred to "random" centralization, I am assuming that the benefit to accuracy in assignment eventually outweighs available economies of scale.

In selecting bundles for each outlet, the firm has the option to ship the same bundle to all outlets, regardless of their differences. When this occurs, I say that the firm is completely standardized. Under complete standardization, the warehouse ships the bundle q_s to every outlet, regardless of the signal it receives. In that case, profits are given by

$$(3) \qquad \Pi_s = \sum_i R_i(q_s) - c(nq_s)$$

Notice that q_s does not depend on ε, since the bundle sent to outlet i is the same whether the firm is shipping correctly (probability $1-\varepsilon$), or making a mistake (probability ε).[10] Also, as long as outlets have different revenue functions, $q_i \neq q_s$ for all i. Although the completely standardized firm would profit from reassignment of goods between outlets, the problem of misassignment is eliminated. Finally, q_s will generally not be the average quantity ($\sum q_i/n$), since the profit function is concave.

To review, our firm operates in n markets and chooses to have either a single decision maker (*centralization*). One option for the centralized firm is to ship the same bundle to all outlets, regardless of differences between them. I call this *complete standardization*. Not surprisingly, complete standardization is never an optimal strategy, although *partial standardization* (shipping similar but not identical bundles) turns out to be an optimal response to increasingly likely mixups.

The first result compares total quantity and profits for the error-free centralized firm to total quantity and profits for the decentralized firm. Errors can be eliminated in two ways, by perfect shipping or when all outlets are the same (since then a single bundle is optimal for everyone).

PROPOSITION 1. *When all outlets have the same revenue function* ($R_i(q) = R_j(q)\,\forall\, i, j$), *or when errors never occur* ($\varepsilon = 0$) *the centralized firm produces more for each outlet* ($q^*_{ic} \geq q^*_{id}\,\forall\, i$) *and enjoys larger profits than the decentralized firm* ($\Pi_c \geq \Pi_d$).

For a proof of Proposition 1 and all subsequent results, see the appendix. The first premise suggests that since similarity between outlets makes centralization preferable, firms with outlets in identical markets are more

9. Note that shipping the correct quantity is included as a potential error. While it is possible to avoid this by considering the probability that a bundle is misshipped as $\varepsilon/(n-1)$, the notation is greatly complicated for no benefit. Using this alternative notation, an error occurs with probability $(n-1)\varepsilon/n$.

10. If we use a different mistake structure, this conclusion may not hold. For example, if outlet i sometimes receives nothing, the standardized bundle may be affected by ε.

likely to be centralized than those with outlets in widely disparate locations. The second premise ($\varepsilon = 0$) suggests that firms with smaller numbers of misshipments are more likely to be centralized. That is, as communication and warehousing technology improvements reduce the likelihood of misshipment, we expect to see firms investing in this improved technology and centralizing their warehousing.

Centralized profits are larger than decentralized when the centralized firm does not make mistakes. By assumption, centralized profits fall to below the decentralized level when the centralized firm makes only mistakes. Continuity of the profit function allows us to appeal to the intermediate value theorem and conclude that there is some likelihood of mixups (ε) for which the firm is indifferent between centralization and decentralization.

How does total centralized quantity change with ε? Proposition 1 tells us that when $\varepsilon = 0$, the centralized firm produces more than the decentralized firm. If we can show that total centralized quantity rises as mistakes become more likely, we can prove that the centralized firm always produces more. Unfortunately, $dQ_c/d\varepsilon$ cannot be signed in general,[11] although if we assume that the revenue function is given by $R_i(q) = \lambda_i R(q)$, we can show that the centralized firm produces more as mistakes become more likely ($dQ_c/d\varepsilon \geq 0$) (see the appendix for details). Since the centralized firm produces more than the decentralized firm when mistakes never occur (result 1), we can conclude that in this special case the firm is larger under centralization (i.e., always produces more). One can think of λ_i as an indicator of intensity of demand, so that larger λ_i implies both higher total and marginal demand. Another interpretation of λ_i is an indicator of market size. In this case, $R(q)$ gives the revenue per customer, and each market has λ_i customers. Larger markets receive larger quantities.

We have yet to see when and if the centralized firm will wish to standardize. Theorem 4 shows that the centralized firm will never completely standardize, as profits improve when the firm exploits information from the outlets, even though doing so occasionally leads to mistakes. We first provide two intermediate results, used to prove theorem 4.

PROPOSITION 2. *When the centralized firm always makes mistakes, its profit equals that of the standardized firm. That is,* $\Pi_c|_{\varepsilon=1} = \Pi_s$.

Mathematically, Proposition 2 is a risk-aversion result. With variable bundle size, as errors become more common, the likelihood of receiving a completely inappropriate bundle rises. This is costly to the firm and causes it to make all of the bundles slightly inappropriate, rather than suffer the lost revenues form completely inappropriate bundles. The intuition behind this result is as follows: if q_i and q_j are different-sized bundles, each of which goes to outlet k with equal likelihood, and q_i earns the firm more revenue than q_j when shipments are random, then the firm will be more profitable shipping two bundles q_i (that is completely standardizing).

Thus, when the centralized firm cannot eliminate mistakes, it ships quantity q_s to every outlet. Notice that this quantity may *not* be the arithmetical average of optimal quantities.[12] Depending on the curvature of the revenue function, the standardized quantity may be greater or less than the average of optimal quantities. The firm may find it profitable to ship slightly more than average in order to provide close to adequate supplies for large markets, or it may ship slightly less than average in order to avoid storage costs in small markets.

To compare standardized and centralized profits when ε is less than one, we must first show that as the likelihood of error rises, profits of the centralized firm fall.

LEMMA 3. *Centralized profits fall as the probability of misshipment rises. That is,* $d\Pi_c/d\varepsilon \leq 0$.

Centralized profits strictly decrease as mistakes become more likely when the firm has at least one outlet different from the others. In that case, we can replace the weak inequality of Lemma 3 with a strict one.

We are now ready to compare the centralized and standardized firms. As noted above, if the centralized firm ever correctly uses information it receives from the outlets, it

11. Simple calculation shows that $dQ_c/d\varepsilon$ agrees in sign with $\sum([R_i'^* - \bar{R}'^*])/[(1-\varepsilon)R_i''^* + \varepsilon\bar{R}''^*]$, where $R_i'^* = R_i'(q_{ic}^*)$ and similarly for the other variables, which cannot be definitely signed.

12. That is, $nq_s \neq \sum_i q_{ic}^*$.

is better off to account for that information, even though doing so increases the costliness of making a mistake.

THEOREM 4. *When the centralized firm ships correctly with any positive probability, its profits are higher than those of the standardized firm. That is,* $\Pi_c|_{\varepsilon<1} \geq \Pi_s$.

As with Lemma 3, if at least one of the outlets is different from the others, we may replace the weak inequality of Theorem 4 with a strict one.

Thus far, we have compared the various profit functions, and the effect on total quantity as the likelihood of misshipment (ε) varied. What is the effect of more probable misshipments on any single outlet's quantity? Does a rise in the likelihood of error cause a given outlet's optimal bundle to rise or fall?

The change in any one outlet's optimal bundle (q^*_{ic}) caused by a rise in the likelihood of error (ε) can be broken down into two parts; that due to the *redistribution of a given total quantity*, and that due to a *change in the total quantity* produced. The first part (known as the redistribution effect) can be explained by noting that as mistakes become more likely, the centralized firm ships large outlets' bundles to small outlets (and vice versa) more often. This suggests that it would be profitable to ship slightly larger bundles to the small outlets, and slightly smaller bundles to the large outlets as ε rises (*partial standardization*).

The second part of the change in an individual outlet's bundle (the total quantity effect) comes indirectly through the change in total quantity caused by more frequent mixups ($dQ_c/d\varepsilon$). A larger (or smaller) total quantity affects the firm's cost structure [$c(Q)$ and $c'(Q)$], which in turn influences the bundle shipped to any one outlet. Since costs are concave, marginal cost for each outlet falls as the firm's total output rises. This suggests that all outlets (big and small) should receive larger bundles as mixups become more common.

Theorem 5 formalizes the intuition of the redistribution effect, showing that for a given total quantity, as mixups become more likely, the firm will reallocate this amount between outlets, so that small outlets receive slightly more and large outlets receive slightly less. More frequent mistakes lead to partial standardization. While the centralized firm should exploit any possibility of shipping correctly, it will look more like a standardized firm as its ability to do so falls.

Notice that standardization of the centralized firm is a result, not an assumption. Although standardization is never "optimal," in that the centralized firm would like to differentiate between outlets, the centralized firm begins to standardize in response to increasing likelihood of shipping incorrectly.

THEOREM 5. *If the firm is facing a distribution issue only, there is a quantity* $\tilde{q}$ *such that optimal centralized quantity rises with* ε *for outlets receiving less than* $\tilde{q}$ *and falls with* ε *for outlets receiving more than* $\tilde{q}$*. That is, when* $dQ/d\varepsilon = 0$*, there exists* $\tilde{q} \in [q^*_{ic,\min}, q^*_{ic,\max}]$ *such that* $dq^*_{ic}/d\varepsilon > (<)\, 0 \Leftrightarrow q^*_{ic} < (>)\, \tilde{q}$.

It would be nice to have a stronger version of Theorem 5, namely that standardization arises endogenously even when total quantity is allowed to vary with ε. The conflict between the total quantity effect and the redistribution effect make this result unobtainable, even in the special case considered above [$R_i(q) = \lambda_i R(q)$]. If the firm has several small outlets whose optimal quantities rise as the probability of error rises, the firm's total quantity may also rise. But this lowers marginal cost, so that even the largest outlets may receive more as ε rises. Similarly, when the firm's total quantity (Q_c) falls as mixups become more probable, the firm's marginal cost is higher, so that even small outlets may receive less as ε rises.

Although the model takes q to represent quantity of a single good, its results continue to hold if we reinterpret q to represent the number of different products carried by each outlet. According to this reasoning, a firm is standardized when each of its outlets sells the same mix of products. A non-standardized firm would allow for at least some local variation, so that an outlet in Seattle carried umbrellas along with other goods, while the Palm Springs outlet carried suntan lotion in its mix of products. Under this interpretation, "producing more" involves carrying a wider array of products.

In the next section, I present two case studies that suggest that this model accurately describes a firm choosing between one and many decision makers. For both firms, mixups occurred under centralization, although economies of scale were achieved. Benetton has been able to centralize both ordering and production since advanced warehouse technology has minimized mixups (Lemma 3). Both firms have standardized (Benetton in its product offering and production technique, and Sears Roebuck & Co. (Sears) in the way its stores are set up) partly in response to errors caused by centralization (Theorem 5).

III. CASES

Benetton

The Italian clothing company Benetton illustrates the model's result that the centralized firm finds it profitable to partially standardize. Benetton has centralized sales and ordering information from all of its stores worldwide, which has led it to standardize product lines and production techniques.

As a retailer, Benetton has over 4,000 outlets throughout the world, which must be geographically dispersed so that Benetton can be close to its customers. For the activities in which it has a choice (ordering and production), Benetton has chosen a highly centralized form. All of its outlets are linked via computer to company headquarters in Ponzano, Italy,[13] where sales data from each outlet can be used to create large production orders for factories. This means that outlets have very little freedom in selecting the source or style of merchandise they carry. On the other hand, Benetton's production, ordering, and shipping costs are much lower, since larger batches imply economies of scale as orders from a given region are grouped together, made together, and shipped together.

Centralizing sales information creates a very large information glut, however, and requires Benetton headquarters to handle large amounts of data. Not only does Benetton have to follow sales at over 4,000 outlets, it also has to keep track of several different styles for each outlet. This is expensive, and makes it more likely that the firm will make mistakes in ordering and shipping. While warehouse technology has reduced this likelihood of error, misshipments are still of concern to Benetton managers. To reduce the costliness of potential errors, Benetton has chosen to reduce the number of styles it sells (i.e., standardize its product line).[14] Fewer styles lowers the information burden on the centralized ordering/sales computer, so that errors are less frequent and less costly. Standardization also means outlets can sell the "mistakes" they receive, since orders cannot be too different when only a few styles exist.

In addition to reducing information processing time and expense, and cutting the costliness of errors, standardizing the product line allows Benetton to have large production runs. If each outlet were allowed to offer its own styles of clothing, Benetton would be forced to order (and/or produce) items in much smaller batches. By requiring that all outlets carry the same basic styles, and by reducing the number of styles it offers, Benetton is able to achieve economies of scale in production.

The Benetton case is the clearest example of a centralized firm choosing to standardize its product line due to "information overload" mistakes. Standardization has enabled Benetton to maintain centralized production and decision making, even as sales are decentralized. The firm obtains economies of scale while minimizing the costliness of errors. This centralization-standardization combination, predicted by the model, has enabled Benetton to maintain profitability in a highly competitive industry.

Sears

Sears has been through several centralizations and decentralizations since Richard Sears founded the company in 1886.[15] During its early years, Sears could be completely centralized because it had only one warehouse and no retail outlets. This changed in 1906, when Sears opened a warehouse in Dallas, Texas. Decisions were still made at the Chicago headquarters, however.

Julius Rosenwald, who joined Sears in 1895 and ran the company from 1908 until his death in 1932, led the push to consolidate

13. Benetton's electronic data interchange network was recognized as quite advanced when it was instituted in the late 1980s (Martin, 1989).

14. In the model, q may be interpreted as the size of single-good bundles shipped to outlets. Alternatively, we may take q to represent the number of different products an outlet carries, without losing any of the model's results. It is this second interpretation that applies to the Benetton case.

15. For a short history of Sears Roebuck & Co., see Hast (1994). Sears recent history is documented in Katz (1987).

all operations into a single building. He was a believer in centralization, and opposed every plan to decentralize operations, including the plan to build the Dallas warehouse.[16]

In 1925, Sears opened its first retail outlet. The undertaking was so successful that by 1930, Sears operated 324 retail outlets. This growth continued through the 1950s, and included foreign markets (a Cuban outlet was opened in 1942, and a Mexican outlet opened in 1947). During the early part of this expansion, Sears remained a highly centralized organization, with all decisions made at company headquarters in Chicago.

Even in the early years of its retail expansion, Sears found it had trouble handling its empire as a centralized organization. For example, warm winter coats were occasionally shipped to the Miami outlet. Decentralization eliminated these mixups, since managers in Miami knew better than to order winter coats.

Under its next chairman (Robert E. Wood), Sears decentralized its operations. Shortly after Wood became company president in 1928, Sears separated into five regional territories, each of which had almost complete autonomy in merchandising decisions. Only buying remained centralized, but in practice even this was done for each region separately. While the firm lost economies of scale available under centralization, mixups were avoided since each regional manager could order the correct product for his stores. The de facto result was five separate but related companies, each of which acted independently of the others.

There are problems with decentralization, as Sears discovered. In the recession of the early 1970s, Sears found itself a bloated federation of feuding regions. Duplication of services meant greatly increased costs. Along with the energy wasted on intramural competition, this led to falling profits and flat earnings throughout the 1970s.[17] In 1978, Edward Telling took the helm and proceeded to centralize all buying and merchandising operations. Coordination between regions was now handled by headquarters.

During this recentralization, Sears began to standardize its retail outlets based on its concept of "The Store of the Future" (Katz 1987). This store was designed both to attract customers and streamline sales procedures. In effect, Sears gave up trying to fit diverse local conditions in order to create an image that was widely recognized.[18] While this new layout increased earnings slightly, they remained flat through most of the 1980s. Errors in centralization (snow blowers in Puerto Rico) remained a problem for Sears throughout this period.

In 1995, Arthur Martinez took over at Sears. Martinez has begun to decentralize Sears' buying and merchandising functions. Stores in a few locations are now allowed to select merchandise to fit local needs. The goal is to reduce the cost of mixups in shipping, and increase incentives (much as it was during the first decentralization). It is too soon to tell if this move away from centralization will be successful, although Sears is apparently moving in the opposite direction from many of its competitors.[19] As we saw in the model presented earlier, as improvements in warehouse technology make errors less likely (i.e., as ε shrinks), we expect to see firms centralizing. Sears is doing the opposite.

This case is a good illustration of the assumptions of the model presented earlier. The centralized firm is able to avoid unnecessary duplication and reduce overhead costs by sharing activities and equipment. On the other hand, it is not able to meet local conditions without occasional errors (winter coats in Miami, snowblowers in Puerto Rico). In order to reduce the costliness of these mixups, Sears has utilized both standardization and decentralization. As in the Benetton case, the model's q represents the number of products carried at an outlet.

16. Rosenwald saw this move as a concession to Texas chauvinism and did not believe the company needed additional facilities to serve the south.

17. "[By the mid 1970s] Robert Wood's vaunted corporate democracy had turned into an ungainly feudal state. The buyers, given complete freedom, operated an internal economy of their own. Terrible inefficiencies and intramural rivalries resulted" (Hast [1994], 182).

18. This points to another reason for standardization—the creation of a well-known image. Fast food chains are standardized for this reason—customers are more likely to come to a store whose quality is known than a place in which quality cannot be easily assessed.

19. "By decentralizing . . . Sears is rowing against the retailing tide. To cut costs, more big retailers centralize buying, or are moving in that direction, than do not" (Dobrzynski [1996]).

IV. CONCLUSIONS

The model presented in this paper considers a multi-plant firm choosing between having one or having many decision makers. The firm obtains economies of scale when it is centralized (one "boss"), but makes mistakes with positive probability. I have shown that when the firm does not make mistakes, it should choose to be centralized. I have assumed that when the firm makes only mistakes, it should decentralize. These two facts imply that there is some level of error that makes the firm indifferent between having one boss and having many.

When the firm is allocating a given total quantity, it will minimize the costliness of its mistakes by partially standardizing the amount received at each outlet. While complete standardization is never strictly preferred to differentiating between outlets, when the centralized firm ships randomly, it can do no better than if it is completely standardized. Additionally, I have shown that it is optimal for the centralized firm to partially standardize as the likelihood of error rises. In this model, standardization is a result, not an assumption.

This model may be used to describe several cases, two of which are included here. Perhaps the best of these is Benetton, which has maintained centralized ordering, warehousing, and production while standardizing its product line. It is also a good description of Sears, which has centralized, decentralized, recentralized, and re-decentralized decision making regarding product lines and sales techniques.

Extensions to this model include allowing for the possibility that firms may make investments to reduce the probability of error. If this investment is costly, the firm's optimization problem then involves both selecting ε and choosing an optimal form. Such a generalization would be useful to describe the possibility that firms may invest in computers and equipment to improve communication between centralized facilities and scattered outlets.

A second extension would involve recharacterizing the cost of errors. Suppose that in addition to lower than optimal revenue from a misshipment, the firm was also required to pay a restocking cost. In this case, we expect the standardization result to be even stronger, since costly restocking increases the benefit to making outlets more similar, while the indirect effect through the change in production cost caused by rising/falling total quantity is not affected by this addition to the model. On the other hand, we are likely to lose the result proved above that the centralized firm is always at least as profitable as the standardized firm. Instead, when restocking costs are included, there may be error probabilities (ε) for which the standardized firm is more profitable than the centralized (and responsive) firm.

APPENDIX

Proof of Proposition 1.

Case 1: If all outlets are the same, both the centralized and decentralized firms are standardized. That is, $q_{ic}^* = q_{jc}^* = q_c^*$ and $q_{id}^* = q_{jd}^* = q_d^*$. Thus, we can write the firm's profit function under each of the three regimes as:

$$\Pi_c = n\overline{R}(q_c^*) - c(nq_c^*)$$
$$\Pi_d = n\left[\overline{R}(q_d^*) - c(nq_d^*)\right]$$
$$\Pi_s = n\overline{R}(q_s^*) - c(nq_s^*).$$

Notice that Π_c and Π_s are the same. To show that $q_c^* > q_d^*$, consider $\Pi_c(q_d^*)$. If $\frac{d\Pi_c}{dq_d^*} > 0$, then we know that centralized profits can be increased by setting $q_c^* > q_d^*$. First, we note that

$$\Pi_c(q_d^*) = n\overline{R}(q_d^*) - c(nq_d^*) > n\left[\overline{R}(q_d^*) - c(q_d^*)\right] = \Pi_d$$

This implies that $\Pi_c(q_c^*) > \Pi_d(q_d^*)$, since the centralized firm has the option to ship q_d^*, and chooses not to do so. Also,

$$\frac{d\Pi_c}{dq_d^*} = n\left[\overline{R}(q_d^*) - c'(nq_d^*)\right] > n\left[\overline{R}(q_d^*) - c'(q_d^*)\right] = 0,$$

so that centralized profits increase as quantities rise from q_d^*. This implies $q_c^* > q_d^*$.

Case 2: Errors never occur ($\varepsilon = 0$). Profit maximization implies that $\frac{d\Pi_d}{dq_{id}^*} = 0$ and that moving in any direction from q_{id}^* will cause Π_d to fall, or remain unchanged. Thus, if we can show that there is some movement from q_{id}^* that causes Π_c to rise, we can conclude that the centralized firm makes at least as much profit as the decentralized firm. If this movement involves increasing q_{id}^*, we can further say that $\sum q_{ic}^* > \sum q_{id}^*$. Noting that $\varepsilon = 0$, centralized profit evaluated at the optimal decentralized quantity is given by:

$$\Pi_c(q_{id}^*)|_{\varepsilon=0} = \sum_i R_i(q_{id}^*) - c\left(\sum q_{id}^*\right).$$

Thus, we see that

$$\frac{d\Pi_c(q^*_{id})|_{\varepsilon=0}}{dq^*_{id}} = R'_i(q^*_{id}) - c'\Big(\sum q^*_{id}\Big).$$

We know that $\sum q^*_{id} \ge q^*_{id}$, which means $c'(\sum q^*_{id}) \le c'(q^*_{id})$. Thus,

$$\frac{d\Pi_c(q^*_{id})|_{\varepsilon=0}}{dq^*_{id}} \ge = R'_i(q^*_{id}) - c'(q^*_{id}) = 0.$$

The centralized firm has the option of shipping decentralized quantities to each outlet, but profit rises when it ships more than this amount. Thus, centralized profits must be at least as high as decentralized profits. Q.E.D.

Signing $\frac{dQ}{d\varepsilon}$. Simple calculation shows that:

$$\frac{dQ}{d\varepsilon} > (<)\, 0 \Leftrightarrow \sum_i \left(f(\lambda_i) \left[\frac{R'_i}{R''_i} \right] \right) > (<)\, 0$$

where $R'_i = R'(q_i), R''_i = R''(q_i)$, and $f(\lambda_i) = (\lambda_i - \bar{\lambda})\ /((1-\varepsilon)\lambda_i + \varepsilon\bar{\lambda})$. Note that $\sum_i f(\lambda_i)R'_i/R''_i > [\underline{R}'/\underline{R}''] \sum_i f(\lambda_i)$, where $\underline{R}'/\underline{R}''$ is the smallest (most negative) of these ratios. Thus, if $\sum_i f(\lambda_i)$ is negative, we know that $dQ/d\varepsilon > 0$.

To see that $\sum_i f(\lambda_i) < 0$, first consider those i for which $\lambda_i < \bar{\lambda}$. We know that

$$\frac{\lambda_i - \bar{\lambda}}{(1-\varepsilon)\lambda_i + \varepsilon\bar{\lambda}} < \frac{\lambda_i - \bar{\lambda}}{\bar{\lambda}}.$$

Next, note that for those i where $\lambda_i > \bar{\lambda}$, we have

$$\frac{\lambda_i - \bar{\lambda}}{(1-\varepsilon)\lambda_i + \varepsilon\bar{\lambda}} < \frac{\lambda_i - \bar{\lambda}}{\bar{\lambda}}.$$

Thus,

$$\sum_i \left[\frac{\lambda_i - \bar{\lambda}}{(1-\varepsilon)\lambda_i - \varepsilon\bar{\lambda}} \right] < \sum_i \left[\frac{\lambda_i - \bar{\lambda}}{\bar{\lambda}} \right] = 0.$$

Thus, we know that $\sum_i f(\lambda_i)R'_i/R''_i > [\underline{R}'/\underline{R}''] \sum_i f(\lambda_i) > 0$. This proves that for this special case, $dQ/d\varepsilon > 0$.

It is also interesting to note that as outlets become increasingly different (λ_i become more spread out), $f(\lambda_i)$ becomes more negative, so that $dQ/d\varepsilon$ is larger. As an illustration, suppose that there are two types of outlets (large, with λ_H, and small with λ_L), and an equal number of each within the firm. Then,

$$\sum f(\lambda_i) = \frac{\lambda_H + \delta - \bar{\lambda}}{(1-\varepsilon)(\lambda_H + \delta) + \varepsilon\bar{\lambda}} + \frac{\lambda_L - \delta - \bar{\lambda}}{(1-\varepsilon)(\lambda_L - \delta) + \varepsilon\bar{\lambda}},$$

where δ indexes the differences between the outlets. As δ rises, $\sum f(\lambda_i)$ becomes more negative, since

$$\frac{d}{d\delta} \sum f(\lambda_i) = \frac{\bar{\lambda}}{[(1-\varepsilon)(\lambda_H + \delta) + \varepsilon\bar{\lambda}]^2} - \frac{\bar{\lambda}}{[(1-\varepsilon)(\lambda_L - \delta) + \varepsilon\bar{\lambda}]^2} < 0,$$

since $(1-\varepsilon)(\lambda_L - \delta) + \varepsilon\bar{\lambda} < (1-\varepsilon)(\lambda_H + \delta) + \varepsilon\bar{\lambda}$. Thus, the larger δ, the more different are the outlets, the more negative is $\sum f(\lambda_i)$, and the more responsive is Q_c to a change in ε.

If we posit a function $g(\gamma_i)$, where $\sum_i g(\gamma_i) > 0$, and such that $dQ/d\varepsilon$ agrees in sign with $\sum(g(\gamma_i) \times [R'(q_i)/R''(q_i)]$, we could show that total quantity produced falls as mistakes become more likely. Thus, a centralized firm may also reduce the total quantity it ships in the face of increasing errors. Q.E.D.

Proof of Proposition 2. The standardized firm's profit function is given by equation (3). When it makes only errors, the centralized firm's profit function is $\Pi_c|_{\varepsilon=1} = \sum_i \bar{R}(q^*_{ic}) - c(\sum q^*_{ic})$. The first-order condition in this case is given by

$$\frac{d\Pi_c}{dq^*_{ic}} = \bar{R}'(q^*_{ic}) - c'(Q) = 0.$$

This equation holds for all q_i, so that $q^*_{ic} = q^*_{jc} = q^*_c$. Thus, centralized profit is $\Pi_c|_{\varepsilon=1} = \sum_i \bar{R}(q^*_c) - c(\sum q^*_c) = n\bar{R}(q^*_c) - c(nq^*_c)$. If we replace q^*_c with the optimal standardized quantity (q^*_s), we can turn $\Pi_c|_{\varepsilon=1}$ into Π_s. Combine this with uniqueness of the solution to conclude that $q^*_s = q^*_c$, which leads directly to the desired result. Q.E.D.

Proof of Lemma 3. Equation (1) gives the centralized firm's profit function. If we differentiate it with respect to ε, we obtain

$$\frac{d\Pi_c}{d\varepsilon} = \sum_i \Big[\bar{R}(q_{ic}) - R_i(q_{ic}) \Big].$$

The envelope theorem allows us to ignore the second-order effect on profits that come through $dq_{ic}/d\varepsilon$.

Define

$$F_i(x) = \varepsilon\bar{R}(x) + (1-\varepsilon)R_i(x) - \frac{1}{n}c(Q)$$

and

$$\bar{F}(x) = \bar{R}(x) - \frac{1}{n}c(Q).$$

Notice that $F_i(x) - \bar{F}(x) = (1-\varepsilon)[R_i(x) - \bar{R}(x)]$, so that

$$\sum_{q^*_{ic}} \big[F_i(x) - \bar{F}(x)\big] = (1-\varepsilon) \sum_{q^*_{ic}} \big[R_i(x) - \bar{R}(x)\big] = (1-\varepsilon)\left[-\frac{d\Pi_c}{d\varepsilon} \right].$$

Thus, if we can show that $\sum[F_i(x) - \bar{F}(x)] \ge 0$, the proof is complete.

Consider $\sum \bar{F}(q^*_{ic})$. We know that there is a number $\hat{q}$ such that $\sum \bar{F}(q^*_{ic}) = \sum \bar{F}(\hat{q})$. Thus, we can write $\sum[F_i(q^*_{ic}) - \bar{F}(q^*_{ic})] = \sum[F_i(q^*_{ic}) - \bar{F}(\hat{q})]$. Since $\sum F_i(q^*_{ic})$ is maximized by the vector $\bar{q}^*_{ic}$, $\sum[F_i(q^*_{ic}) - \bar{F}(\hat{q})]$ is maximized by the same vector. Furthermore, $\sum[F_i(\hat{q}) - \bar{F}(\hat{q})] = 0$. Since the centralized firm has the option to ship $\hat{q}$ to each outlet, for $q^*_{ic} \ne \hat{q}$, $\sum[F_i(q^*_{ic}) - \bar{F}(\hat{q})] \ge 0$. But $\sum[F_i(q^*_{ic}) - \bar{F}(\hat{q})] = (1-\varepsilon)[-\frac{d\Pi_c}{d\varepsilon}]$, which proves the result. Q.E.D.

An alternative proof for Lemma 3 is as follows:[20] suppose two versions of our firm exist; the first makes mistakes with probability $\varepsilon_1 < 1$ and the second with probability $\varepsilon_2 < \varepsilon_1$. The second "firm" can, by strategically making a few additional errors, imitate the first. If this second firm ships quantity $q_{ic}(\varepsilon_1)$, it earns profits

$$\Pi_c^2 = (1-\varepsilon_2)\sum R_i(q_{ic}(\varepsilon_1)) + \varepsilon_2 \sum R_i(q_{ic}(\varepsilon_1)) - c(Q).$$

If we subtract the profits earned by "firm" one (which makes mistakes with probability ε_1), we have

$$\Pi_c^2 - \Pi_c^1 = (\varepsilon_1 - \varepsilon_2)\sum_i \left[R_i(q_{ic}(\varepsilon_1)) - \overline{R}(q_{ic}(\varepsilon_1))\right] > 0,$$

because $\varepsilon_1 - \varepsilon_2 > 0$ and $\sum_i [R_1(q_i) - \overline{R}(q_i)] > 0$ as long as some outlets i and j are different from each other. Thus, the more likely mistakes are, the less profitable is the firm. Q.E.D.

Proof of Theorem 4. From Lemma 3, we know that $\Pi_c|_{\varepsilon<1} \geq \Pi_c|_{\varepsilon=1}$. From proposition 2, we have $\Pi_c|_{\varepsilon=1} = \Pi_s$. Putting the two together proves the result.

Proof of Theorem 5. This proof proceeds in three steps. First, we show that $dq_{ic}^*/d\varepsilon$ depends on the sizes of the total marginal cost and average marginal revenue, and may be positive or negative. Next, we show that there is a quantity that sets $dq_{ic}^*/d\varepsilon = 0$. Finally, we conclude that for outlets with optimal quantities smaller (larger) than this, $dq_{ic}^*/d\varepsilon > (<)\ 0$, and that this quantity is between the smallest and largest outlets' optimal quantities.

Step 1. $dq_{ic}^*/d\varepsilon$ agrees in sign with $\overline{R}'(q_{ic}^*) - c'(Q)$. The first-order conditions for the centralized firm are given by

$$\text{(4)} \qquad \frac{d\Pi_c}{dq_{ic}} = (1-\varepsilon)R_i'(q_{ic}) + \varepsilon\overline{R}'(q_{ic}) - c'(Q) = 0.$$

These equations hold for $q_{ic} = q_{ic}^*$. Thus, we can totally differentiate (4), and rearrange to get

$$\text{(5)} \qquad \frac{dq_{ic}}{d\varepsilon} = \frac{R_i'(q_{ic}^*) - \overline{R}'(q_{ic}^*)}{(1-\varepsilon)R_i''(q_{ic}^*) + \varepsilon\overline{R}''(q_{ic}^*)}.$$

The $c''(Q)\,dQ$ term drops out of this calculation, since by assumption $dQ = 0$. The denominator is negative, so that

$$\text{(6)} \qquad \frac{dq_{ic}^*}{d\varepsilon} \text{ agrees in sign with } \overline{R}'(q_{ic}^*) - R_i'(q_{ic}^*).$$

Rearrange the firm's first-order condition (equation (4)) to get

$$R_i'(q_{ic}^*) = \frac{1}{1-\varepsilon}\left[c'(Q) - \varepsilon\overline{R}'(q_{ic}^*)\right].$$

This allows us to rewrite equation (6) as

$$\frac{dq_{ic}^*}{d\varepsilon} \text{ agrees in sign with } \overline{R}'(q_{ic}^*) - \frac{1}{1-\varepsilon}[c'(Q) - \varepsilon\overline{R}'(q_{ic}^*)].$$

Rearranging gives

$$\frac{dq_{ic}^*}{d\varepsilon} > (<)\,0 \Leftrightarrow \overline{R}'(q_{ic}^*) - c'(Q) > (<)\,0.$$

Step 2. There exists a $\tilde{q}$ such that $\overline{R}'(\tilde{q}) = c'(Q)$, and $\frac{d\tilde{q}}{d\varepsilon} = 0$. Continuity of $\overline{R}'(\cdot)$ allows us to find a number $\tilde{q}$ such that

$$\text{(7)} \qquad \overline{R}'(\tilde{q}) = (1-\varepsilon)R_i'(q_{ic}^*) + \varepsilon\overline{R}'(q_{ic}^*).$$

If $R_i'(q_{ic}^*) > \overline{R}'(q_{ic}^*)$, then $\overline{R}'(\tilde{q}) > \overline{R}'(q_{ic}^*)$, so that $\tilde{q} < q_{ic}^*$ satisfies equation (7). If $R_i'(q_{ic}^*) < \overline{R}'(q_{ic}^*)$, then equation (7) is satisfied by $\tilde{q} > q_{ic}^*$. Since $(1-\varepsilon)R_i'(q_{ic}^*)+\varepsilon\overline{R}'(q_{ic}^*) = c'(Q)$, we have $\overline{R}'(\tilde{q}) = c'(Q)$. Thus, $\frac{d\tilde{q}}{d\varepsilon} = 0$ (see step 1).

Note that the quantity $\tilde{q}$ is not necessarily the arithmetical average quantity shipped to outlets ($\bar{q} = \frac{Q}{n}$). The revenue function is concave, so that the revenue earned from the average quantity ($\sum_i R_i(\bar{q})$) must be greater than the average revenue ($\sum_i \overline{R}(q_i)$). Thus, $\tilde{q}$ satisfying $\overline{R}'(\tilde{q}) = c'(Q)$ will *not* equal $\bar{q}$ in general.

Step 3. $\tilde{q} \in [q_{ic,\min}^*, q_{ic,\max}^*]$, and for $q_{ic}^* < (>)\,\tilde{q}$, $\frac{dq_{ic}^*}{d\varepsilon} > (<)\,0$. To see that $\tilde{q} \in [q_{ic,\min}^*, q_{ic,\max}^*]$, order the q_i so that $q_1 > q_2 \cdots > q_n$. Concavity of the revenue function implies that for all i,

$$\begin{aligned}
&(1-\varepsilon)R_i'(q_{ic}^*) + \varepsilon\overline{R}'(q_{ic}^*) - c'(Q) \\
&\quad \geq (1-\varepsilon)R_i'(q_{1c}^*) + \varepsilon\overline{R}'(q_{1c}^*) - c'(Q) \\
&\quad \Leftrightarrow 0 \geq (1-\varepsilon)R_i'(q_{1c}^*) + \varepsilon\overline{R}'(q_{1c}^*) - c'(Q).
\end{aligned}$$

Sum over all i and divide by n to get $0 \geq \overline{R}'(q_{1c}^*) - c'(Q) \Rightarrow c'(Q) \geq \overline{R}'(q_{1c}^*) \Rightarrow \overline{R}'(\tilde{q}) \geq \overline{R}'(q_{1c}^*) \Rightarrow \tilde{q} \leq q_{1c}^*$.

Similarly, for all i, we know

$$\begin{aligned}
&(1-\varepsilon)R_i'(q_{ic}^*) + \varepsilon\overline{R}'(q_{ic}^*) - c'(Q) \\
&\quad \leq (1-\varepsilon)R_i'(q_{nc}^*) + \varepsilon\overline{R}'(q_{nc}^*) - c'(Q) \\
&\quad \Leftrightarrow 0 \leq (1-\varepsilon)R_i'(q_{nc}^*) + \varepsilon\overline{R}'(q_{nc}^*) - c'(Q).
\end{aligned}$$

Sum over all i and divide by n to get $0 \leq \overline{R}'(q_{nc}^*) - c'(Q) \Rightarrow c'(Q) \leq \overline{R}'(q_{nc}^*) \Rightarrow \tilde{q} \geq q_{nc}^*$.

Using steps 1 and 2, and noting that $\overline{R}''(q_{ic}^*) < 0$ implies $\overline{R}'(q_{ic}^*) > (<)\,\overline{R}'(\tilde{q}) \Leftrightarrow q_{ic}^* < (>)\,\tilde{q}$, we construct the following chain:

$$\begin{aligned}
\frac{dq_{ic}^*}{d\varepsilon} > (<)\,0 &\Leftrightarrow \overline{R}'(q_{ic}^*) > (<)\,c'(Q) \\
&\Leftrightarrow \overline{R}'(q_{ic}^*) > (<)\,\overline{R}'(\tilde{q}) \\
&\Leftrightarrow q_{ic}^* < (>)\,\tilde{q}.
\end{aligned}$$

Q.E.D.

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