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Estimate guarantee service costs using learning curve model: A watch chain store empirical study

Chin-Nung Liao
Department of Business Administration
China Institute of Technology
No. 245, Sec. 3, Academia Rd., Nankang, Taipei, 115
Taiwan , R.O.C
e-mail: *lliao@cc.chit.edu.tw*

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Abstract. *The learning curve has traditionally been used a management tool for many years. The study of learning effects is very important for the Taiwanese chain store, due to tremendous chain store growth and rapid changes in competition and business conditions, these chain stores must innovate and provide a great variety of new products and services. The provision of these new products and services often requires a period of "learning". In this paper, we develop a learning curve model to estimate product guarantee service costs taking into account the effects of product performance quality improvement and increases in guarantee service efficiency by chain store employee service skills.*
Keywords. Learning curve, Chain store, Product guarantee, Franchising, Marketing.

1 Introduction

The learning curve has traditionally been used as a management tool. It describes the empirical relationship between input and output quantities in a situation when a learning effect exists (Chan and Liao [3]). The relevance of the learning curve model to cost estimation has been well worked in most leading textbooks in management (Horngren and Foster [5]). The primary use of learning curves has been in budgeting and production cost estimation for high-volume, batch-processing manufacturing and labor-intensive, but it is also useful for service industries (Yelle [11]), for example the chain store of services. The study of learning effects is particularly important for the Taiwanese service industries operation, where recent rapid channel growth has resulted in a large number of new service enterprises.

As an important service industries model, chain stores take the form of either a regular or franchise store. A chain store extends the company franchisor not only by decreasing overhead costs, but also by achieving economies of scale (Hsu and Chen [6]). Due to tremendous chain store growth and rapid changes in competition and business conditions in Taiwan, these chain stores must innovate and provide a great variety of new products and services. The provision of these new products and services often requires a period of "learning". In recent years, the use of learning curve in managerial planning and control has received a great deal of attention (e.g., Wu et al. [12], Chan and Liao [3]; Bailey and McIntyre [2], Kemerer [7], Peles [10]). The learning curves effect has been used with success in describing the time-production relationship for many chain store operations. In the area of guarantee maintenance, some noted experience showed that there was a strong relationship between the amount of service required to perform guarantee maintenance and cumulative production because of the improvement in product performance quality as production progresses. In addition, the size of the total maintenance in hours was usually reduced by the increase in maintenance skills through service experience. The increase in maintenance skills was due to service technician's progress to improved techniques, tools, and training, as well as through repetition of specific repairs.

The product performance quality is an important factor in determining the number of service calls required. An increase in a product's performance quality requires a lesser number of service calls. In the other hand, the service technician's learning is a significant factor in determining the service costs needed for each service call. Therefore, guarantee service costs appear to be a function of both product performance quality and guarantee service learning (Chan and Liao [3]). For protection, the policies of guarantee service not only reduce the risk of consumers purchase, but also protect producers from consumers' unreasonable expectation (Wu et al [12]). Mamer [9] proposed three types of guarantee service policies: the 'ordinary free renewal' guarantee, the 'unlimited free renewal' guarantee and the 'pro-rate' guarantee. The policy of 'ordinary free renewal' guarantee is the most widely used one in practice to cover consumer durables, and therefore is adopted in the present paper. Under an ordinary free renewal guarantee policy, the produce is responsible to renew or repair the failed product during the fixed guarantee period with no additional charge to consumers. In addition, to determine the reasonable guarantee period for the product, manufacturer must evaluate its guarantee service cost.

In this paper, we develop a learning curve model to estimate the cost of providing product guarantee services. The model considers the improvement in a product's performance quality due to learning effect by chain store employee as well as by the service skills. In addition, this paper also illustrate that when the business volume is high and learning effects exist, the model provides a significantly more meaningful estimate of guarantee service costs than methods that do not account for learning effects. Next section, we developed learning curve model from product performance quality and guarantee service learning. The third section presents the application of a watch chain store in Taiwan. Finally, we provided the concluding remark.

2 Model formulation of learning curve

In the 1960s evidence began mounting that the phenomenon was broader. The Boston Consulting Group (BCG) (1970), in particular, showed that each time cumulative volume of production of a product doubled, marginal value-added cost including sales, administration, and so on fell by a constant percentage. The relationship between marginal costs and cumulative production became known as the learning curve or experience curve (Lilien et al. [8]). The simplest form of learning or experience curve is the log-linear function with an exponential form as follows:

$$C_m = C_n(\frac{m}{n})^{-b} \tag{2.1}$$

or

$$C_m = C_n(\frac{n}{m})^{b}, \tag{2.2}$$

where m is the cumulative production to date, n is the cumulative production at particular, earlier time, and $m > n$. Both C_m and C_n are marginal cost of m-th and n-th unit (in constant dollars), respectively. Denote b as the learning constant and the value of b is between zero and one.

In practice, experience curves are characterized by their learning rate. Assume that each time experience doubles, cost per unit drops to 85% of the original level. Then the 80% is known as the learning rate. The learning rate is related to the learning constant as follows:

$$r = 2^{-b} \cdot 100 \tag{2.3}$$

or

$$b = \frac{\ln 100 - \ln r}{\ln 2}, \tag{2.4}$$

where r is the learning rate (percentage), and b is the learning constant (Lilien et al. [8]).

Take a simple example of cost reduction following from equations (2.1) or (2.2), and equation (2.3) or (2.4) by Abell and Hammond [1] in Table 1 to illustrate how to use the above-mentioned concept in learning curve. Table 1 indicates how costs fall with experience for various learning rates and levels of experiences.

Following Chan and Liao [3], the model developed in this paper, is a marginal unit learning curve form which defines the cost required for a discrete

Table 1: Cost reduction following from equations (2.2) and (2.3)

Ratio of old experience (n) to new experience (m)	Learning rate (r)					
	70%	75%	80%	85%	90%	95%
1.1	5	4	3	2	1	1
1.3	11	9	7	5	4	2
1.5	19	15	12	9	6	3
1.8	25	21	16	12	8	4
2.0	30	25	20	15	10	5
2.5	38	32	26	19	13	7
3.0	43	37	30	23	15	8
4.0	51	44	36	28	19	10
6.0	60	52	44	34	24	12
8.0	66	58	49	39	27	14
16.0	76	68	59	48	34	19

Source: Abell & Hammond (1979).

unit of the product. An alternative model is a cumulative average form which defines the average cost required for a cumulative unit. Different implications of the two forms are fully discussed by Chen and Manes [4]. The proposed model assumes a homogeneous defect or a similar kind of guarantee service work for each service call. This assumption is particularly relevant when a manufacturer offers a guarantee for a key component of its product. In this case, the manufacturer usually replaces the key component of a defect item.

This work considers two separate learning effects include product quality improvement and guarantee service efficiency. Since it is likely that the two operations are subject to different measure of learning curve or experience curve, two different sets of learning parameters are needed in this model. In other words, the guarantee service cost measurement model is a multiplicative form with four model parameters such as ϵ, q, κ and c. Denote ϵ as guarantee service efficiency index, $0 < \epsilon < 1$, and q represent the product performance quality improvement index. On the other hand, κ is number of guarantee service calls expected during the guarantee period for the first batch of the product produced, and c is the guarantee service cost expected for the first service call. Therefore, the number of guarantee service calls need for the the y-th batch of the sales can be expressed by:

$$B_y = \kappa y^q, \tag{2.5}$$

where B_y is the number of guarantee service calls for yth batch, $q = \log \alpha / \log 2$, and α is the improvement rate of product quality.

Denote β is the learning rate of guarantee service technicians, and

$0 < \beta < 1$. Based on the concept of learning curve, a lager value of β refers to the mature period in product life cycle and a small value of β represents the early stage in product life cycle (Wu et al. [12]). Thus, the guarantee service cost function of the zth service call can be expressed by:

$$G_z = cz^{\epsilon}, \tag{2.6}$$

where G_z is the guarantee service cost of the zth service call, $\epsilon = \log\beta/\log 2$.

In Chan and Liao's model [3] that when product flow in a manner of first-produced-first-sold (*e.g.*, first in, first out), any inventory at the end of a period would consist of the latest units produced. Furthermore, using the logic of equation (2.2) and (2.3) that when guarantee service technicians gain experience and become more efficient, a smaller service cost applies to each service call. Thus, the cumulative total number of guarantee service calls for all individual batches up to a planning horizon of t, the N_t may be evaluated from equation (2.5) as:

$$N_t = \sum B_y = \sum_{y=1}^{X_t} \kappa y^{\log\alpha/\log 2}, \tag{2.7}$$

where N_t is the cumulative total number of guarantee service calls expected for all individual batches, and X_t is the cumulative total batches of sales up to a planning horizon of t.

By integral test of mathematics theory, if X_t is very large that a well approximation of N_t can be expressed by:

$$\begin{aligned} N_t &= \int_{0.5}^{x_t+0.5} \kappa y^{\log\alpha/\log 2} dy \\ &= \Big(\frac{\kappa}{\log\alpha/\log 2+1}\Big)[(X_t+0.5)^{\log\alpha/\log 2+1} - 0.5^{\log\alpha/\log 2+1}], \end{aligned} \tag{2.8}$$

similarly, substitute t in equation (2.8) by $t-1$ then we get

$$\begin{aligned} N_{t-1} &= \int_{0.5}^{x_{t-1}+0.5} \kappa y^{\log\alpha/\log 2} dy \\ &= \Big(\frac{\kappa}{\log\alpha/\log 2+1}\Big)[(X_{t-1}+0.5)^{\log\alpha/\log 2+1} - 0.5^{\log\alpha/\log 2+1}], \end{aligned} \tag{2.9}$$

The sequential differences between N_t and N_{t-1}, for all time t to estimate of periodic guarantee service calls.

From the cumulative total number of guarantee service calls for all individual batches up to a planning horizon of N_t, the cumulative total number of guarantee service costs (TC$-t$) can be evaluated from equation (2.6) as:

$$\mathrm{TC}_t = \sum G_z = \sum_{z=1}^{N_t} cz^{\log\beta/\log 2} dz \tag{2.10}$$

Table 2: Expect future sales

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Sales (batches)	12	15	18	22	26	30	30	32	33	35

By integral test of mathematics theory, if N_t is very large that a well approximation of can be expressed by:

$$\begin{aligned} \mathrm{TC}_t &= \int_{0.5}^{N_t+0.5} cz^{\log\beta+\log 2} dz \\ &= (\frac{c}{log\beta/\log 2+1})[(N_t+0.5)^{\log\beta/\log 2+1} - 0.5^{\log\beta/\log 2+1}], \end{aligned} \quad (2.11)$$

substituting equation (2.8) into equation (2.11) and after rearranging, then we get

$$\mathrm{TC}_t = (\frac{c}{\lambda})\{\frac{\kappa}{V}(X_t+0.5)^V - \frac{\kappa}{V}0.5^V + 0.5]^\lambda - 0.5^\lambda\}, \quad (2.12)$$

where

$$\lambda = \frac{\log\beta}{\log 2} + 1 \quad (2.13)$$

and

$$V = \frac{\log\alpha}{\log 2} + 1 \quad (2.14)$$

Similarly, substitute t in equation (2.12) by $t-1$ then we get,

$$\mathrm{TC}_{t-1} = (\frac{c}{\lambda})\{[\frac{\kappa}{V}(X_{t-1}+0.5)^V - \frac{\kappa}{V}0.5^V + 0.5]^\lambda - 0.5^\lambda\}, \quad (2.15)$$

where all variables are defined as in equations (2.12), (2.13) and (2.14).

The sequential differences between TC_t and TC_{t-1}, for all time t to estimate of periodic guarantee service costs.

3 Application

In this section, a model is developed and evaluated based on data from large and well-know watch chain store organization in the world, the 'Formosa Watch Co., Ltd.' (FWCL). This company have 113 chain stores in Taiwan, especially, the scale of watch chain store of watch industrial have not occurs in other country. Based on FWCL's past experience, that the new product quality of FWCL produces which would reduce the number of guarantee service calls per batch as volume increases. Thus, increase in guarantee service efficiency is expected to decrease the guarantee service cost per call as service technician benefit experience. According to the sales and production record in batches of the product in the last five years by FWCL and expect future sales (batches)

Table 3: Parameters calculation from the last five years record

κ	α	c	β
12	90%	36	80%

Table 4: Model data output

Period (t)	Sales (batches)	(a) X_t	(b) N_t	(c) $N_t - N_{t-1}$	(d) TC_t	(e) $TC_t - TC_{t-1}$
1	12	12	87.04	87.04	1068.35	1068.35
2	15	27	156.39	69.34	1602.84	534.50
3	18	45	224.53	68.14	2056.18	453.33
4	22	67	296.77	72.24	2490.28	434.10
5	26	93	372.87	76.11	2912.09	421.81
6	30*	123*	452.61*	79.73*	3325.13*	413.04*
7	30*	153*	526.27*	73.67*	3686.31*	361.17*
8	32*	185*	599.89*	73.62*	4031.29*	344.98*
9	33*	218*	671.63*	71.74*	4354.57*	323.28*
10	35*	253*	743.99*	72.36*	4669.58*	315.01*

(a) is the cumulative total sales (batches); (b) is the cumulative total number of guarantee service calls; (c) is the total number of guarantee service call by period; (d) is the cumulative guarantee service cost ($); (e) is the periodic guarantee service cost ($); and $*$ is the estimation value in future period.

estimate from composites of sales force opinions and expert opinion by Delphi method are as Table 2:

On the other hand, the following estimates of model parameters are given by FWCLs data base calculated from the last five years record as Table 3.

Using above parameters given, Table 4 showed the results of the FWCL's problem presenting the cumulative and the periodic guarantee service costs for each planning horizon.

This study has demonstrated that the watch sector in Taiwan emphasize the condition of both product performance quality and guarantee service learning. Table 2 shows a clear reduction of periodic guarantee service cost over the period due to combined learning curve effects. In other words, the increase in guarantee service technicians' efficiency, resulting in a net reduction of periodic guarantee service costs. For purpose of further comparisons, a simple approach that dose not take learning effects in product quality and maintenance service efficiency into consideration is also used to estimate the guarantee service costs for the FWCL's problem. With no consideration of learning effect, the guarantee service costs of the product are based upon the FWCL past data to be $ 112 per batch, the average cost of the first year's operations. The resulting guarantee service costs are then compared to those costs with consideration of learning effects.

Table 5: Comparisons of period guarantee service costs

Period (t)	With consideration of learning effects ($)	Without consideration of learning effects ($)
1	1068	1344
2	534	1680
3	453	2016
4	434	2464
5	422	2912
6	413	3360
7	361	3360
8	345	3584
9	323	3696
10	315	3920

Table 5 presents this comparison. As the cumulative production and sales increase in the latter years, guarantee service costs without consideration of learning effects are much larger than those with consideration of learning effects. The significant difference in estimated service costs is due to guarantee technicians progress in skill through service experience and product quality improvement as production increases. It is proofed that recognition of learning effects in service efficient and product quality, as they exist, can result in significantly more meaningful estimate of guarantee service costs.

4 Conclusion

Learning effects exist in product guarantee services maintenance because of product quality improvement and increase in maintenance skills through new experience. This work presents a learning effect for a watch chin store company from the perspective of the improvement rate of product quality and the learning rate of service technicians. The proposed learning curve model takes into account both product quality improvement and maintenance efficiency in estimating guarantees service costs. Therefore, when offering a new product or service is subject to learning experience, the presented method should be more significant estimates of guarantee service costs than the situation that do not consideration to learning effects.

In addition, the proposed model provides a forecast decision model for marketing managers and budget directors to implement when determine the reasonable price, and guarantee cist and length for their product. Future research should focus on applying the proposed model to a wide range of empirical data from different characteristics (i.e., product, service and size) chain store. Future extensions of this work will includes a separate in-depth empirical study on applying the proposed model to a wide range of empirical data from different products, different sizes of maintenance operations and different industries. It will also be worthwhile to look at the guarantee maintenance practices in different countries in the Asia-Pacific region (*e.g.*, China) as national economic may affect such business practices.

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