Peer-reviewed academic journal

Innovative Issues and Approaches in Social Sciences

IIASS – VOL. 14, NO. 1, JANUARY 2021

Innovative Issues and Approaches in Social Sciences

IIASS is a double blind peer review academic journal published 3 times yearly (January, May, September) covering different social sciences: political science, sociology, economy, public administration, law, management, communication science, psychology and education.

IIASS has started as a SIdip – Slovenian Association for Innovative Political Science journal and is being published by ERUDIO Center for Higher Education.

Typeset

This journal was typeset in 11 pt. Arial, Italic, Bold, and Bold Italic; the headlines were typeset in 14 pt. Arial, Bold

Abstracting and Indexing services

COBISS, International Political Science Abstracts, CSA Worldwide Political Science Abstracts, CSA Sociological Abstracts, PAIS International, DOAJ, Google scholar.

Publication Data:

ERUDIO Education Center

Innovative issues and approaches in social sciences, 2021, vol. 14, no. 1

ISSN 1855-0541

Additional information: www.iiass.com

THE LEARNING CURVE: AN APPLICATION IN TURKISH MANUFACTURING INDUSTRY

Gürkan Çalmaşur[1], Hüseyin Daştan[2], Zeynep Karaca[3]

The learning curves have traditionally been used for manufacturing industries. Manufacturing industry is the branch of industry in which raw materials are processed by machine or manual labor and converted into intermediate goods. The main aim of this article is to make a detailed analysis the learning curves in the Turkish manufacturing industry for 2003-2017 period. In order to satisfy this aim, the cubic learning model has been estimated and calculated the progress ratio values for 24 Turkish manufacturing industries from 2003 to 2017. As a result, between 2003 and 2017, total Turkish manufacturing industry has a convex learning curve.

Key words: Learning curve; Progress ratio, Manufacturing industry, Turkey.

DOI: http://dx.doi.org/10.12959/issn.1855-0541.IIASS-2021-no1-art6

Introduction

The manufacturing industry has a very important position in Turkey's economy because of their contribution to employment and exports. The Manufacturing industry is the sector that makes the biggest contribution to the gross domestic product. Therefore, it is important to determine the technological learning levels of the firms operating in the Turkish manufacturing industry.

When firms produce more goods or services, the cost of unit production often varies at a decreasing rate. This phenomenon refers to a learning curve or an experience curve (Argote and Epple, 1990). The learning curve was initially used by authorities during World War II, to estimate the construction costs of ships and aircraft to be used in the war (Yelle,

---

[1] Gürkan Çalmaşur, PhD in Economics, is an Associate professor at the Erzurum Technical University (Faculty of Economics and Administrative Sciences) and a Specialist Microeconomics. Contact address: gurkan.calmasur@erzurum.edu.tr

[2] Hüseyin Daştan PhD in Economics, is an Associate professor at the Erzurum Technical University (Faculty of Economics and Administrative Sciences) and a Specialist Microeconomics. Contact address: hdastan@erzurum.edu.tr

[3] Zeynep Karaca, PhD in Economics, is an Assistant professor at the Erzurum Technical University (Faculty of Economics and Administrative Sciences) and a Specialist Microeconomics. Contact address: zeynep.karaca@erzurum.edu.tr

1979). Analysts discovered that with the cumulative increase in the number of aircraft produced, labour input per aircraft is drastically reduced (Petrakis et al., 1997; Krajewski, Malhotra and Ritzman, 2019).
Learning curves or experience curves have been applied in manufacturing and service industries including manufacturing of airplanes, appliances, ships, etc. Besides, in order to detect the need for labour, materials and raw materials and to plan the production process, to identify the price at which the goods or services will be sold, and even to assess the suppliers' price quotations, learning curves have been utilized (Salvatore, 2003). A new firm that tries to enter any industry faces a significant cost disadvantage. Because it will not go down its the learning curve yet. In markets characterized by significant learning by doing, entry can be difficult (Waldman and Jensen, 2013).
The learning curves explain to firm managers how the production cost per unit varies for the cumulative amount of production. The firm managers compete with other firms in price and non-price competition. Managers that prefer low price as a competitive strategy rely on high production levels to maintain their profit margins (Krajewski, Malhotra and Ritzman, 2019). There are different learning curve models including univariate and multivariate. Log-linear model, S-curve, Stanford-B model, DeJong's model, Levy's model, Glover's model, Pegel's model, Knecht's model, Yelle's model and impact power model are univariate examples of models (Badiru, 1992; Asgari and Gonzalez-Cortez, 2012).
The main purpose of this article is to analyze the learning curve in the Turkish manufacturing industry under the NACE Rev.2 classification for 2003-2017 period. In this regard, to estimate the progress ratios of Turkish manufacturing industries used the cubic learning model. This article is organized as follows. The research is composed of five main sections. The second section presents studies cited in the literature review. The third section explains the methodology of the article. The fourth section covers the learning curve estimation results. The fifth and the final section draws conclusions from the estimation results.

1. Literature review

There are several articles in the literature that analyzes the learning curve models. These articles in different industries have showed that costs decrease with more production. Table 1 shows some of the articles concentrating on the learning curve model.

Table 1 Some of Articles Focusing on the Learning Curve Model

Year	Investigator	Industry	Year	Investigator	Industry
1936	Wright, T. P.	Aircraft	2003	Franceschini, F. & Galetto, M.	Manufacturing

1965	Hartley, K.	Aircraft	2004	Goldemberg J. et al.	Ethanol
1973	Boston Consulting Group	Semiconductor	2005	Karaoz, M. & Albeni, M.	Manufacturing
1971	Baloff, N.	Automobile, apparel and large musical instruments	2009	Asgari, B. & Yen, L. W.	Manufacturing, Service
1972	Dudley, L.	Metal	2010	Nadeau, M. C. et al.	Hydroforming
1974	Sultan, R.	Steam turbine generators	2012	Asgari, B. & Gonzalez-Cortez, J. L.	Manufacturing
1984	Lieberman, M. B.	Chemical			
1990	Argote, L. & Epple, D.	Aircraft	2012	Chen C. H. & Lu, Z. N.	wind power and other power technologies
1990	Argote L. et al.	Ship	2013	Levitt, S. D. et al.	Automobile
1991	Dick, A. R.	Semiconductor	2015	Karali, N. et al.	Iron and steel
1994	Jarmin, R. S.	Rayon	2017	Bongers, A.	Aircraft
2000	Sinclair, G. et al.	Chemical	2017	Xu, Y. et al.	Wind power and other power technologies
2000	Tan, W. & Elias, Y.	Construction	2018	Aduba, J. J. & Izawa, H.	Manufacturing, Non-Manufacturing
2001	Chung, S.	Semiconductor	2018	Hayashi, D. et al.	Wind power and other power

					technologies
2002	Pramongkit, P. et al.	Manufacturing	2019	Aduba, J. J. & Asgari, B.	Manufacturing
			2019	Kim, I. et al.	Ship

Wright was the first researcher to analyse the learning curve model in 1936. Wright (1936), investigate the cost of production in the aircraft industry. Wright find out that unit labour costs in airplanes production declined with cumulative output. Since Wright's work, the learning curve models have been widely applied in different areas.

The learning curve concept by Boston Consulting Group (1970) was replaced by the experience curve concept. The experience curve states that learning should include not only one input but all inputs, while the learning curve considers a single input in the production process (Karaoz and Albeni, 2005). Studies such as Spence (1981) and Kalish (1983) show that a firm with a high technological learning level should produce more than other firms in any industry (Majd and Pindyck, 1989).

There are many articles that estimate the experience or learning curve through the log-linear model (Yelle, 1979; Badiru, 1992). In the log-linear model, the level of technological learning does not reflect the actual situation. Technological learning level can vary over time. Therefore, various extended nonlinear models have been derived (Asher, 1957; De Jong, 1957; Levy, 1965; Knetch, 1974).

There are articles presenting a comprehensive literature review on learning curve models (Anzanello and Fogliatto, 2011). Today, several learning curve models are performed in different fields, especially in business, and log-linear model is the most widely employed.

2. Methodology

The data on the Turkish manufacturing industry 24 sub-sectors was obtained NACE Rev. 2, reflecting the fourth revision of ISIC, code levels from the TurkStat (Turkish State Institute of Statistics). Data set covers the annual data set for 2003-2017 period. In this article, production value is used to represent the output level (Q) and personnel cost variables are used to represent is the labour level (L). These data are monetary data. The monetary data was deflated with Costumer Price Indices published by the Turkish State Institute of Statistics. Eurostat forms a categorization according to NACE Rev. 2 at 2-digit level. Sub-sectors were classified with respect to technological intensity level as high, medium-high, medium-low and, low-technology as shown in Table 2.

Table 2 Eurostat Industrial Classifications

High-technology industries	Medium-high-technology industries
Basic pharmaceutical products and pharmaceutical preparations (21)	Chemicals and chemical products (20)
Computer, electronic and optical products (26)	Electrical equipment (27)
	Machinery and equipment n.e.c. (28)
	Motor vehicles, trailers and semi-trailers (29)
	Other transport equipment (30)
Low-technology industries	**Medium-Low-technology industries**
Food products (10)	Coke and refined petroleum products (19)
Beverages (11)	Rubber and plastic products (22)
Tobacco products (12)	Other non-metallic mineral products (23)
Textiles (13)	Basic metals (24)
Wearing apparel (14)	Fabricated metal products, except machinery and equipment (25)
Leather and related products (15)	Repair and installation of machinery and equipment (33)
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials (16)	
Paper and paper products (17)	
Printing and reproduction of recorded media (18)	
Furniture (31)	
Other manufacturing (32)	

As a firm gains experience in the production process of a good, its average cost of production regularly decreases. In other words, for a given level of production in a given year, as the total output increases cumulatively over many years, it will usually allow the firm's average cost to be significantly reduced. The learning or experience curve illustrates the decrease in average cost as the cumulative total output of the firm increases (Church and Ware, 2000; Salvatore, 2003).

The learning curve has different functional forms. These models are the Log-linear Model, the Plateau model, the Stanford model, the Dejong model, the S model etc. Besides, learning model generated by Wright is until now the most commonly employed (Yelle, 1979). The log-linear model will be used to estimate the progress ratio under the traditional linear experience curve assumption. Wright's the traditional learning curve model can be expressed as:

$$C_t = C_1 X_t^{-a} \quad (1)$$

Where C_t is the labour input per unit level of output at time t; C_1 is the labour input needed to produce the first unit level of output; X_t is the cumulative number of units produce until time t; and $-a$ represents the learning elasticity.
The logarithmic form of Equation 1 is as follows (Karaoz and Albeni, 2005):

$$lnC_t = lnC_1 + alnX_t \quad (2)$$

Equation 2 expresses that the unit production cost at time t (C_t) is a function of cumulative production level X_t, and the cost of producing the first unit C_1 in the production process. Additionally, the learning effect is determined by the value of a.
The bigger the value of a, the more important are the learning effects. The progress ratio (d) is reproduced from the representing learning elasticity a. The progress ratio is a portion of the beginning unit cost when the cumulative production level or experience doubles. This is expressed as; $d = 2^{-a}$ (Pramongkit, Shawyun and Sirinaovakul, 2000; Aduba and Izawa, 2018).
If there is learning in any firm or industry, the values of the progress ratio are hoped to be between zero and one. When the value of the progress ratio approaches 0, the learning becomes better and better. However, the value of the progress ratio close to 1 suggest low learning rate. In addition to, when the value of the progress ratio is 1, there is neither learning nor forgetting (Argote and Epple, 1990; Karaoz and Albeni, 2005).
To measure the learning curve effect, the traditional neoclassical production function commonly used. We use the function stated as:

$$Q_t = A_t L_t^{\alpha} K_t^{\beta} \quad (3)$$

Where Q_t is the output level at time t; L_t is the labour level at time t; K_t is the capital level at time t. A_t refers the level of technology at time t. α and β are respectively the output elasticity of labor and output elasticity of capital. The sum of the α and β parameters is a measure of the returns to scale for the production function. If $\alpha + \beta > 1$, we have increasing returns to scale. If $\alpha + \beta < 1$, we have decreasing returns to scale. Finally, If $\alpha + \beta = 1$, we have constant returns to scale (Salvatore, 2003). Equation 3 can also be expressed in a logarithmic form:

$$lnQ_t = lnA_t + \alpha lnL_t + \beta lnK_t \quad (4)$$

Equation 3 assumes that there exists a functional relationship between the level of technology at time t, A_t and the cumulative level of production at time t, X_t. Equation 5 is expressed as:

$$A_t = HX_t^{a} \quad (5)$$

Where H refers a constant and X_t^{a} is the inverse of X_t^{-a} earlier expressed in equation 1 ($X_t^{a} = {}^{C_1}/_{C_t}$). The natural log form of equation 5 can be expressed as:

$$lnA_t = lnH + alnX_t \quad (6)$$

Hence, using $X_t^a = {C_1}/{C_t}$ relationship, we could rewrite equation 5 as:

$$A_t = H\frac{C_1}{C_t} \quad (7)$$

Equation 7 can also be expressed in a logarithmic form:

$$lnA_t = lnH + ln\left(\frac{C_1}{C_t}\right) \quad (8)$$

The cubic learning model assumes that the level of learning varies over time. Carlson (1973) justifies the use of the S-curve function to estimate cubic learning rates. The S-curve function express that per unit cost of output at time t is a function of a cumulative production up to a third order polynomial. In this article, we used the cubic learning model. The cubic learning model can be expressed as (Badiru, 1992; Carlson, 1973; Karaoz and Albeni, 2005).

$$lnC_t = lnC_1 + BlnX_t + C(lnX_t)^2 + D(lnX_t)^3 \quad (9)$$

Equation 4 states per unit cost of output at time t is a function of the cumulative production level. The learning index is determined by the first derivative of the Equation 4.

$$-a = \frac{dlnC_t}{dlnX_t} = B + 2ClnX_t + 3D(lnX_t)^2 \quad (10)$$

In addition to, Equation 11 derived from Equation 9 as:

$$ln\left(\frac{C_1}{C_t}\right) = -[BlnX_t + C(lnX_t)^2 + D(lnX_t)^3] \quad (11)$$

We replace the $ln\left(\frac{C_1}{C_t}\right)$ in Equation 8 with Equation 11. Then,

$$lnA_t = lnH - BlnX_t - C(lnX_t)^2 - D(lnX_t)^3 \quad (12)$$

Equation 12 is added in Equation 4 and the following form is obtained:

$$lnQ_t = lnH - BlnX_t - C(lnX_t)^2 - D(lnX_t)^3 + \alpha lnL_t + \beta lnK_t \quad (13)$$

Additionally, in Equation 13, the relationship between capital and labour is assumed to be:

$$K_t = \mu L_t^\lambda \quad (14)$$

where μ and λ are constants. The logarithmic form of this equation can be added in Equation 13:

$$lnQ_t = lnH - BlnX_t - C(lnX_t)^2 - D(lnX_t)^3 + \alpha lnL_t + \beta(ln\mu + \lambda lnL_t) \quad (15)$$

after adding lnL_t to both sides of the equation, the following final equation is attained:

$$ln\left({L}/{Q}\right)_t = -lnH - \beta ln\mu + BlnX_t + C(lnX_t)^2 + D(lnX_t)^3 + (1 - \beta\lambda - \alpha)lnL_t \quad (16)$$

To express in a shorter way, presume $\theta_1 = -(lnH + \beta ln\mu)$, $\theta_2 = (1 - \beta\lambda - \alpha)lnL_t$ and $lnC_t = ln\left({L}/{Q}\right)_t$. Then,

$$lnC_t = \theta_1 + BlnX_t + C(lnX_t)^2 + D(lnX_t)^3 + \theta_2 lnL_t \quad (17)$$

The derivative of Equation 17 gives us the learning elasticity, stated as follows:

$$-a = \frac{\partial C_t}{\partial X_t}\frac{X_t}{C_t} = B + 2ClnX_t + 3D(lnX_t)^2 \qquad (18)$$

Through regression analysis, to estimate B, C and D parameters Equation 17 is employed and then to compute the value of learning elasticity α, and finally the progress ratio Equation 3 is employed.

3. Learning Curve Estimation Results

In order to determine the learning level for 24 sub-sectors and total manufacturing industry in the 2003-2017 period, Equation 17 was estimated. Table 3 shows coefficients of all manufacturing industries estimated using the cubic models. All the models estimated in table 3 are statistically significant as a whole at a 1%, 5%, and 10% level significance level respectively (F values). That is, the independent variables significantly explain the dependent variable as a whole. R^2 values of the models vary between 47.2%-98.8%. Most industries had high coefficient of determinations R^2, implying that higher percentage of the variations in the data set was explained by the model. The t values for θ_1, θ_2, B, C, and D parameters demonstrate that the estimates are significant for most of the manufacturing industries.

Table 3 Regression Result Estimated Using Cubic Model

	Codes	θ_1	θ_2	B	C	D	F values	R^2
High-tech. industries	21	1377,95 (4,52)*	-0,192 (-0,60)	-217,888 (-4,57)*	11,470 (4,61)*	-0,201 (-4,64)*	34,59*	0,933
	26	843,317 (1,62)	0,222 (1,13)	-132,762 (-1,62)	6,899 (1,60)	-1,119 (-1,59)	30,27*	0,924
Medium-high-tech. industries	20	-1202,592 (-7,34)*	-2,842 (-5,75)*	201,373 (7,63)*	-10,782 (-7,76)*	0,191 (7,86)*	66,82*	0,964
	27	2530,25 (-2,81)**	-0,640 (-0,94)	-355,338 (-2,79)**	16,630 (2,75)**	-0,259 (-2,70)**	46,81*	0,950
	28	-27,178 (-0,08)	-0,320 (-0,55)	5,712 (0,11)	-0,357 (-0,14)	0,007 (0,16)	5,60**	0,691
	29	335,140 (1,72)	0,943 (5,53)*	-53,292 (-1,83)***	2,690 (1,87)***	-0,045 (-1,92)***	45,98*	0,948
	30	-363,352 (-2,33)**	1,898 (2,84)**	58,552 (2,11)***	-3,367 (-2,11)***	0,063 (2,07)***	47,43*	0,950
Low-tech. industries	10	-245,785 (-1,25)	0,227 (0,53)	33,399 (1,14)	-1,549 (-1,10)	0,024 (1,05)	3,29***	0,568
	11	-826,042 (-3,97)*	1,689 (5,07)*	132,102 (3,77)*	-7,231 (-3,70)*	0,131 (3,61)*	30,72*	0,925
	12	1404,651 (4,31)*	0,553 (6,08)*	-234,701 (-4,40)*	12,969 (4,46)*	-0,239 (-4,53)*	197,17*	0,988
	13	-224,980 (-1,29)	2,629 (1,81)	29,877 (0,91)	-1,598 (-0,88)	0,027 (0,83)	135,97*	0,982

	14	-212,517 (-0,72)	5,752 (6,27)*	13,288 (0,28)	-0,403 (-0,16)	0,001 (0,02)	63,77*	0,962
	15	-124,865 (-0,79)	0,008 (0,04)	19,394 (0,75)	-1,030 (-0,73)	0,018 (0,72)	22,56*	0,900
	16	-770,047 (-1,92)***	0,191 (0,17)	120,777 (1,83)***	-6,344 (-1,79)	0,111 (1,74)	2,80***	0,528
	17	197,688 (1,92)***	0,935 (3,37)*	-35,001 (-2,10)***	1,914 (2,16)***	-0,035 (-2,23)***	17,46*	0,875
	18	-113,097 (-1,01)	0,389 (1,85)***	16,967 (0,93)	-0,911 (-0,92)	0,016 (0,92)	18,67*	0,882
	31	-506,070 (-2,29)**	0,387 (2,00)***	76,018 (2,17)***	-3,862 (-2,11)***	0,065 (2,04)***	43,24*	0,945
	32	436,297 (0,55)	4,427 (3,52)*	-83,781 (-0,66)	4,688 (0,70)	-0,088 (-0,75)	12,58*	0,834
	19	-1940,047 (-2,75)**	-0,867 (0,45)	310,082 (2,66)**	-16,361 (-2,65)**	0,286 (2,64)**	35,41*	0,934
	22	-241,571 (-0,93)	-0,968 (-0,20)	36,656 (0,91)	-1,861 (-0,91)	0,031 (0,90)	3,26***	0,566
Medium-Low-tech. industries	23	-293,937 (-1,33)	0,244 (0,73)	43,029 (1,27)	-2,136 (-1,26)	0,035 (1,24)	2,24*	0,472
	24	-136,789 (-0,23)	3,524 (3,37)*	7,609 (0,09)	-0,161 (-0,04)	-0,001 (-0,02)	10,93*	0,814
	25	-4,591 (-0,03)	0,490 (1,10)	-1,536 (-0,05)	0,117 (0,08)	-0,003 (-0,11)	6,90*	0,734
	33	-387,736 (-3,29)*	0,951 (2,67)**	62,167 (3,15)**	-3,423 (-3,08)**	0,062 (2,99)**	12,21*	0,830
Industry		62,475 (1,88)***	0,644 (18,61)*	-10,706 (-2,05)**	0,532 (1,95)**	-0,001 (-1,95)***	156,33*	0,638

*,**, and *** denotes statistical significance at 1%, 5%, and 10% level respectively.

Then, the annual technological progress ratio (the learning level) for all manufacturing industries were computed and presented in Table 4. The annual learning elasticities for each sub-sector were computed by using the estimates from Equation 17. After, these elasticities were transformed to the annual technological progress ratios via $d = 2^{-a}$.
Table 4 shows the technological learning levels about any manufacturing industry and for the 2003-2017 period. Shaded cells emphasize technological learning level over unity. Shaded cells indicate forgetting scenario with loss in efficiency and increase in per unit production cost. Unshaded cells indicate learning scenario with per unit cost efficiency gain in the manufacturing process by the corresponding industry.
Each year's annual technological learning level in Table 4 shows the decreases or increases in unit production costs in the face of doubling production for corresponding industry. The fact that annual learning levels vary from one year to the next indicates that the level of technological learning is different for each year. For example, in 2003, 2004, and, 2005, the annual technological learning levels for the

Manufacture of food products industry are 1.158, 1.022, and 0.974 respectively. These numbers imply the per unit cost efficiency acquired or missed for a given year. For instance, in 2003 and 2004, the unit production costs for the manufacture of food products industry increased 15.8% and 2.2% for each doubling of the production level but in 2005, unit production costs declined to 97.4%. This number demonstrates that the manufacture of food products industry learned better in 2005.

Table 4 The Annual Progress Ratio for Turkish Manufacturing Industries, 2003-2017

Year Code	2003	2004	2005	2006	2007	2008	2009	2010
10	1,158	1,022	0,974	0,952	0,941	0,936	0,935	0,936
11	1,845	0,908	0,722	0,611	0,564	0,525	0,521	0,538
12	0,557	0,870	0,919	0,865	0,791	0,720	0,651	0,596
13	1,001	0,771	0,639	0,565	0,531	0,510	0,464	0,476
14	1,729	1,118	0,895	0,732	0,644	0,582	0,401	0,322
15	0,990	0,900	0,869	0,852	0,845	0,841	0,840	0,840
16	2,310	1,396	1,143	1,029	0,982	0,959	0,944	0,951
17	0,884	0,926	0,914	0,886	0,857	0,829	0,799	0,769
18	0,925	0,848	0,817	0,806	0,801	0,799	0,800	0,802
19	4,626	1,052	0,621	0,459	0,405	0,382	0,394	0,509
20	1,718	0,632	0,415	0,363	0,351	3,375	0,441	0,585
21	0,822	1,289	1,378	1,365	1,315	1,250	1,168	1,088
22	1,149	1,033	1,010	1,011	1,023	1,041	1,058	1,079
23	1,146	0,971	0,917	0,895	0,891	0,896	0,904	0,915
24	1,294	1,040	0,930	0,851	0,802	0,760	0,710	0,662
25	0,832	0,786	0,759	0,736	0,719	0,705	0,693	0,681
26	0,762	1,170	1,286	1,305	1,289	1,262	1,235	1,205
27	0,011	0,382	0,960	1,584	2,021	2,288	2,332	2,358
28	0,795	0,825	0,851	0,877	0,898	0,919	0,931	0,946
29	1,048	1,207	1,238	1,229	1,202	1,169	1,135	1,097
30	0,935	0,598	0,488	0,435	0,407	0,389	0,371	0,380
31	1,575	1,258	1,058	0,978	0,940	0,920	0,913	0,912
32	0,690	0,626	0,542	0,474	0,434	0,401	0,338	0,300
33	1,300	0,876	0,728	0,645	0,606	0,583	0,565	0,566
Ind.	1,107	0,550	0,320	0,194	0,137	0,119	0,041	0,041

Year Code	2011	2012	2013	2014	2015	2016	2017	Av.
10	0,940	0,946	0,953	0,961	0,970	0,979	0,989	0,973
11	0,565	0,599	0,637	0,683	0,733	0,785	0,843	0,739
12	0,553	0,506	0,465	0,424	0,385	0,346	0,312	0,597
13	0,499	0,523	0,547	0,572	0,596	0,619	0,644	0,596
14	0,273	0,241	0,217	0,198	0,183	0,170	0,160	0,524
15	0,841	0,844	0,847	0,851	0,856	0,861	0,866	0,863
16	0,975	1,013	1,059	1,115	1,178	1,244	1,325	1,175

17	0,738	0,709	0,681	0,652	0,625	0,600	0,573	0,763
18	0,804	0,808	0,812	0,816	0,820	0,824	0,829	0,821
19	0,806	1,281	1,908	2,624	3,407	4,252	5,643	1,891
20	0,818	1,115	1,495	1,985	2,580	3,279	4,268	1,561
21	1,018	0,952	0,893	0,835	0,775	0,720	0,665	1,035
22	1,107	1,135	1,164	1,196	1,227	1,259	1,294	1,119
23	0,930	0,946	0,965	0,985	1,006	1,027	1,049	0,963
24	0,615	0,581	0,554	0,530	0,512	0,496	0,477	0,721
25	0,669	0,659	0,649	0,640	0,631	0,623	0,615	0,693
26	1,166	1,124	1,084	1,039	0,993	0,951	0,903	1,118
27	2,364	2,351	2,318	2,271	2,211	2,143	2,059	1,844
28	0,962	0,977	0,992	1,008	1,023	1,037	1,052	0,940
29	1,053	1,015	0,978	0,941	0,902	0,864	0,824	1,060
30	0,398	0,420	0,446	0,478	0,510	0,547	0,590	0,493
31	0,917	0,928	0,944	0,964	0,988	1,012	1,041	1,023
32	0,266	0,238	0,217	0,202	0,188	0,176	0,164	0,350
33	0,573	0,588	0,609	0,638	0,674	0,711	0,751	0,694
Ind.	0,066	0,101	0,142	0,186	0,233	0,280	0,333	0,257

Table 5 shows the learning curves derived from the numbers indicating the technological learning levels of each industry in Table 4, for the period 2003-2017. The learning curves used to figure and categorize the manufacturing industries with regards to technological learning paths. The manufacturing industries have been collected under three classes depending on the similarity of shapes of the learning curves. These classes and the industries within them are given in Table 3. The sub-categories divide the classes in terms of considering the forgetting (Karaoz and Albeni, 2005; Asgari and Gonzalez-Cortez, 2012).

Table 5 Paths of Industrial Learning in Turkish Manufacturing Industry, 2003-2017

Paths of Industrial Learning in Turkish Manufacturing Industry for 2003-2017		Forgetting	Industry
Convex learning path with a minimum		With forgetting at some end periods	Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials, Coke and refined petroleum products, Chemicals and chemical products, Rubber and plastic products, Other non-metallic mineral products, Machinery and equipment n.e.c., Furniture

		No forgetting in any period	Leather and related products, Printing and reproduction of recorded media, Other transport equipment
		No forgetting at end periods	Food products, Beverages, Textiles, Repair and installation of machinery and equipment
Concave learning path with a maximum		With forgetting at some periods	Basic pharmaceutical products and pharmaceutical preparations, Electrical equipment and Computer, electronic and optical
		No forgetting in any period	Tobacco products, Paper and paper products
Convex learning path that either have not reached or have not got a minimum		With forgetting at some periods	Wearing apparel, Basic metals, Motor vehicles, trailers and semi-trailers
		No forgetting in any period	Fabricated metal products, except machinery and equipment, Other manufacturing

The first-class includes the manufacturing industries that have the convex learning curves with a minimum. It implies that the progress ratio declines over time and rises later on. The first sub-category of this class includes the industries that have already passed the forgetting value (which is one) during an end year of the 15-year period. These industries cover Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials, Coke and refined petroleum products, Chemicals and chemical products, Rubber and plastic products, Other non-metallic mineral products, Machinery and equipment n.e.c. and, Furniture. The second sub-category consists of the industries not having forgetting in any given year. These industries involve Leather and related products, Printing and reproduction of recorded media and, Other transport equipment. The third sub-category refers to industries that experience a slowdown in learning levels but do not reach the

forgetting points which is one. These industries are Food products, Beverages, Textiles, Repair and installation of machinery and equipment.
The second-class in Table 5 involves the manufacturing industries that have the concave learning curves with a maximum. It indicates that the progress ratio increases over time and decreases later. The second class is divided into two sub-categories, whether or not there is forgetting in any year. Basic pharmaceutical products and pharmaceutical preparations, Electrical equipment, and Computer, electronic and optical products industries experienced forgetting in some periods but Tobacco products, and Paper and paper products industries have not experienced forgetting any period.
In Table 5, the third-class incorporates the manufacturing industries that have the convex learning curves have not got a minimum. That is the progress ratio continuously declines over time. The third-class is divided into two sub-categories according to the existence of forgetting in any given year alike second-class. Wearing apparel, Basic metals, Motor vehicles, trailers and semi-trailers industries experienced forgetting in some periods, However Tobacco products, Fabricated metal products, except machinery and equipment and, Other manufacturing industries have not experienced forgetting any period.
Between 2003-2017, total Turkish manufacturing industry has high technological learning levels in all years except 2003. The highest technological learning level was experienced in Electrical equipment industry in 2003. For 2003-2017 period, the best performance was experienced in the Other manufacturing industry and the worst performance in the Rubber and plastic products industry.
According to the results of the analysis, in the high-technology industries, the learning curve has a concave slope. That is, forgetting has been experienced in these industries until a certain period and then the technological learning has taken place. The learning curve in the Chemicals and chemical products and Other transport equipment industries within the medium-high technology industries has a convex learning curve and other industries in this class have a concave learning path with a maximum. In addition to, in the low-technology industries, the learning curve is convex, except for Tobacco products and Paper and paper products industries. Finally, the medium-low-technology industries have the convex learning path with a minimum.
In this article, it has been determined that different industries have different progress ratios. Within the manufacturing industry some industries continue to learn better after the beginning period, while others show good learning potential at some start and end periods. The manufacturing industry as a whole is at learning stage. As the positive effects of the learning curve are better understood, better production and

technological decisions can be made at less cost. Technological differences between industries, differences in the level of R&D expenditures and differences in production process and etc. cause the shape of the learning curve of each industry to be different. Firm and industry-specific factors also determine how the learning curve will exhibit a slope. Governments should intervene to deregulate any industry, taking into account the technological learning or forgetting levels of corresponding industry.

4. Conclusion

Manufacturing industry is a sector that has an important contribution to the development and growth of countries. Today, the development of this industry and the strengthening of its competitive structure depend on the speed of technological change and transformation. This is closely related to the technological learning level. The learning curve, which has been used for more than seven decades, is used to determine the technological learning level of any industry.

In this article, we analyzed the shapes of learning curves for the Turkish manufacturing industry and sub-sectors for the 2003-2017 period through the cubic learning model. The estimation results obtained from cubic learning model have indicated that the progression ratio in the Turkish manufacturing industry and sub-sectors vary over time period. It was found that the total Turkish manufacturing industry had a convex learning path that reached its minimum in 2009.

As a result, the technological learning levels factors that may vary from period to period, country to country and region to region. Also, the results obtained in the article are limited to the data gathered during the examination period, the variables used, and the analysis methodology. Using different periods, variables and methods may lead to different analysis results.

The technological learning levels were analysed by considering the micro-economic variables in this article. Also, macro-economic variables that may affect the technological learning levels can be the subject of analysis. The results of this article are expected to set light to future studies on the technological learning level (progress ratio).

References

Aduba, Joseph Junior, and Hiroshi Izawa. 2018. “Industry (Economic)-Wide Learning: A Comparative Study of Manufacturing and Non-Manufacturing Sector in Japan.” Asian Journal of Economics, Business and Accounting, 9(4): 1–14.

Aduba, Joseph Junior, and Asgari, Behrooz. 2019. “Productivity and Technological Progress of The Japanese Manufacturing Industries, 2000–2014: Estimation with Data Envelopment Analysis and Log-

Linear Learning Model." Asia-Pacific Journal of Regional Science, 3(3): 1-45.

Anzanello, Michel J., and Flavio S. Fogliatto. 2011. "Learning Curve Models and Applications: Literature Review and Research Directions." International Journal of Industrial Ergonomics, 41(5): 573–583.

Argote, Linda, Sara L. Beckman, and Dennis Epple. 1990. "The Persistence and Transfer of Learning in Industrial Settings." Management Science, 36(2): 140–154.

Argote, Linda, and Dennis Epple. 1990. "Learning Curves in Manufacturing." Science, 247(4945): 92–924.

Asgari, Behrooz, and Jose Luis Gonzalez-Cortez. "Measurement of Technological Progress Through Analysis of Learning Rates; The Case of the Manufacturing Industries in Mexico." Ritsumeikan Journal of Asian Pacific Studies, 31: 101–119.

Asgari, Behrooz, and Lim Wee Yen. 2009. "Accumulated Knowledge and Technical Progress in Terms of Learning Rate; A Comparative Analysis on the Manufacturing Industry and Service Industry in Malaysia." Asian Journal of Technological Innovation, 17(2): 71–99.

Asher, Harold. 1956. "Cost-Quantity Relationships in the Airframe Industry." Report No. 291, RAND Corporation.

Badiru, Adedeji B. 1992. "Computational Survey Univariate and Multivariate Learning Curve Models." IEEE Transaction on Engineering Management, 39(2): 176–188.

Baloff, Nicholas. 1971. "Extension of the Learning Curve-Some Empirical Results." Operational Research Quarterly, 22(4): 329–340.

Bongers, Aneli. 2017. "Learning and Forgetting in The Jet Fighter Aircraft Industry." PLoS ONE, 12(9): 1-19.

Boston Consulting Group. 1970. Perspectives on Experience. Boston: Boston Consulting Group.

Boston Consulting Group. 1973. The Experience Curve-Reviewed II: History, Perspectives. Boston: Boston Consulting Group.

Carlson, James A. 1973. "Cubic Learning Curves: Precision Tool for Labor Estimating." Manufacturing Engineering and Management, 71(5): 22–25.

Chen, C. H., and Lu, Z. N. 2012. "Technology Learning and Production Scale Expansion: The Source of Wind Power Investment Costs Reduction." Sci. Technol. Prog. Policy, 29: 58–60.

Chung, Sangho. 2001. "The Learning Curve and the Yield Factor: The Case of Korea's Semiconductor Industry." Applied Economics, 33(4): 473–483.

Church, Jeffrey, and Roger Ware. 2000. Industrial Organization: A Strategic Approach. Boston: McGraw Hill.

De Jong, J. R. 1957. "The Effects of Increasing Skill on Cycle Time and Its Consequences for Time Standards." Ergonomics, 1(1): 51–60.

Dick, Andrew R. 1991. "Learning by Doing and Dumping in the Semiconductor Industry." Journal of Law and Economics, 34(1): 133–159.

Dudley, Leonard. 1972. "Learning and Productivity Change in Metal Products." The American Economic Review, 62(4): 662–669.

Franceschini, Fiorenzo, and M. Galetto. 2002. "Asymptotic Defectiveness of Manufacturing Plants: An Estimate Based on Process Learning." International Journal of Production Research, 40(3): 537–545.

Goldemberg, Jose, Suani Teixeira Coelho, Plinio Mario Nastari, and Oswaldo Lucon. 2004. "Ethanol Learning Curve-The Brazilian Experience." Biomass and Bioenergy, 26(3): 301–304.

Hartley, Keith. 1965. "The Learning Curve and Its Application to the Aircraft Industry." The Journal of Industrial Economics, 13(2): 122–128.

Hayashi, Daisuke, Huenteler, Joern, and Lewis, Joanna. I. 2018. "Gone with The Wind: A Learning Curve Analysis of China's Wind Power Industry." Energy Policy, 120: 38-51.

Jarmin, Ronald S. 1983. "Learning by Doing and Competition in the Early Rayon Industry." The RAND Journal of Economics, 25(3): 441–454.

Kalish, Shlomo. 1983. "Monopolist Pricing with Dynamic Demand and Production Cost." Marketing Science, 2(2): 135-159.

Karali, Nihan, Park, Won Young, and McNeil, Michael A. 2015. Using Learning Curves on Energy-Efficient Technologies to Estimate Future Energy Savings and Emission Reduction Potentials in the U.S. Iron and Steel Industry. Lawrence Berkeley National Laboratory. LBNL Report: LBNL-184179.

Karaoz, Mesut, and Murat Albeni. 2005. "Dynamic Technological Learning Trends in Turkish Manufacturing Industries." Technological Forecasting and Social Change, 72(7): 866–885.

Kim, Ilhyung, Springer, Mark, Zhang, Zhe George, & Park, Young Sun. 2019. "Organizational Learning: Approximation of Multiple-Level Learning and Forgetting by an Aggregated Single-Level Model." Computers & Industrial Engineering, 131(2019): 442–454.

Knecht, George R. 1974. "Costing Technological Growth and Generalized Learning Curves." Operations Research Quarterly, 25(3): 487–491.

Krajewski, Lee J., Manoj. K. Malhotra, and Larry P. Ritzman. 2015. Operations Management: Processes and Supply Chains. Essex: Pearson Education.

Levitt, Steven D., List, John A., and Syverson, Chad. 2013. "Toward an Understanding of Learning By Doing: Evidence From an Automobile Assembly Plant." Journal of Political Economy, 121(4): 643-681.

Levy, Ferdinand K. 1965. “Adaptation in the Production Process.” Management Science, 11(6): 136–154.

Lieberman, Marvin B. 1984. “The Learning Curve and Pricing in the Chemical Processing Industries.” The RAND Journal of Economics, 15(2): 213–228.

Majd, Saman, and Robert S. Pindyck. 1989. “The Learning Curve and Optimal Production under Uncertainty.” The RAND Journal of Economics, 20(3): 331-343.

Nadeau, Marie Calude, Ashish Kar, Richard Roth, and Randolph Kirchain. 2010. “A Dynamic Process-Based Cost Modeling Approach to Understand Learning Effects in Manufacturing.” International Journal of Production Economics, 128(1): 223–234.

Petrakis, Emmanuel, Eric Rasmusen, and Santanu Roy. 1997. “The Learning Curve in a Competitive Industry.” The RAND Journal of Economics, 28(2): 248-268.

Pramongkit, Prasopchoke, Teay Shawyun, and Boonmark Sirinaovakul. 2002. “Productivity Growth and Learning Potentials of Thai Industry.” Technological Forecasting and Social Change, 69(1): 89–101.

Salvatore, Dominick. 2003. Microeconomics: Theory and Applications. New York: Oxford University Press.

Sinclair, Gavin, Steven Klepper, and Wesley Cohen. 2000. “What’s Experience Got to Do With it? Sources of Cost Reduction in a Large Specialty Chemicals Producer.” Management Science, 46(1): 28–45.

Spence, A. Michael. 1981. “The Learning Curve and Competition.” Bell Journal of Economics, 12(1): 49-70.

Sultan, Ralph G. M. 1974. Pricing in the Electrical Oligopoly. Boston: Harvard University Press.

Tan, Willie, and Yahya Elias. 2000. “Learning by Doing in Singapore Construction.” Journal of Construction Research, 1(2): 151–158.

Xu, Yan, Yuan, Jiahai, and Wang, Jianxiu. 2017. “Learning of Power Technologies in China: Staged Dynamic Two-Factor Modeling and Empirical Evidence.” Sustainability, 9(5): 861-875.

Waldman, Don. E., and Elizabeth J. Jensen. 2013. Industrial Organization: Theory and Practice. Boston: Pearson Education.

Wright, Theodore Paul. 1936. “Factors Affecting the Cost of Airplanes.” Journal of the Aeronautical Sciences, 3: 122–128.

Yelle, Louis E. 1979. “The Learning Curve: Historical Review and Comprehensive Survey.” Decision Science, 10(2): 302–328.