Lecture No. 9: Control and Improvement of Cost and Productivity

1. Corrected Labor Productivity
2. Total Factor Productivity
3. Learning Effect and Its Measurement

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1. Corrected Labor Productivity

Necessary for an apple-to-apple comparison

(1) Correction with respect to product mix
(2) Correction with respect to self-manufacturing rate
(3) Correction with respect to automation rate
(4) Correction with respect to capacity-operating rate

production volume = Q   input = I   production capacity = C
capacity-operating rate = u = Q/C   productivity before correction = Q/I

--- in this case, productivity after corrected capacity-operating rate is Q/I ÷ u = C/I ? excessive correction?

Engineering approach and statistical approach

Case: Comparison of American auto assembly factories operated by Japanese and American companies (IMVP by MIT, USA)

Example: Comparison of Productivity of Auto Assembly Factories

Factory	NUMMI	Framingham
Number of welding workers	400	500
Number of welding robots	170	10
Number of welding spot /unit	3850 points	2500 points
Payable working hours/day	8 hours	8 hours
Actual working hours/day	7.5 hours	7.23 hours
Production units/day	940 units per 2 shifts	736 units per 2 shifts
Number of welding/assembly workers	1660	2880
Number of welding/assembly robots	0	0
Product content (H x L x W) /table	565 cubic inches	712 cubic inches
Option assembly cost / table	$48	$104
Hourly personnel cost / head	$25/man-hour	$25/man-hour

Reference: J. Krafcik

Productivity at Auto Maker's Assembly Factory (1989)

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due to copyright restrictions

James P. Womack, Daniel T. Jones, Daniel Roos 'The Machine That Changed the World' HarperBusiness,Perennial

Quality at Auto Maker's Assembly Factory (1989) <conformity quality>

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James P. Womack, Daniel T. Jones, Daniel Roos 'The Machine That Changed the World' HarperBusiness,Perennial

Productivity of Product Development

---- basic data

自動車製品開発国際比較の基礎データ

		日本	アメリカ	欧州量産	欧州高級	平均
	企業（組織）数	8	5	5	4	22
	プロジェクト数	12	6	7	4	29
	発売時期	1981-85	1984-87	1980-87	1982-86	1980-87
開発成果	開発工数（百万時間）（平均・最大・最小）	Av. 1.2 Min. 0.4 Max. 2.0	Av. 3.5 Min. 1.0 Max. 7.0	Av. 3.4 Min. 2.4 Max. 4.5	Av. 3.4 Min. 0.7 Max. 6.5	Av. 2.5 Min. 0.4 Max. 7.0
	開発期間（月）（平均・最大・最小）	Av. 42.6 Min. 35.0 Max. 51.0	Av. 61.9 Min. 50;2 Max. 77.0	Av. 57.6 Min. 46.0 Max. 70.0	Av. 71.5 Min. 57.0 Max. 97.0	Av. 54.2 Min. 35.0 Max. 97.0
	総合商品力（TPQ）（平均・最大・最小）	Av. 58 Min. 23 Max. 100	Av. 41 Min. 14 Max. 75	Av. 41 Min. 30 Max. 55	Av. 84 Min. 70 Max. 100	Av. 55 Min. 14 Max. 100
プロジェクトの複雑さ	標準小売価格（1987米ドル）	9238	13193	12713	31981	14032
	車輌サイズ（プロジェクト数）					
	軽自動車	3	0	0	0	3
	サブコンパクト（大衆車）	4	0	3	0	7
	コンパクト（小型車）	4	1	3	1	9
	中・大型車	1	5	1	3	10
	ボディ・タイプ数	2.3	1.7	2.7	1.3	2.1
	仕向地					
	国内市場のみ	3	3	0	0	6
	先進国以外の市場に輸出	1	2	2	0	5
	先進国市場に輸出	8	1	5	4	18
プロジェクトの範囲	共通部品率	18%	38%	31%	30%	27%
	調達部品のタイプ					
	部品メーカーの標準品（A）	8%	3%	10%	3%	7%
	承認図方式の部品(B)	62%	16%	38%	41%	44%
	貸与図方式の部品(C)	30%	81%	52%	57%	49%
	部品メーカーの開発参加度（A＋B×0.7）	52%	14%	36%	31%	37%
	開発工数内製率（推定）	57%	66%	62%	63%	61%

資料：クラーク・藤本，Product Development Performance，1991.

Estimation Procedure for Corrected Development Productivity (example of statistical method)

Development of product for each project man-hour(productivity)

n＝29、(Japan 12、North America 6)
Europe mass production car 7 and European luxury car 4

↓

Level production before it totals and average → is corrected to regional

Japan 1.2 million / hours , North America 3.5 million / hours,
Europe mass production car 3.4 million / hours,
European luxury car 3.4 million / hours.

Project content data

n＝29

- Complexity of product (price)(14032 dollars on average)
- Number of body types(2.14 on average)
- New, internal design ratio (0.44 on average) and others

↓

Multiple regression analysis(project content variable and explained variable = man-hour and explaining variable = regional dummy variable)

Man-hour before corrected＝-3993 + 0.061 [Price] + 7500 [New, internal design ratio] + 729 [Number of body types]
+1421 [North America dummy] + 1211 [Europe mass production car dummy] + 1331 [European luxury car dummy]

All regression coefficients are significant in 5% level;Coefficients of determination =0.76;The man-hour is (1000 people/hours) Unit
If the dummy variable is the region, it is 1, and discrete variable in which 0 is taken otherwise.

↓

Regional average "Development productivity that has been corrected" is presumed.

"Project of an average content" is assumed. The mean value of the project content variable (above-mentioned) is substituted for the regression.

Level production of Japan(Corrected) ＝ -3993 + 0.061x14032 + 7500 x0.44 + 729 x 2.14
Level production of level production (Corrected)= Japan in North America (Corrected) + 1421
Level production of level production (Corrected)= Japan of the Europe mass production car(Corrected)+ 1211
Level production of level production (Corrected)= Japan of a European luxury car (Corrected) + 1331

The difference of the regional average presumption value of the productivity that has been corrected is just a egression coefficient of the regional dummy variable.

↓

Regional correction ending level production

Japan 1.7 million / hours , North America 3.1 million / hours,
Europe mass production car 2.9 million / hours,
European luxury car 3.1 million / hours.

Development productivity index according to project that has been corrected

The regression coefficient of a regional dummy is added to the rest error paragraph of each project in the above-mentioned regression and it presumes.

Material: Author making from Fujimoto and Clark such as diamond companies and ‘Product development power’ Fujimoto‘ The Evolution of a Manufacturing System at Toyota Oxford Unversity Press'.

Recurrence Analysis on Development Productivity

Area strategy dummy variable →

Price (complexity substitution variable) →

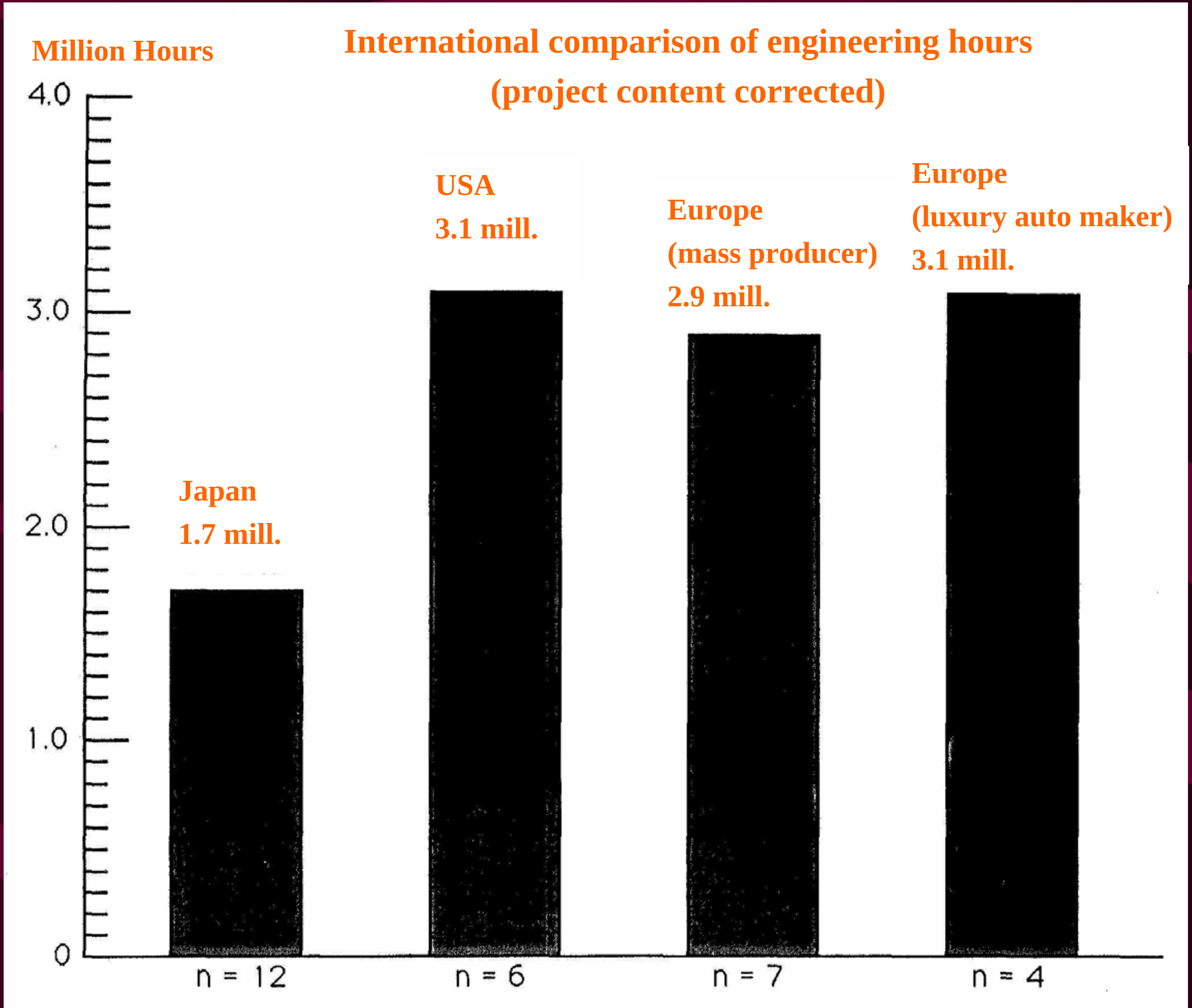
Number of body types →

Interchangeable parts, Development by parts' maker(s) →

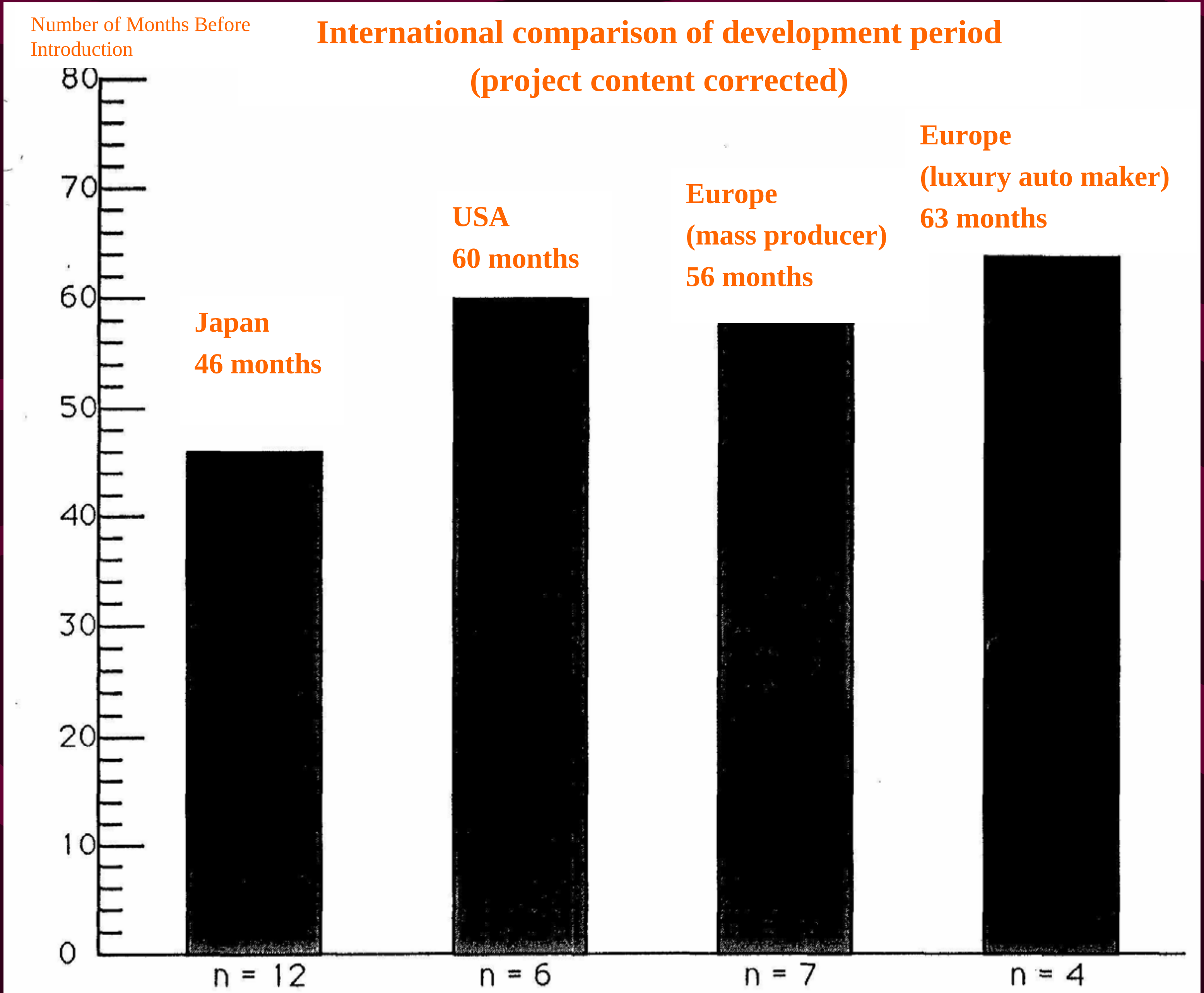
Independent Variable (独立変数) / Dependent Variable: 開発工数（1000時間）Engineering Hours (000 H) / Model	EH1	EH2	EH3	EH4	EH5	EH6
Constant	1,155	1,155	-1,329	-7,710	-7,713	-6,779
U.S. Company	2,323† (724)	2,323† (738)	1,794* (768)	1,075# (575)	1,073# (602)	1,521* (581)
European Company	2,263† (604)		1,510# (772)	801 (577)		1,302* (556)
European Volume Producer		2,252† (702)			805 (616)	
High-End Specialist		2,281* (852)			785 (1021)	
Retail Price ($000)			0.050 (0.038)	0.071* (0.028)	0.072# (0.038)	0.050# (0.028)
Number of Body Types			530# (291)	874† (222)	873† (230)	738† (229)
Innovativeness (pioneering component)			742 (680)	828 (490)	825 (526)	
Innovativeness (major body change)			912 (592)	554 (434)	558 (482)	
Unique Parts Ratio (1 - C)						
In-House Component Engineering Ratio (1 - S)						
Project Scope Index (NH)				9,656† (2,090)	9,655† (2,141)	10,103† (2,202)
Sample Size	29	29	29	29	29	29
Adjusted R-squared	0.38	0.33	0.40	0.69	0.67	0.64
Degrees of Freedom	26	25	22	21	20	23

Source: Clark, Fujimoto(1991) P385

Corrected Engineering Hours (Development Productivity)



Corrected Development Period (Development Leadtime)



2. Total Factor Productivity (TPF)

Total Factor Productivity is ---

“Ratio of tabulated input and tabulated output”

“Material total cost per 1 unit of output”

“Relationship between income and cost in material terms”

“Of output volume in certain period, a portion that cannot be explained by production function”

Rate of climb of total factor productivity means ---

“Increase in output cannot be explained by increase in input”

---- in other words, shift of production function (“technological progress”)

Formulation of Total Factor Productivity

In general, when production function is $f(L_t, K_t)$

total factor productivity in t period is $Q_t / f(L_t, K_t)$

Q_t = output in t period

L_t = labor input in t period

K_t = capital input in t period

Calculation of Climb Rate of Total Factor Productivity

(1) For each productivity factor (labor, capital, etc.), calculate a rate of climb of <u>physical factor productivity</u> (e.g., Yt / Lt)

(2) Calculate <u>distribution rate</u> at actual factor prices.
E.g., labor distribution ratio
w･Lt / (w･Lt + r･Kt)　(Passche method)
or,　w･Lt −1/ (w･Lt−1 + r･Kt−1)　(Laspeyres method)

(3) Multiply productivity climb rate and distribution rate for each factor, and add them up.
The sum is <u>climb rate of total factor productivity</u> (approximation).

---- But in actuality, measuring is difficult (calculation of capital input, especially).

Measurement of Total Factor Productivity

	Turning on and calculation of price display: The first stage	The second stage	Price Defrata: second stage /first stage	Turning on and the calculation of the second stage are made substance	Physical superiority growth rate of turning on and calculation	The material element productivity rate of increase
	A	B	C	D = B/C	E = D/A	F：Eより作成
Amount of production (Y)	p^1Y^1	p^2Y^2	p^2/p^1	p^1Y^2	Y^2/Y^1	-
Raw material (M)	q^1M^1	q^2M^2	q^2/q^1	q^1M^2	M^2/M^1	$\frac{Y^2/Y^1}{M^2/M^1}$
Manpower (L)	w^1L^1	w^2L^2	w^2/w^1	w^1L^2	L^2/L^1	$\frac{Y^2/Y^1}{L^2/L^1}$
The capital (K)	r^1K^1	r^2K^2	r^2/r^1	r^1K^2	K^2/K^1	$\frac{Y^2/Y^1}{K^2/K^1}$

Total Factor Productivity of the first stage

$$TFP^1 = \frac{p^1Y^1}{q^1M^1 + w^1L^1 + r^1K^1}$$

Total Factor Productivity of the second stage

$$TFP^2 = \frac{p^1Y^2}{q^1M^2 + w^1L^2 + r^1K^2}$$

（第１期を基準として）

The Total Factor Productivity rate of increase (Raspaires method)

$$\frac{TFP^2}{TFP^1} \fallingdotseq C^{M1}\left(\frac{Y^2/Y^1}{M^2/M^1} - 1\right) + C^{L1}\left(\frac{Y^2/Y^1}{L^2/L^1} - 1\right) + C^{K1}\left(\frac{Y^2/Y^1}{K^2/K^1} - 1\right)$$

Note

$$C^{M1} = \frac{q^1M^1}{q^1M^1 + w^1L^1 + r^1K^1}$$

$$C^{L1} = \frac{w^1L^1}{q^1M^1 + w^1L^1 + r^1K^1}$$

$$C^{K1} = \frac{r^1K^1}{q^1M^1 + w^1L^1 + r^1K^1}$$

‡

Robert H.Hayes, Steven Wheelwright, Kim B.Clark 'Dynamic Manufacturing: Creating the Learning Organization' Free Press 1988

Calculation of Climb Rate of Total Factor Productivity: Numerical Example

		first period			second period		factor productivity climb rate (second period / first period)
		cost composition	factor input	factor production	factor input	factor productivity	
input	material 1(kg))	40%	25.99	0.852	29.08	0.852	0%
	material 2 (m²)	20%	19.41	1.141	20.95	1.183	+3.68%
	energy (mill.BtU)	5%	51.30	0.432	56.19	0.441	+2.08%
	labor (thousand･hours)	25%	4.73	4.681	5.31	4.667	-0.30%
	equipment (thousand machine hours)	10%	3.22	6.876	3.60	6.876	0%
output (thousand)		–	22.14	–	24.78	–	–

total productivity factor (TFP) climb rate	0.4 x 0% + 0.20 x 3.68% + 0.05 x 2.08% + 0.25 x (-0.30%) + 0.1 x 0% = **0.77%**

reference: Hayes, Wheelwright and Clark, Dynamic Manufacturing. Pp142-148 (data changed partially) ‡

note: Weight allocation is based on Laspeyres method. For simplification, items on working capital have been omitted.

Causes Affecting Total Factor Productivity
(Studies by Hayes, Clark, and others, 1985)

Measured vast amount of monthly data of 3 companies' 12 factories in USA.

log (TFP) = b0 + b1 log (cumulative production volume)
+ b2 log (capacity operating rate) + B3 log (explanation variable X)

Result of analysis:

- loss rate, increase in material-scrap rate → negative impact on total factor productivity
- increase in in-process inventory → negative impact on total factor productivity
- new investment amount in current period
  → negative impact on total factor productivity
  (complication caused by new investment → adjustment cost)
- design change, fluctuation in production volume
  → negative impact on total factor productivity
  (Process stir factor→Adjustment cost)

3. Learning Effect and Its Measurement
(to explain increase in productivity)

Learning effect ----

in narrow sense, "achievement of skills on particular operation or process"

Learning curve (familiarizing curve)---

Direct labor man-hour (m: man-hour) per 1 product is
a decreasing function of cumulative production volume (N).

Production of an American military plane' fuselage
(Alchian, *Econometrica*, 1963)

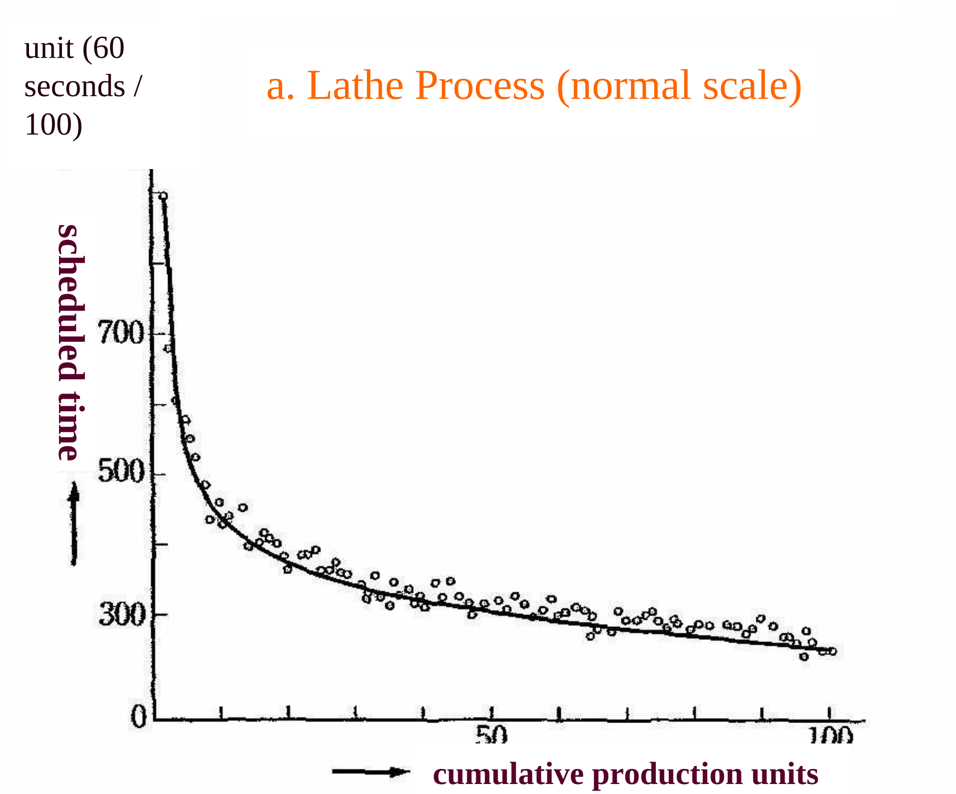
$m = a \cdot N^{b}$ i.e, an approximation in $\log m = \log a + b \log N$

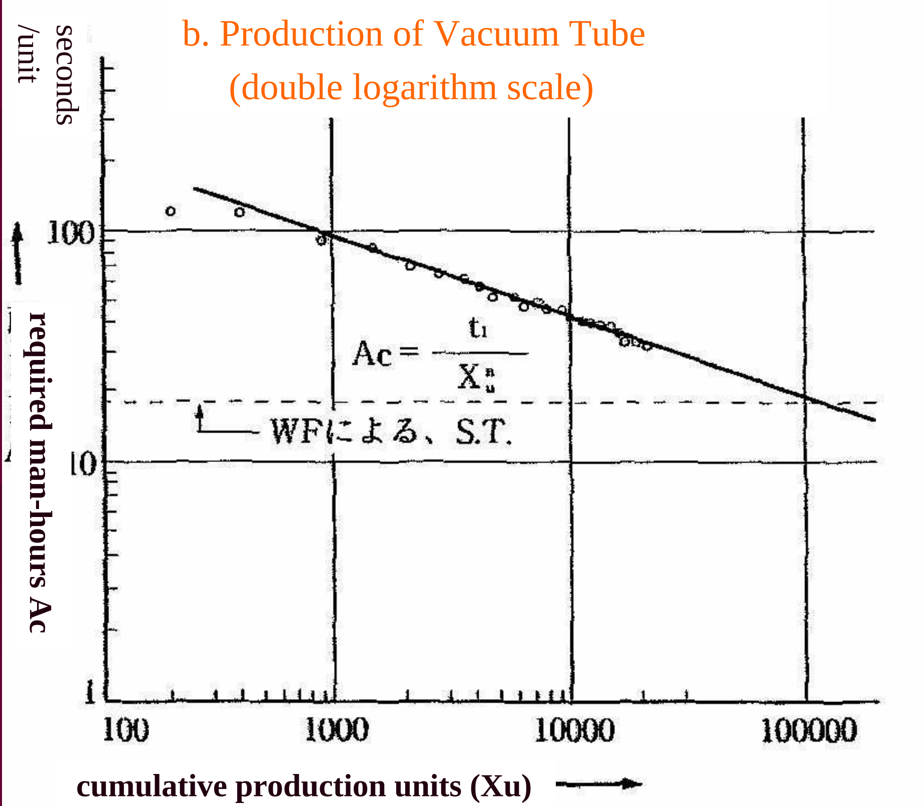
(but, $b < 0$)

on Normal Graph--

on double logarithm graph--

Diagram5.8 Example of Learning Curve





Source: Koji Shioka, "Initiation on IE", Nihon Keizai Shinbun

Approximation on the straight line

80% Curve

$$\log \mathbf{m} = \log \mathbf{a} + \mathbf{b} \log \mathbf{N} \quad \cdots$$

When cumulative production volume **N** increases at certain <u>rate</u>, direct man-hours **m** decreases at certain <u>rate</u>.

When cumulative production volume **N** increases 2 times as large, direct man-hours **m** becomes **X** %.

This is called " **X %** Curve", or typically "**80% Curve**".

Whence, $b ≒ -0.3$

$$\log \mathbf{m} = \log \mathbf{a} + \mathbf{b} \log \mathbf{N}$$

$$\log 0.8\,\mathbf{m} = \log \mathbf{a} + b \log 2\mathbf{N}$$

$$\rightarrow \log 0.8 = \mathbf{b} \log 2$$

$$\rightarrow \mathbf{b} ≒ -0.1/0.3 ≒ -0.3 \quad \text{(bottom 10)}$$

Distribution of Progress Rations Observed in Twenty-Four Field Studies

(n=126)

Curves in vicinity of 80% are in the center.

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'The History of Progress Functions as a Managerial Technology' Business History Review

Experience curve

Between cumulative production volume and real total cost per unit, a downward-sloping curve similar to a learning curve is experimentally observed.

(Boston Consulting)

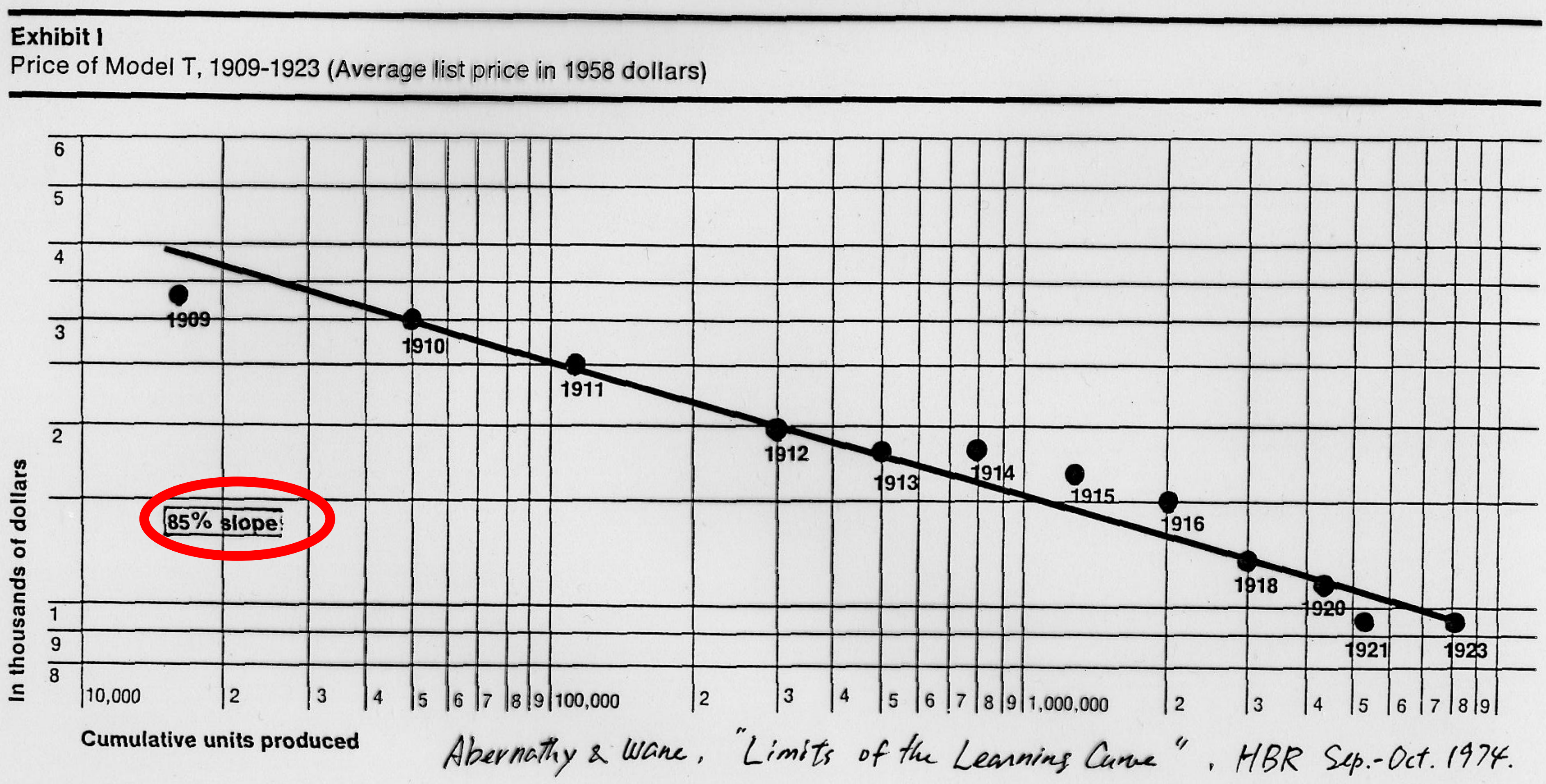
This could be included in Learning Curve in its extended meaning.

As cost data is difficult to obtain, often real average unit price is used as its substitute.

But, the premise is that a margin rate is constant.

This does not apply to Umbrella Pricing (case of gas range).

Learning Curve of Model-T Ford (1909-'23) (Approximation of Experience Curve)



Nearly a strait line on a double logarithm graph. ---- productivity dilemma

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"Abegren & Boston Consulting Group 'Portfolio Strategy' PRESIDENT Inc. 1977 (p.40 figure.9) "

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(p.32 figure.5)

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(p.32 figure.6)

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(p.41 figure.10)

Abegren & Boston Consulting Group 'Portfolio Strategy' PRESIDENT Inc. 1977

Example:
Productivity Climb Rate of Each Product Sector in Iwaya Porcelain

表 ３－３ 主要事業の比較（３）： 生産

	Relief	Besera	Tradition porcelain	Tile	Product related to chemistry
製造工場	上有田	山内第二	T窯	有田（本社） 山内第一	西有田 有田（本社） 山内第一 山内第三
生産能力	１０面／月 （200平米／月）	4000-4500個／月 （傘立て換算）	５トン／月	85000平米／月 (小口平タイル換算1100万個)	400立米／月
最近の生産実績	１０面／月	3000-3500個／月 （傘立て換算）	4.5トン／月	85000平米／月	300立米／月
窯の数	シャットル窯：１ 電気炉：３	シャットル窯：４	本窯：１ 素焼窯：１ 電気炉：４	トンネル窯：４ その他：３	トンネル窯：２ シャットル窯：２ 高温炉：２ 電気炉：２
平均的なロットサイズ	１面（一品生産）	50個	2000個	1000平米 （小口平13.5万個）	通常１０立米以下
品種数（月当り）	１０ （全て異なる）	100	300	100-150	５ （西有田のケース）
生産スループットタイム	６０日	１５－３０日	３０日	３０－９０日	９０日
生産量の季節変動	大	小	大	小	小
生産量の景気変動	小	小	大	大	大
機械台数（窯を除く）	1	5	8	150	27
有形固定資産額 （1990年、100万円）	35	61	42	600	350
生産要員数	21	28	30	180	86
製品原価構成 材料費	10%	20%	17%	32%	n.a.
製品原価構成 直接労務費	65%	45%	41%	34%	25%*
製品原価構成 減価償却費	5%	5%	0%	4%	n.a.
製品原価構成 その他経費	20%	30%	42%	30%	n.a.
歩留り（焼成工程）	99%	90%	96%	90%	94%
段取り替え時間	無し	２時間	１時間	２－４時間 **	４時間 **
仕掛品回転日数	６０日	１５日	３０日	２－１０日	７－３０日
Rate of productivity growth(1990/1980 Ratio)	50%	16%	30%	70%	30%

注： ＊＝ボールのケース
＊＊＝トンネル窯の段取り替えを除く

Debates Over Learning Curve

- Produce ahead of rivals, run down a learning fast, and win the race?

  Then, it is a simple competition for market share, like an antecessor's sure win (BCG).

  ---- but,

  Do all companies, all factories, share the same learning curve?

- Is a climb of productivity a function of cumulative production volume, or a function of hours?

  For example, when production volume is on an increase at a constant rate, it cannot be distinguished for an increase in productivity to be a function of either cumulative production volume or hours.

Experience Curve Under Constant Growth Rate

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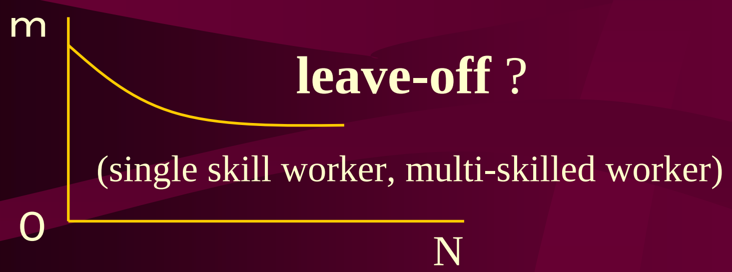
Abegren & Boston Consulting Group 'Portfolio Strategy' PRESIDENT Inc. 1977 (p.30 figure.3)

Individual Learning and Organizational Learning

- **Individual Learning** --- through <u>repetitive works</u>, skills for certain operation and an efficiency go up.
- **Organizational Learning** --- through improvements of product, process, equipment, work method, organization, etc., an efficiency goes up. <u>**Individual Learning** is one factor of this.</u>

①Individual Learning



②Organizational Learning

① Individual Learning

Momentum

- incentive system
- training, coaching
- systematized works
- trial & error

Limit

- physical limit
- poor incentive
- mental block
- walking distance, etc.
- halt experiments (satisfied with status quo)

② Organizational Learning

Momentum

- change in technology
- transfer of learning
- operational planning (specialization)
- reallocation of personnel
- inter-organizational pressure

Limit

- satisfying (even-keel)
- satisfied with status quo
- lacking critical mass
- halt knowledge acquisition

Effect of Individual Learning and Effect of Organizational Learning

Effect of Individual Learning : "Experience" by repetition of works

Incentives and training accelerate individuals' learning.

Restricted by physical and memory capability limitations, etc.

Effect of Organizational Learning :

Productivity increase by improvements of manufacturing routine.

Management's approach largely changes an effect of organizational learning.

The effect is not much restricted by limitations of individuals.
(continuous improvements possible)

Purpose of Utilizing Learning Curve: Forecast or Objective

(1) Use to forecast future man-hours and manufacturing cost
(e.g. to determine a bidding price)

but, a learning curve is not to have a practical prediction accuracy.

(2) Consider a learning curve not as given, but as something, the slope of which can be changed by way of approach.

→ Regard a learning curve as a target to achieve.

(c.f., an effect of "Self-Actualization Prediction" by 80% Curve)

Learning Curve as Forecast

Price determination of Airplane

〔第 2 表〕

生産号機数$_N$	1	2	4	8	16	32	64	102*	128	170*	256	300*	500*	512
$\log_2 N$	0	1	2	3	4	5	6	6.67	7	7.41	8	8.23	8.97	9
CA	1	0.900	0.810	0.729	0.656	0.590	0.531	0.495	0.478	0.458	0.430	0.420*	0.389*	0.387
UF	1	0.800	0.701	0.624	0.559	0.502	0.451	0.420*	0.405	0.389*	0.365	0.356	0.330	0.328

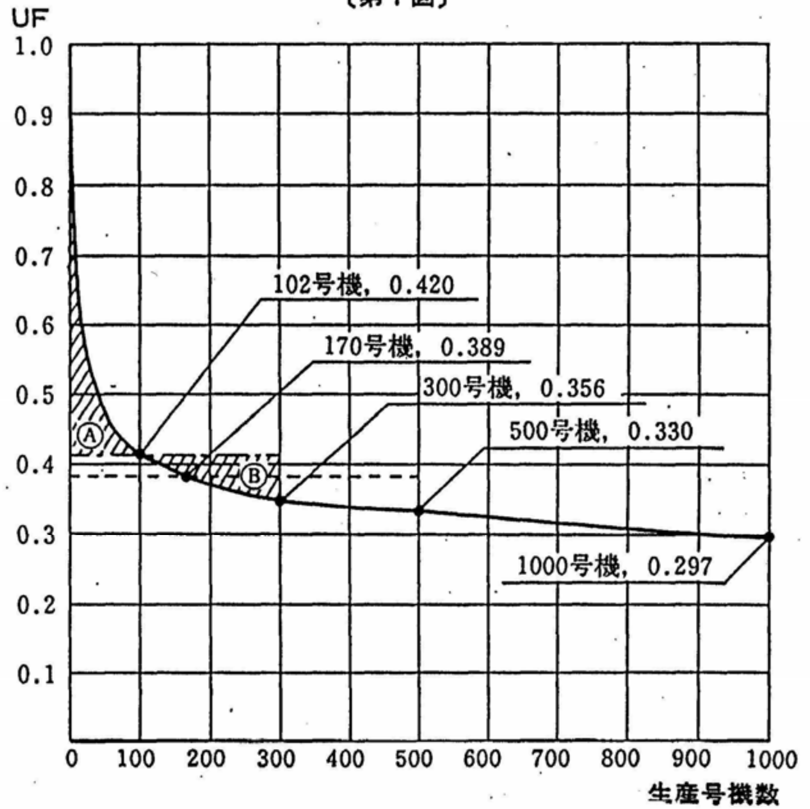
UF ：UNIT FACTOR　号機別工数

$UF_N = \{CA_N \times N\} - \{CA_{N-1} \times (N-1)\}$

米国では $UF = \left(\frac{R}{100}\right)^{\log_2 N}$ を用いる事が多いが，我国ではCA方式を用いる．

＊本文参照

〔第 1 図〕

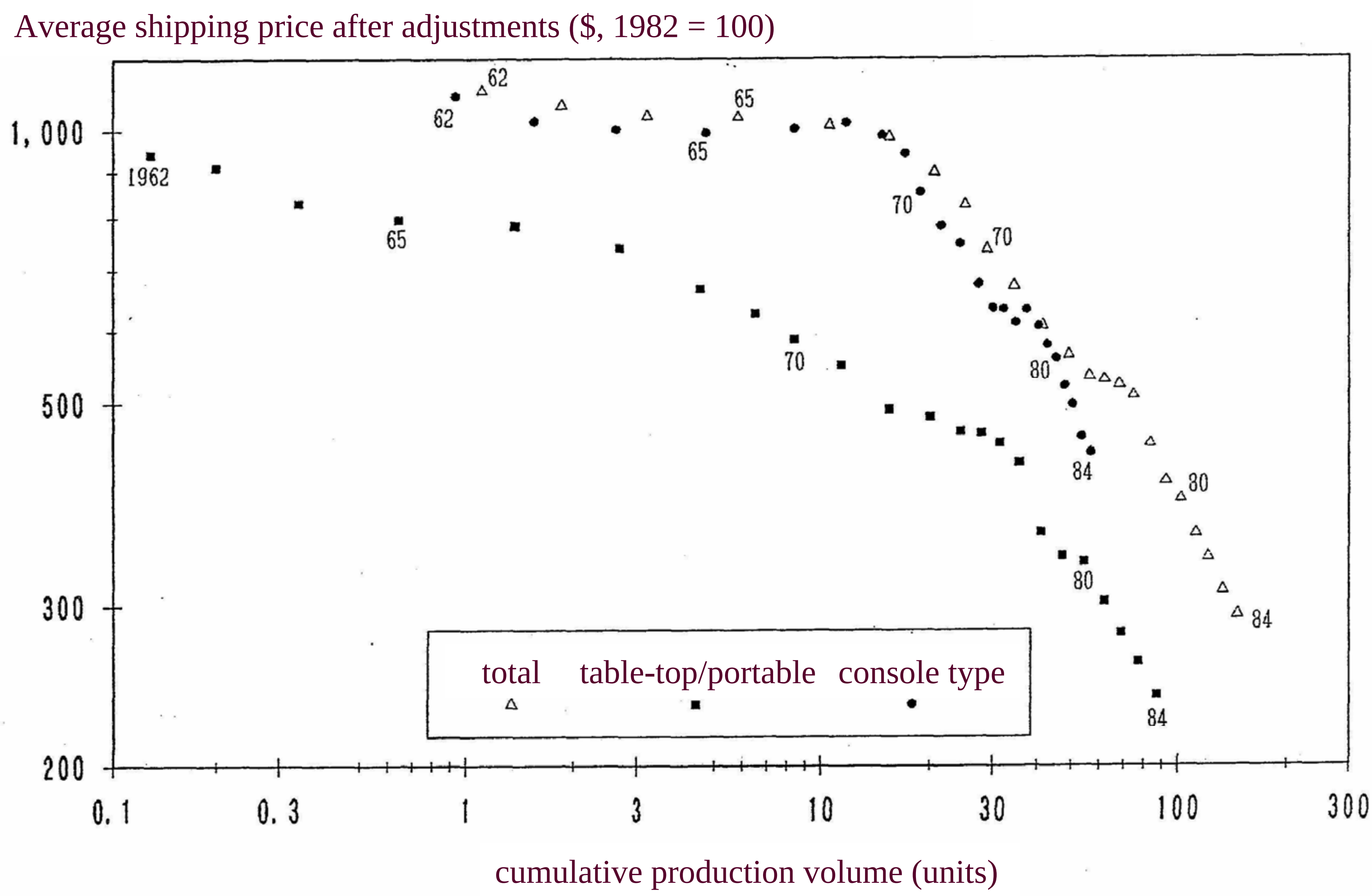


Is a learning curve different between products and processes?

Case of a plane fuselage（Alchain)

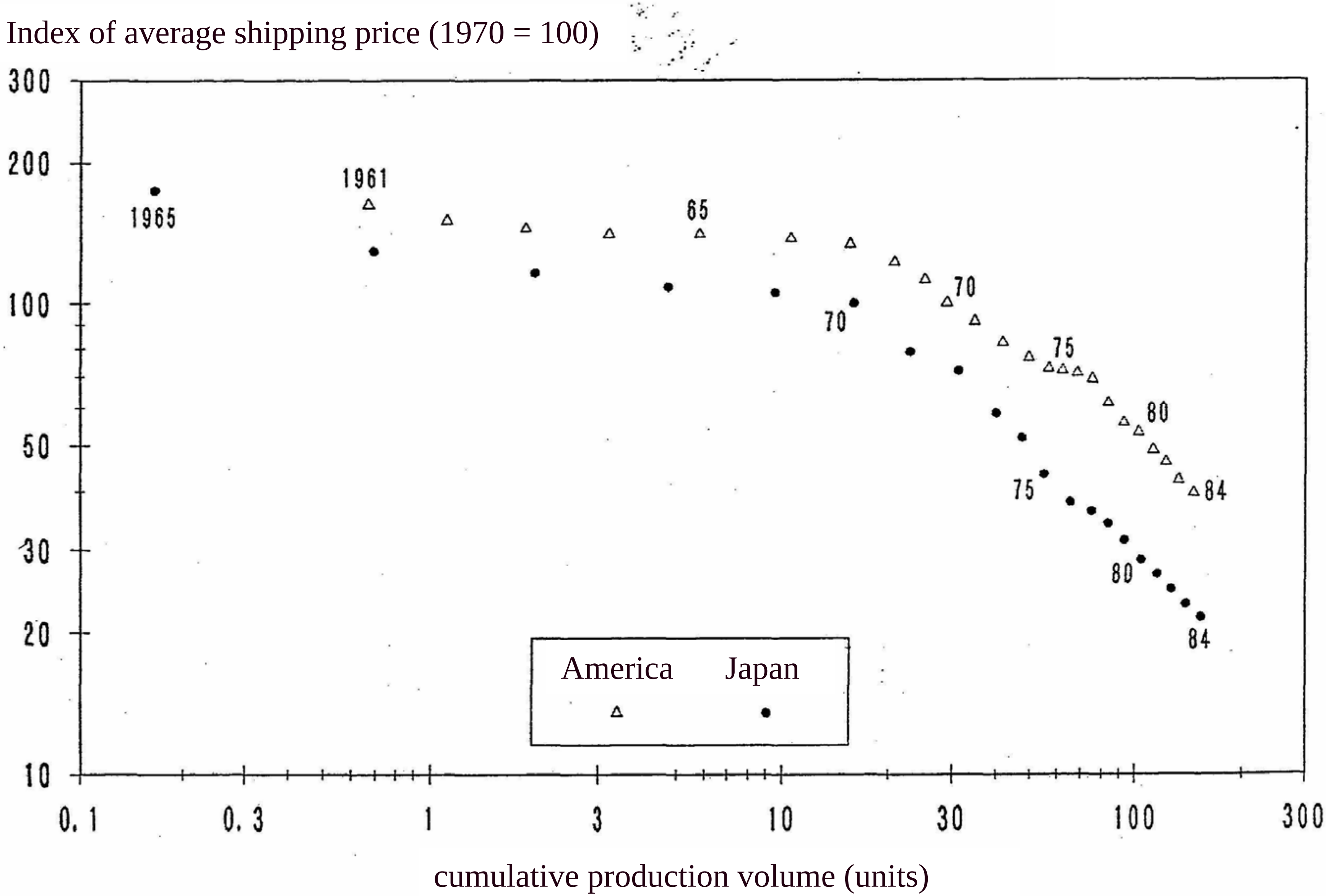
Case of a color TV (Shintaku)

America: Experience Curve of Color TV by Type



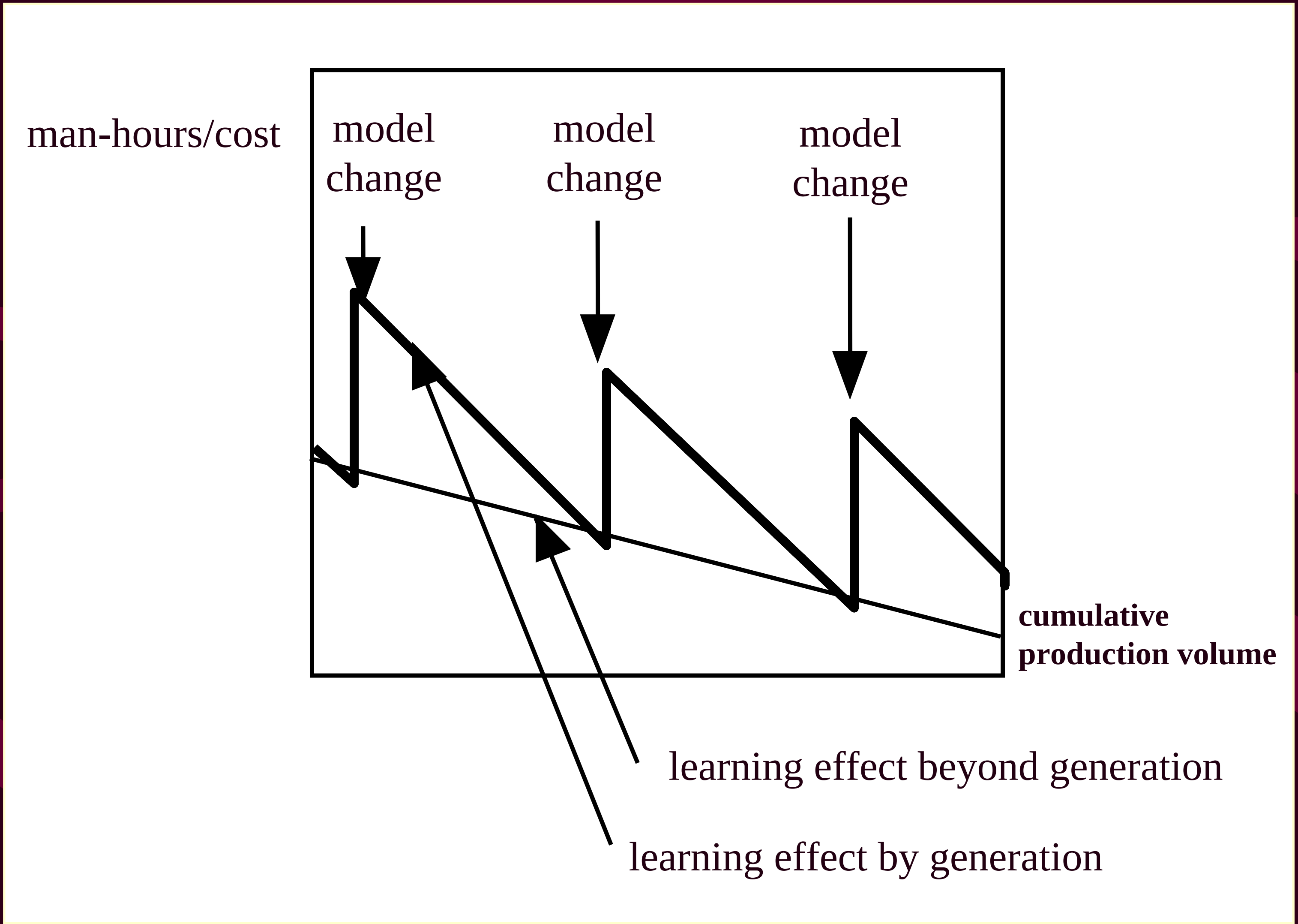
Junjiro Shintaku 'Competition and Technological Conversion' 1991

Experience Curve of Color TV



Junjiro Shintaku 'Competition and Technological Conversion' 1991

Model Change and Learning Effect



Example of Auto's Production Man-Hours (Toyama)

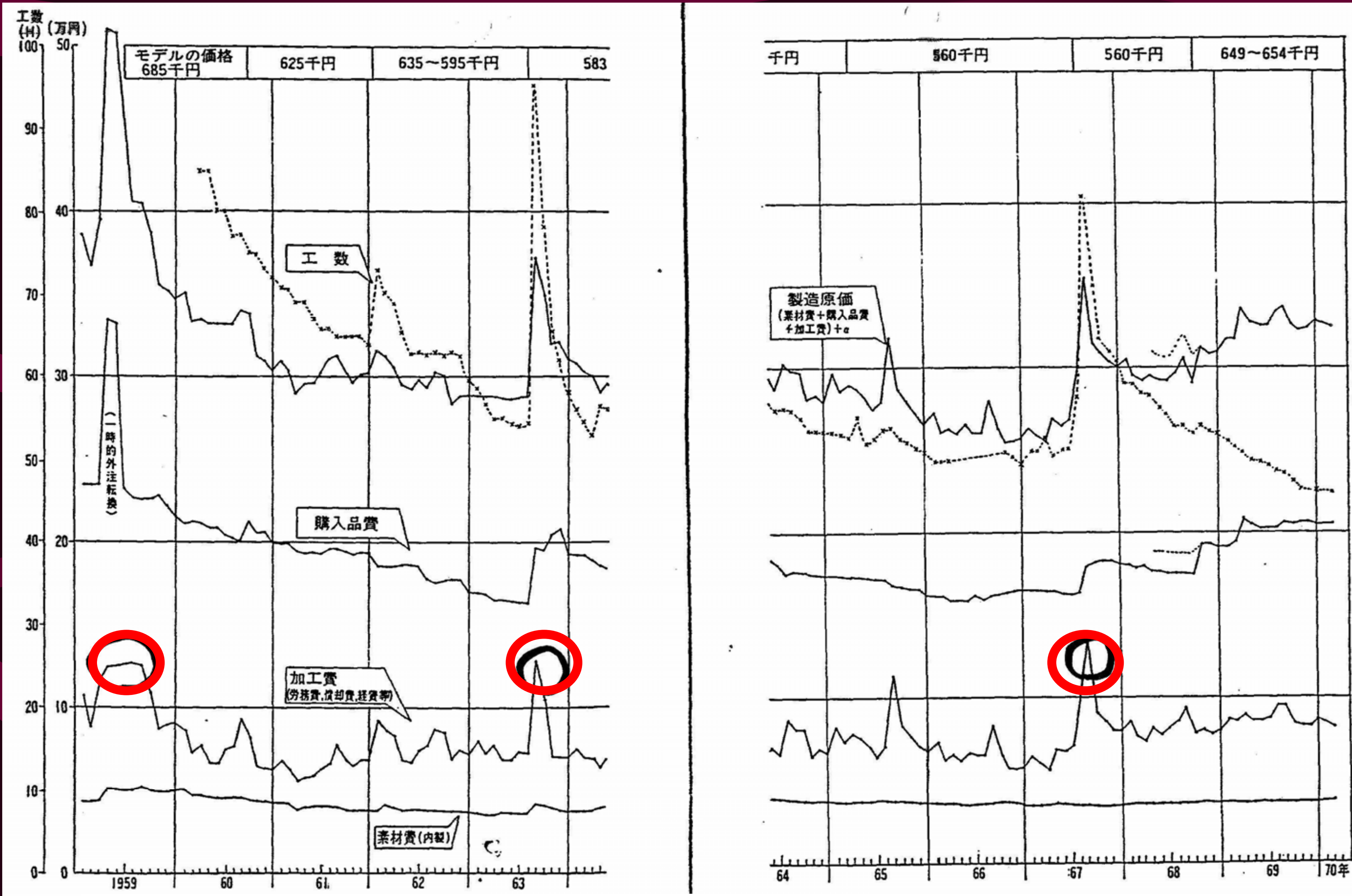


Diagram 3-8 Transition of manufacturing cost for brand A of certain firm (passenger car)

Kazuo Toyama 'Auto Sector of Japan' TOYO KEIZAI INC. (p.117 figure.3)

Does a learning effect transport between products' generations?

- When a group of products is linked to generation along the axis of time ---
  (cars, semiconductors, etc.)

  Learning effect in total may be considered as a synthesis of

  (1) learning curve of each generation

  (2) general learning curve commonly shared beyond generations.

- Or, as a result of "leaning of learning curve",

  learning speed may go up (change in b's value) over generations.

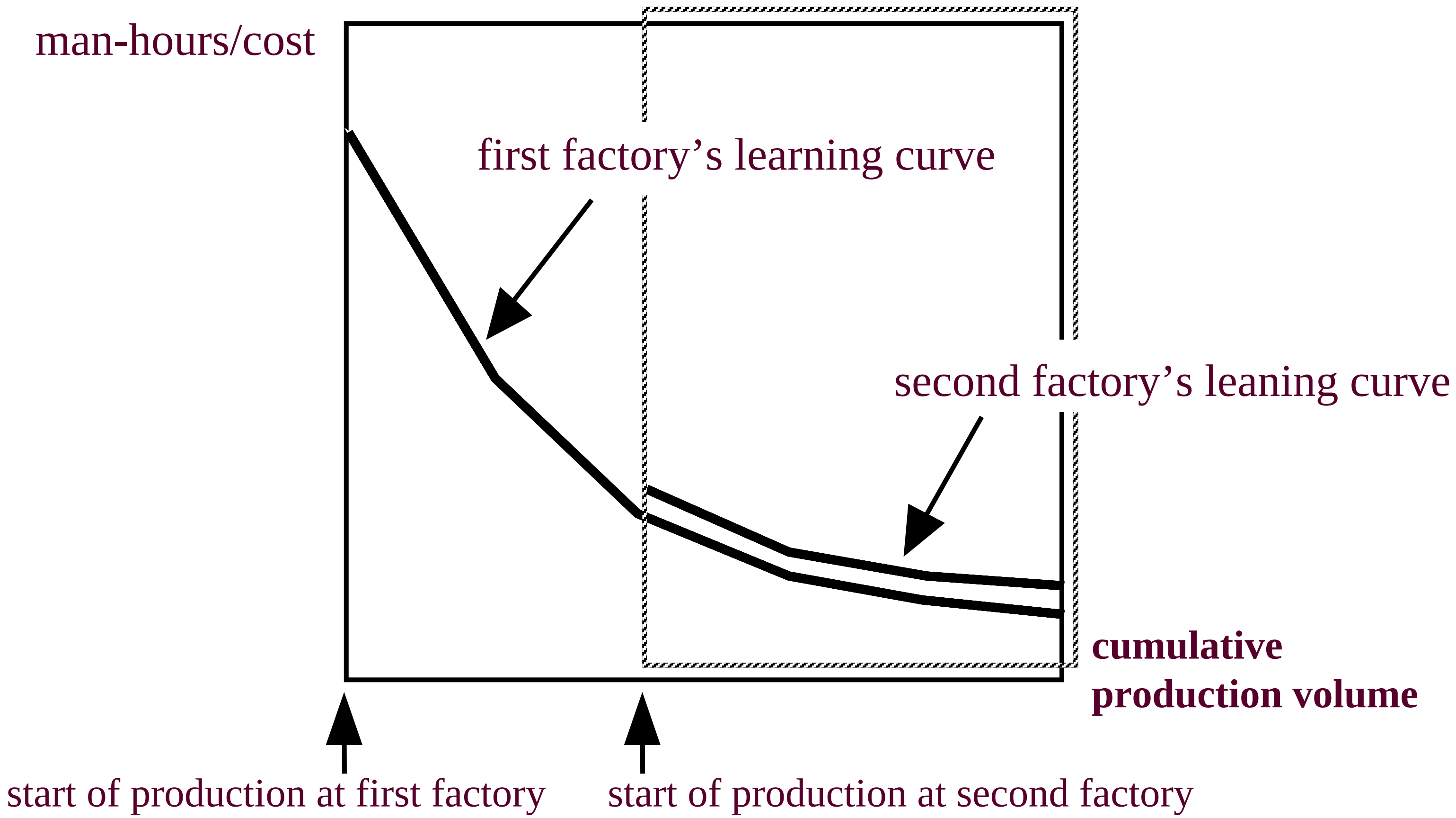
Does a learning effect transport between factories' generations ?

- Transport of learning effect from an existing factory to a new factory (shared learning?)

  If it happens, the shape of learning curves of old and new factories must be different.

(Is a new factory's curve of small intercept and gentle slope?)

Transport Possibility of Learning Effect Between Factories



Note: assuming non-logarithm graph