ORIGINAL RESEARCH:

Measurement of technological progress through analysis of learning rates; the case of the manufacturing industry in Mexico

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Abstract

The development and advancement of a manufacturing industry relies on specialization changes over time with a shift from low-tech labor-intensive to high-tech capital-intensive industries. The stocks of knowledge and technological capabilities influence the technological progress of an industry. We analyzed the Mexican manufacturing subsectors and estimated their progress ratios through a linear and a cubic model integrated into the neoclassical production function. The purpose was to determine whether Mexico has moved from labor-intensive to capital-intensive industries, and which subsectors would perform better. Three main patterns of technological learning were found among various industries; a convex learning path with continuous forgetting or learning at the beginning but forgetting afterwards, a concave learning path with forgetting in the beginning but learning afterwards, and a concave learning path with continuous forgetting. To sustain industrial and economic growth, Mexico could prioritize the mid-low and mid-high-tech industries that show learning potentials, and adjust its technology policy structure to reverse the high-tech industry performance. Policies to support the food industry are recommended as it has been very competitive and shown a high assimilation capacity.

Keywords: learning curve, manufacturing industry, Mexico, progress ratio, technological progress

Introduction

Macroeconomic policies in Mexico have undergone major changes over the last 40 years. Prior to the 1970's, the Mexican economy was under the control of the government through state-owned companies and strict controls over the domestic market and international trade, but in the early 1980's the recommendations by the International Monetary Fund and the World Bank resulted in several "neoliberal policies" (Calva, 2004). The Mexican gross domestic product (GDP) showed a sustained growth after 1995 including a growth of 381% between 1980 and 1998 (Figure 1).

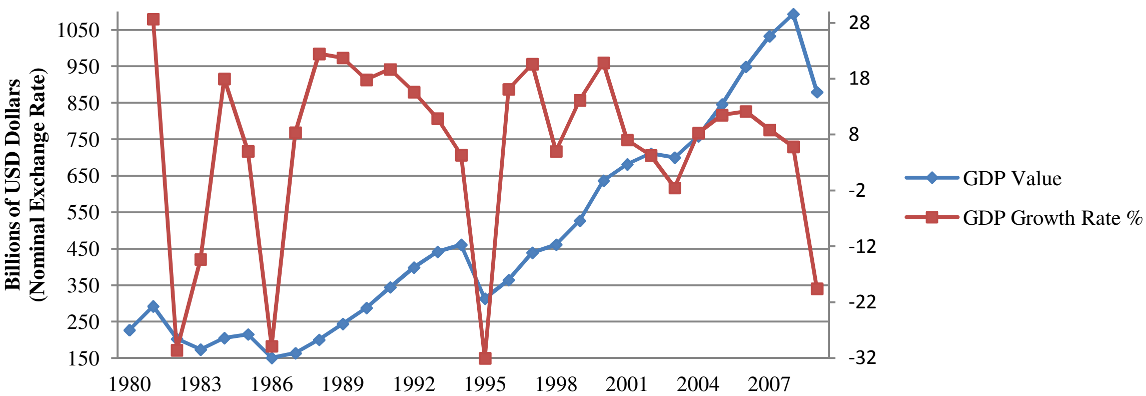

Figure 1. Mexico's GDP value and growth rate from 1980's to 2010; Source: UNCTAD, UNCTADstat

The trade liberalization process in Mexico happened in three main stages; economic reforms initiated in the early 1980's by recommendations of the International Monetary Fund (IMF) and the World Bank, Mexico's adherence to the General Agreement on Tariffs and Trade (GATT) in 1986, and the North America Free Trade Agreement (NAFTA) that

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came into effect in 1994. The implementation of policies and institutions to stimulate trade was a key factor in the attraction and allocation of Foreign Direct Investment (FDI) in the Mexican industry and service sectors as illustrated in Table 1. The NAFTA stimulated capital inflows to the industrial sector, which also contributed to the increase in the Mexican industrial manufacturing activity.

Table 1 Mexico's foreign direct investment distribution by economic sector

Definition/Year	1980	1985	1990	1995	2000	2002	2004	2005	2006	2007	2008	2009	2010
Industry	79.2	67.4	32.0	58.7	57.4	41.2	59.6	47.2	49.9	45.5	30.0	36.1	59.7
Services	8.1	25.2	59.2	28.3	27.6	49.6	34.1	40.0	44.7	43.2	44.7	49.9	22.8
Retailing	7.3	6.3	4.6	12.1	13.6	7.8	5.5	12.0	3.3	5.2	7.1	9.0	14.2
Extraction	5.3	1.0	2.5	0.9	0.9	1.1	0.8	0.8	2.0	5.6	18	4.9	3.3
Agriculture and livestock	0.1	0.0	1.6	0.1	0.5	0.4	0.1	0.0	0.1	0.5	0.1	0.1	0.0
Total Percentage	100	100	100	100	100	100	100	100	100	100	100	100	100

Source: Vazquez Galan (2009) and Mexican Economy Bureau

Figure 2 demonstrates the trends in Mexico's GDP and its growth rate. Although the contribution of the manufacturing industry to the Mexican GDP remained the same, the production value and total exports were not stagnant and there was a sustainable growth in all sectors of the Mexican economy in the last two decades. Especially since the intervention of the IMF and WB in the Mexican macro-policies in early 1980's, the Mexican industry and international trade policies supported the industrial manufacturing exports (CEFP, 2004).

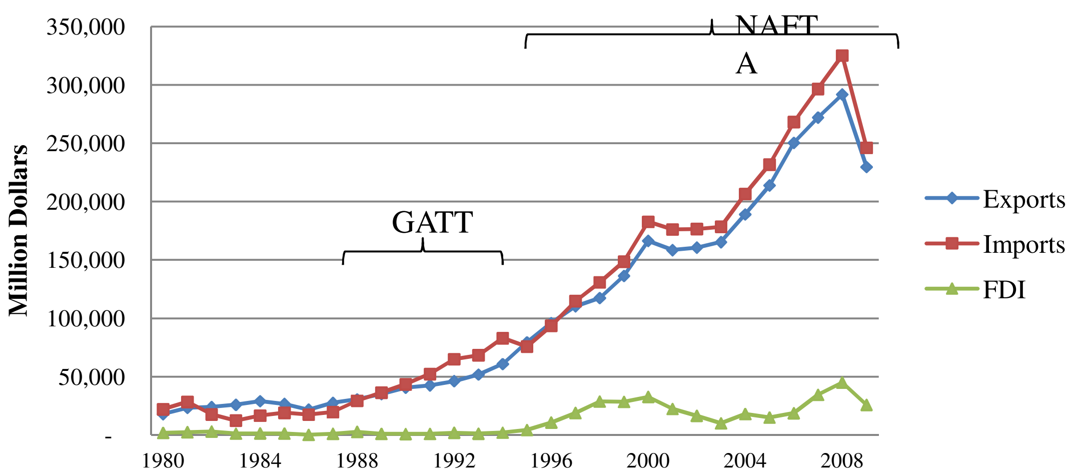


Figure 1. Mexican import, export and FDI (in US Dollars at current prices and current exchange rates in millions); Source: UNCTAD, UNCTADstat

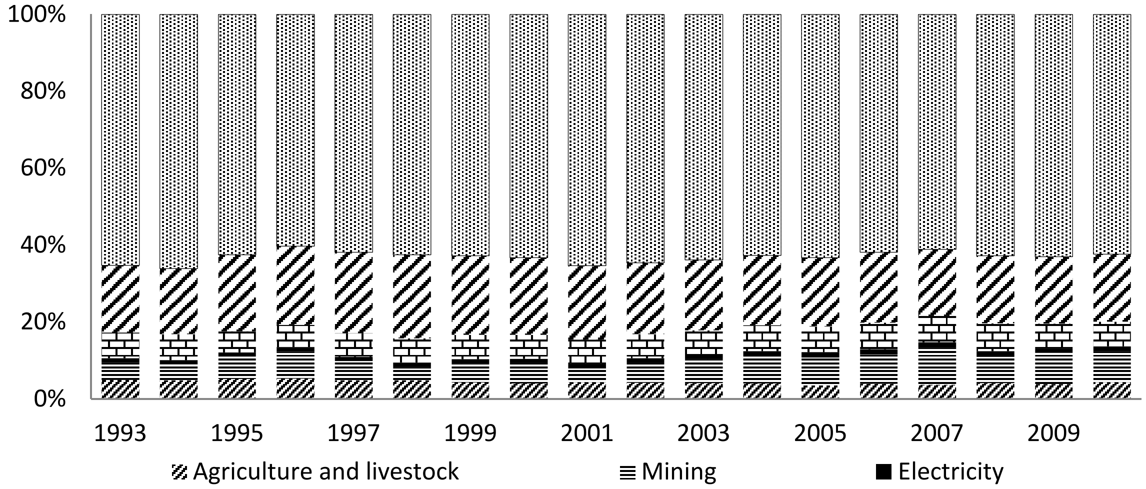


Figure 2. Contribution of various sectors to the Mexican GDP; Source: INEGI

The Mexican manufacturing industry's contribution to the total non-oil exports increased from around 50% in the 1980's to above 90% in the last decade. The manufacturing industry plays an active role in Mexican exports, though its contribution to the total GDP has remained the same at around 18% since 1993 (Figure 3). Nevertheless, the manufacturing industry is considered the main contributor to economic growth and industrial development in Mexico (CEFP, 2004). As such, it is important to analyze the evolution of the manufacturing industry to determine its current level of specialization. The question is whether all the sub-sectors are performing well or if this continuous growth relies on only a few sub-sectors.

This research aims to examine all the sub-sectors and determine which manufacturing industries should Mexico focus on, whether the high-tech industries are showing progress in Mexico, and what changes in industrial manufacturing strategy may enhance Mexico's growth. This is done by measuring the technological progress through an analysis of the learning rates in each sub-sector, and by identifying the different levels of knowledge accumulation among them.

Several studies have previously demonstrated that an increased efficiency in processes may result from an increased familiarity with the routine of such processes; as a process is recurred in t_1 *(t* for time), there is an accumulation of knowledge that leads to a better performance of that process in t_{1+n}. This accumulation or acquisition of knowledge has been called "learning" (Arrow, 1962). Learning by doing refers to the process by which production costs are reduced as experience is accumulated over time (Hornstein & Peled, 1997); knowledge accumulation can be captured by a learning curve that shows the relationship of outputs and inputs. Arrow (1962) in his seminal work "economic implications of learning by doing" concluded that learning occurs when attempts are made to solve a problem.

The initial observation of the learning curve is attributed to T.P. Wright in 1936 during research on factors affecting the cost of airplanes; he found that learning contributes to the reduction in labor hours spent in the production of an airframe. In 1954, F.J. Andress conducted a research on the learning curve as a production tool; he focused on the role of direct labor in the learning system (Adler & Clark, 1991). Baloff (1966) undertook a research to broaden the application of the learning curve in capital-intensive industries, introduced a learning model for a variety of industries, and reviewed some empirical results (Baloff, 1966). Baloff and Kenelly (1967) argued that a learning model should be taken into consideration when estimating the productivity path of a start-up process.

A learning curve can be defined as a function which relates performance to experience (Jackson, 1998). Learning curves demonstrate that an improvement in the output performance of any process caused by knowledge accumulation follows an *S* shape over time; it may be concluded that the learning effects are bound at some point in t_n, or learning eventually ceases (Hornstein & Peled, 1997). Five main characteristics of the learning curves were described in Hornstein and Peled's research, as the "stylized facts" of learning-by-doing: learning has a significant effect on efficiency; learning increases as a function of production volume; the scope of learning is bounded; there is an important component to learning which is firm-specific; and the experience effect on the development of new goods is more modest than its impact on efficiency.

Several papers have documented the evolution of the learning curve models, from univariate models to more complex multivariate models. Conventional univariate learning curves express a dependent variable (e.g. total production) in terms of a particular independent variable such as labor cost, investment, etc. According to Badiru (1992) the most famous univariate models include the log-linear model, the S-curve, the Stanford-B model, DeJong's learning formula, Levy's adaptation formula, Glover's learning formula, Pegel's exponential function, Knecht's upturn model, Yelle's product model, and multiplicative power model.

The experience curve phenomenon, developed by the Boston Consulting Group (BCG, 1960-1970's), looks at the total cost and widening of the inputs to the learning system. The experience curve, contrary to the learning curve, takes into consideration all possible inputs in a production process to find a relationship between one of many substitutable inputs and the cumulative output (OECD, experience curves for energy technology policy, 2000). The BCG may be applied to the total cost of a product, including different learning means such as research and development, economies of scale, and other cost factors. This concept was applied not only within a single company or process, but also to entire industries (Sark Van, 2008).

Technological capability and technological progress

Technological capability is the ability of an organization to utilize a variety of available knowledge and skills in order to acquire, assimilate, use, adapt, change and create technology (Ernst, Ganiatos, & Mytelka, 1998). Economies or organizations acquire knowledge to build up and accumulate their own technological capabilities by engaging in a process of technological learning. This technological learning is the transformation of knowledge acquired by individuals into organizational learning (Figueiredo, 2001).

Technological change or technical progress brings about production efficiencies which have a direct impact on productivity growth; several studies have concluded that technological change is the most important factor in aggregate economic growth (Ruttan, 2001). In order to understand technological change, as described by Link *et al* (1987), technology may be conceptualized as the physical representation of knowledge. The economic and social impacts of new knowledge are realized only with its adoption and utilization (Ruttan, 2001).

It is possible to evaluate or estimate the effect of technological change on production in terms of changes in the amount of production factors, with capital and labor being the most important. Technological change alters the input mix for a fixed level of output; a very simple scheme is summarized in Table 2 (Link, Kaufer, & Mokyr, 1987).

Table 2 Classification scheme of technological change

Neutral technological change	**Labor-saving technological change**	**Capital-saving technological change**
K/L ratio remains unchanged	K/Q ratio remains unchanged	L/Q ratio remains unchanged
Marginal rate of substitution among factors remains the same	K/L ratio increases	K/L ratio decreases
	Labor increases	Capital increases

K: Capital, L: Labor and Q: Output; Source: Ruttan (2001)

Technological progress enables organizations to achieve a higher output with the same amount of limited resources (labor and capital for instance). Innovations are labor-saving, capital-saving or neutral depending on whether capital's share in output increases, decreases or remains unchanged, respectively (Ramanathan, 1982). Several studies have calculated the technological learning rates; among them, Pramongkit *et al* (2000) calculated the technological learning rates for the Thai industry using a linear model; Karaoz and Albeni (2005) examined the Turkish industry, and Asgari and Yen (2009) examined the manufacturing and service industry in Malaysia, both using a cubic model.

The technological learning coefficient or learning elasticity, denoted in this paper as "α", is required for computing the learning level or progress ratio. This learning level or progress ratio describes the effect of learning every time production doubles over the unit production costs, or as described by Sark Van (2008) it is the relative amount of cost reduction per each doubling of the cumulative output.

According to Belkaoui (1986) the average time model of the log-linear model is represented by $Y = a X^{-\alpha}$ …..... (1) where: Y is the average cumulative labor hours, labor dollars, material costs of X number of units, or in this paper, the production value; a is the theoretical or actual value of the first unit; X is the cumulative number of units produced, or in this paper the cumulative production value; and α is the slope coefficient, exponent or learning index.

According to Belkaoui (1986) if production doubles then the formula changes into: $Y^* = a (2X)^{-\alpha}$ .... (2) Given the fact that learning takes place per doubling of production, the progress ratio or learning level is denoted as d (in this paper) or PR (as in Asgari and Yen, 2009): $d= Y^*/ Y= a (2X)^{-\alpha} / a X^{-\alpha}$ or $d= 2^{-\alpha}$ ………………………….... (3)

To measure the level of learning, the Progress Ratio (d) is estimated from the equation $d= 2^{-\alpha}$, given an already calculated measure for learning elasticity.

The interpretation of the progress ratio value is summarized in Table 3. A learning level below 1 indicates that learning is still taking place; therefore unit production cost decreases and efficiency increases, as total production increases. A learning level above 1 indicates forgetting; therefore unit production cost increases and efficiency decreases, as total production increases. A learning level equal to 1 indicates that there is no improvement or worsening, implying that productivity does not change and remains constant over time (Karaoz & Albeni, 2005).

Table 3 The interpretation of the progress ratio value

d < 1	d = 1	d > 1
Learning stage	No learning, no forgetting	Forgetting stage
Unit production cost decreases as output increases	Unit production cost remains the same as output increases	Unit production cost increases as output increases
Efficiency increases	No change in efficiency	Efficiency decreases
Productivity increases	No change in productivity	Productivity decreases

The learning elasticity is traditionally considered as a constant in the linear model; therefore, the progress ratio results in a unique single value. However as postulated by Arrow (1962) and some other scholars, the learning process is cumulative and its effects are enhanced as production continues over time (Asgari & Yen, 2009). An S-curve model, as previously described, portrays the actual trend of the learning process better. Badiru (1992) proposed a cubic model that was later tested and supported by Pramongkit *et al* (2000), and Asgari and Yen (2009). This dynamic cubic model treats learning elasticity as a variable; therefore, the progress ratio results in variable values over the period under analysis. We use both the linear model and cubic model in order to find the model that best fits the data for the Mexican manufacturing industry. Our research is focused on two main hypotheses about the development of a manufacturing industry which over time moves from labor-intensive to capital-intensive. For the analysis of the Mexican manufacturing industry, the hypotheses are:

a) If the Mexican manufacturing industry follows the same trend that currently developed countries did in the past, the Mexican labor-intensive sub-sectors (low-tech) should show a learning level (d) equal to or above 1.
b) The participation of low-tech sub-sectors in the total manufacturing production should be declining, and those in mid-low-tech and high-tech industries should be increasing.

Methodology

The data for the Mexican manufacturing industry sub-sectors was collected at 3-digits level from the Mexican Statistics, Geography and Information Bureau (INEGI). Prior to 2003, the Mexican sub-sector classification was grouped in 9 sub-sectors: 1) Food, beverages and tobacco products; 2) Textiles, wearing apparel, fur, leather, leather products and footwear; 3) Wood products including furniture; 4) Paper and paper products, printing and publishing; 5) Chemicals, petroleum products, rubber and plastics products; 6) Non-metallic mineral products; 7) Basic metals; 8) Fabricated metal products, machinery and equipment, medical, precision and optical instruments; and 9) Other manufacturing industries. Given the fact that the old classification cannot be re-organized following the ISIC classification, our research followed the original classification and re-grouped the 21-sub-sectors into 9 sub-sectors for data collected from 2003 to 2008.

The monetary data was converted into US$ based on the annual average exchange rates published by the Mexican Bank, and deflated based on 2005-CPI indices published by the Organization for Economic Cooperation and Development (OECD) to reflect all data at constant prices of US$ in 2005. Sub-sectors were classified according to the "classification of manufacturing industries based on technology" (technological intensities) published by the OECD as shown in Table 4.

Table 4 The Mexican sub-sector classification of "technological intensity"

SUB-SECTOR	Short description	Technological intensity
Food, beverages and tobacco products	Food	Low tech
Textiles, wearing apparel, fur, leather, leather products and footwear	Textile	Low tech
Wood products including furniture	Wood	Low tech
Paper and paper products, printing and publishing	Paper	Low tech
Chemicals, petroleum products, rubber and plastics products	Chemicals	Mid-high tech
Non-metallic mineral products	Non-metallic	Mid-low tech
Basic metals	Basic metals	Mid-low tech
Fabricated metal products, machinery and equipment, medical, precision and optical instruments	Machinery	High tech
Other manufacturing industries	Others	Low tech

The traditional linear model construction:

A linear model is used to calculate the learning elasticity (α) needed for estimation of the progress ratio or learning level (d) given the equation $d= 2^{-\alpha}$ ………………………………………………………..…………………………...… (3)
which indicates that every doubling of total production reduces unit production costs by a factor of $2^{-\alpha}$.

The most common linear model is $c_t= c_1X_t^{-\alpha}$ or its equivalent in a logarithmic form $\ln c_t= \ln c_1- \alpha \ln X_t$……….... (4)
It states that the unit production cost in time *t* is a function of the cumulative production powered to the learning elasticity, multiplied by the unit production cost at time 1.

In the Cobb-Douglas production function $Q_t=A_tL_t^{\beta}K_t^{\Theta}$ or its equivalent logarithmic form
$\ln Q_t= \ln A_t + \beta \ln L_t+ \Theta \ln K_t$ ……………………………………………………………………………..……..….. (5)
Q is the production value added, A is the total factor productivity, L is the labor cost, K the capital, and β and Θ are the elasticities for labor and capital, respectively.

Learning and technology spillovers of the technology stock enhance the total factor productivity which in turn contributes to production increases, and leads to higher cumulative production outputs that stimulate learning (Watanabe & Asgari, 2004). The level or stock of technology, A_t in this particular case, can be written as follows: $A_t= H X_t^{\alpha}$ or its logarithmic equivalent $\ln A_t= \ln H + \alpha \ln X_t$ ……………………………………………………………………… (6)

It states that the level of technology at time *t* is a function of the cumulative production raised to the power of the learning elasticity, and multiplied by a constant H.

With the logarithmic forms of equation 5 and 6 combined, the new equation is:

$\ln Q_t= \ln H + \alpha \ln X_t + \beta \ln L_t+ \Theta \ln K_t$ ………………………………………………………………………… (7)

Expressing labor in terms of the production value added (labor ratio):

$\ln(L/Q)_t= -\ln H-\alpha \ln X_t+(1-\beta)\ln L_t-\Theta \ln K_t$ …………………………………………………………………… (8)

Because capital may be expressed as a function of labor, with the expansion of output the relationship between capital and labor can be expressed as $K_t=\mu L_t^{\lambda}$ or its equivalent logarithmic form $\ln K_t = \ln\mu + \lambda \ln L_t$.)……………… (9)

Here λ expresses the type of technological bias as production expands, and μ is a constant; when λ is greater than 1, capital intensity as measured by capital-labor ratio increases as output increases (Pramongkit, Shawyun, & Sirinaovakul, 2000

Substituting $\ln K_t = \ln\mu + \lambda \ln L_t$ in equation $\ln(L/Q)_t= -\ln H-\alpha \ln X_t+(1-\beta)\ln L_t-\Theta \ln K_t$:

$\ln(L/Q)_t= -\ln H-\Theta \ln\mu -\alpha \ln X_t+(1-\beta-\Theta\lambda)\ln L_t$ ……………………………………………………………… (10)

If we consider $\sigma_1 = -\ln H -\Theta \ln\mu$, $\sigma_2 = -\alpha$ and $\sigma_3 = 1-\beta-\Theta\lambda$ then the final equation is:

$\ln(L/Q)_t= \sigma_1 + \sigma_1 \ln X_t + \sigma_3 \ln L_t$ …………………………………………………………………………… (11)

Construction of the cubic model

A cubic model is used to calculate the learning elasticity (α) which is required to estimate the progress ratio or learning level (d) given the equation $d= 2^{-\alpha}$………………………………………………………………………… (3)

The dynamic cubic model proposed by Belkaoui (1986) and Badiru (1992), and later tested by Asgari and Yen (2009) is: $\ln c_t= \ln c_1+ B \ln X_t + C (\ln X_t)^2 + D (\ln X_t)^3$ ……………………………………………………… (12)

where c_t is the unit production cost in time *t*; c_1 is the unit production cost at the beginning of the period; and X_t is the cumulative production at time *t*. This function states that per unit cost of output at time *t* is a function of cumulative production (Karaoz & Albeni, 2005).

The most common linear model is $c_t= c_1 X_t^{-\alpha}$ or $\ln c_t= \ln c_1- \alpha \ln X_t$………………………………………… (13)

$Q_t = A_t L_t^{\beta} K_t^{\Theta}$ or $\ln Q_t = \ln A_t + \beta \ln L_t+ \Theta \ln K_t$ ………………………………………………………… (14)

is the Cobb-Douglas production function.

The level or stock of technology can be written as follows: $A_t= HX_t^{\alpha}$ or its logarithmic equivalent

$\ln A_t= \ln H + \alpha \ln X_t$. ……………………………………………………………………………………… (15)

From equation 13 we have that $X_t^{\alpha} = c_1/c_t$ and after combining 13 and 15 we have $A_t= H c_1/c_t$ or its logarithmic form $\ln A_t = \ln H + \ln c_1/c_t$. ……………………………………………………………………………………… (16)

Transforming equation 12 to represent the ratio between the unit production cost in time 1 and the unit production cost in time *t*, $\ln c_1/c_t=-[B\ln X_t + C(\ln X_t)^2 + D(\ln X_t)^3]$ ……………………………………………………………(17)

After replacing equation 16 into equation 17, the resulting equation is:

$\ln A_t= \ln H-B\ln X_t - C(\ln X_t)^2 - D(\ln X_t)^3$…………………………………………………………………… (18)

Capital may be expressed as a function of Labor, $K_t=\mu L_t^{\lambda}$ or its equivalent logarithmic form

$\ln K_t = \ln\mu + \lambda \ln L_t$. ………………………………………………………………………………………… (19)

Equation 18 is inserted into the Cobb-Douglas production function described in equation 16, resulting in the equation $\ln Q_t = \ln H - B\ln X_t - C(\ln X_t)^2 - D(\ln X_t)^3 + \beta \ln L_t + \Theta \ln K_t$ ……………………………………………….........………. (20)

Replacing equation 19 into equation 20, and expressing labor in terms of the production value added $\ln(L/Q)_t = -\ln H - \Theta\ln\mu + B\ln X_t + C(\ln X_t)^2 + D(\ln X_t)^3 + (1-\beta-\Theta\lambda)\ln L_t$ ……………………………………………………………….…..… (21)

If we consider $\sigma_1 = -\ln H - \Theta\ln\mu$ and $\sigma_2 = 1-\beta-\Theta\lambda$ then the final equation is:

$\mathbf{\ln(L/Q)_t = \sigma_1 + B\ln X_t + C(\ln X_t)^2 + D(\ln X_t)^3 + \sigma_2 \ln L_t}$ ……………………………………………………………… (22)

Through regression analysis, the A, B, C and D coefficients are calculated and then used to compute the value of learning elasticity α, and finally the progress ratio.

Estimation of the learning elasticity

According to Karaoz and Albeni (2005) the first derivative of equation, $\ln(L/Q)_t = \sigma_1 + B\ln X_t + C(\ln X_t)^2 + D(\ln X_t)^3 + \sigma_2 \ln L_t$ gives the learning elasticity.

$\ln c_t = \ln(L/Q)_t$ where unit production cost at time *t* is a function of the difference between unit labor cost and the unit value added, then $\ln c_t = \sigma_1 + B\ln X_t + C(\ln X_t)^2 + D(\ln X_t)^3 + \sigma_2 \ln L_t$ or $c_t = e^{\sigma 1 + B\ln Xt + C(\ln Xt)2 + D(\ln Xt)3 + \sigma 2 \ln Lt}$ ……..... (23)

And after applying derivation:

$\partial c_t / \partial X_t = e^{\sigma 1 + B\ln Xt + C(\ln Xt)2 + D(\ln Xt)3 + \sigma 2 \ln Lt} [B/X_t + (2C/X_t)\ln X_t + (3D/X_t)\ln X_t^2]$ ……………..……………………… (24)

Substituting c_t with $c_t = e^{\sigma 1 + B\ln Xt + C(\ln Xt)2 + D(\ln Xt)3 + \sigma 2 \ln Lt}$ $\partial c_t / \partial X_t = c_t / X_t [B + 2C\ln X_t + 3D\ln X_t^2]$ ……………...… (25)

And the learning elasticity **–α** is: $(\partial c_t / \partial X_t)(X_t / c_t) = B + 2C\ln X_t + 3D\ln X_t^2$ ………………..……………….....…… (26)

The equation to calculate the learning elasticity is $\boldsymbol{\alpha = -[B + 2C\ln X_t + 3D(\ln X_t)^2]}$

Model Computation

a) The linear model computation

The model $\mathbf{\ln(L/Q)_t = \sigma_1 - \sigma_2 \ln X_t + \sigma_3 \ln L_t}$ was computed and through regression analysis the coefficients (σ_1, σ_2 and σ_3) were obtained (Table 5), and α values were used to estimate the progress ratio indices for every single sub-sector in the Mexican manufacturing industry, as shown in Table 6.

Table 5 Linear model regression results and progress ratio value

Manufacturing industry	R^2	F	σ_1	σ_2	σ_3	d
Food	0.11	1.1	-4.64	0.09	0.08	1.061
Textile	0.51	9.24	-3.15	0.13	-0.02	1.096
Wood	0.89	70.73	-0.66	0.12	-0.19	1.083
Paper	0.81	37.68	-7.97	0.19	0.21	1.144
Chemicals	0.40	5.88	-7.79	0.10	0.29	1.068
Non-Metallic	0.81	38.70	-6.25	0.08	0.21	1.060
Basic Metals	0.60	13.74	-10.31	0.18	0.35	1.136
Machinery	0.95	166.98	-8.63	0.09	0.34	1.064
Others	0.86	53.85	-3.80	0.19	-0.06	1.142

b) The cubic model computation

The cubic model: $\mathbf{\ln(L/Q)_t = \sigma_1 + B\ln X_t + C(\ln X_t)^2 + D(\ln X_t)^3 + \sigma_2 \ln L_t}$ was computed and through regression analysis the coefficients (σ_1, B, C, D and σ_2) were obtained (Table 7); these coefficients were then used to estimate the learning elasticity according to the formula $\alpha = -[B + 2C\ln X_t + 3D\ln X_t^2]$. The learning level (progress ratio) indices were calculated for every single sub-sector in the Mexican manufacturing industry as shown in Table 8.

Table 6 Progress ratio estimates by sub-sector (1988-2008)

Sub-Sector	Progress Ratio	Rank
Non Metallic	1.060	1
Food	1.061	2
Machinery	1.064	3
Chemicals	1.068	4
Wood	1.083	5
Textile	1.096	6
Basic Metals	1.136	7
Others	1.142	8
Paper	1.144	9
Total Mexican Manufacturing Industry	1.061	

Table 7 Cubic model regression results

Manufacturing Industry	R^2	F	σ_1	B	C	D	σ_2
Food	0.31	1.79	2034.67	-299.79	14.71	-0.24	-0.05
Textile	0.57	5.25	-2338.33	362.17	-18.71	0.32	0.05
Wood	0.89	31.50	-315.37	51.58	-2.80	0.05	-0.18
Paper	0.81	17.16	-24.22	3.66	-0.23	0.01	0.24
Chemicals	0.86	25.38	4115.65	-617.25	30.81	-0.51	0.07
Non-Metallic	0.91	41.39	984.53	-160.73	8.71	-0.16	0.09
Basic Metals	0.66	7.73	1549.23	-244.92	12.85	-0.22	0.22
Machinery	0.95	77.04	-378.64	54.45	-2.66	0.04	0.37
Others	0.86	24.29	-105.86	16.75	-0.89	0.02	-0.06

Table 8 Progress ratio estimates by manufacturing sub-sector

Year	Total MFG	Food	Textile	Wood	Paper	Chemicals	Non Metallic	Basic Metals	Machinery	Others
1988	0.83	0.80	1.60	1.14	1.09	0.67	1.03	0.94	1.12	1.23
1989	1.20	1.17	0.99	1.06	1.13	1.37	1.18	1.21	1.04	1.15
1990	1.21	1.20	0.97	1.06	1.15	1.41	1.13	1.19	1.04	1.13
1991	1.12	1.11	1.06	1.08	1.17	1.25	1.03	1.12	1.06	1.12
1992	1.01	1.00	1.19	1.10	1.19	1.07	0.93	1.05	1.08	1.12
1993	0.91	0.89	1.35	1.12	1.21	0.89	0.84	0.98	1.10	1.12
1994	0.81	0.79	1.53	1.14	1.22	0.74	0.76	0.91	1.13	1.12
1995	0.75	0.75	1.65	1.16	1.23	0.66	0.72	0.87	1.15	1.12
1996	0.72	0.72	1.69	1.16	1.23	0.61	0.71	0.83	1.16	1.12
1997	0.70	0.70	1.74	1.16	1.23	0.57	0.69	0.79	1.16	1.12
1998	0.68	0.68	1.77	1.16	1.24	0.54	0.67	0.76	1.17	1.12
1999	0.66	0.66	1.81	1.16	1.24	0.51	0.66	0.74	1.18	1.12
2000	0.64	0.65	1.84	1.16	1.24	0.48	0.65	0.71	1.19	1.12
2001	0.62	0.63	1.87	1.16	1.24	0.45	0.63	0.70	1.20	1.12
2002	0.61	0.61	1.90	1.17	1.25	0.43	0.62	0.68	1.20	1.12
2003	0.59	0.60	1.93	1.17	1.25	0.39	0.61	0.66	1.21	1.12
2004	0.57	0.58	1.96	1.17	1.25	0.35	0.59	0.64	1.22	1.12
2005	0.55	0.57	1.99	1.17	1.25	0.31	0.58	0.62	1.22	1.12
2006	0.53	0.55	2.03	1.17	1.25	0.27	0.57	0.60	1.23	1.12
2007	0.51	0.54	2.06	1.17	1.26	0.24	0.55	0.57	1.24	1.12
2008	0.49	0.52	2.09	1.18	1.26	0.21	0.54	0.55	1.25	1.12

Results and Discussion

Table 9 summarizes the progress ratio average values before and after the NAFTA, and highlights the impact of NAFTA on the different manufacturing subsectors. The overall learning level performance of the manufacturing industry was stagnant from 1988 to 1994[2], indicating that the industry did not experience any productivity gain during this period. NAFTA stimulated technological change in the industry, with an average overall learning level of 0.62 from 1995 to 2008, which indicates that productivity levels had remarkable improvements after new policies were implemented under the NAFTA agreement.

Table 9 Average progress ratio values before and after NAFTA

	total MFG	food	textile	wood	paper	chemicals	non metallic	basic metal	machinery
Before NAFTA	1.01	1.00	1.24	1.10	1.17	1.06	0.98	1.06	1.08
After NAFTA	0.62	0.63	1.88	1.17	1.24	0.43	0.63	0.69	1.20
21 Years	0.75	0.75	1.67	1.14	1.22	0.64	0.75	0.81	1.16

In the analysis of 1998-2008 data, the linear model indicates that all Mexican subsectors were in a forgetting stage, but the cubic model before and after NAFTA shows that almost all subsectors were forgetting before NAFTA with the exception of the non-metallic industry; the NAFTA had a positive impact on the food, chemicals, non-metallic and basic metals industries as observed in Table 9, but a negative impact on the textile, wood, paper (labor intensive subsectors), and machinery industry. The chemical industry benefited the most during the NAFTA period while the textile industry shows the worst performance.

The expected results for capital intensive industries were progress ratio values below 1. It is interesting, however, that the estimated values depicted in Figure 4 show the "food industry" in a learning stage although this industry is a low-tech or labor intensive industry.

The food industry suffered productivity issues during 1989, 1990 and 1991; but the unit production cost increase was stabilized in 1992 (progress ratio d= 1.0) and from 1993 onward the food industry exhibited a sustained decrease in the unit production cost per doubled production, culminating in a 51% decrease in 2008. It can be inferred that the food industry experienced innovation activities and technological assimilation that contributed to its outstanding performance between 1994 and 2008.

The food industry is the only low-tech sub-sector that is still accumulating knowledge leading to a more competitive industry, but its contribution to the total manufacturing industry in terms of production value decreased from 24.50% to 21.85% during the period of analysis as summarized in Table 10.

The chemical industry classified as mid-high tech based on its technological intensity, had the most remarkable performance in terms of technological change by the estimated progress ratio values shown in Figure 5. The industry had productivity issues from 1989 to 1992 with 41% increase in its unit production cost per doubled production, in 1991. This tendency of the unit production cost increase was reversed from 1994, and the industry achieved around 50% unit production cost reduction between 1998 and 2001.

[2] Although NAFTA came into effect on January 1st, 1994, the analysis considers 1994 as before the NAFTA period because the impact on the industry cannot be observed until at least a year has passed.

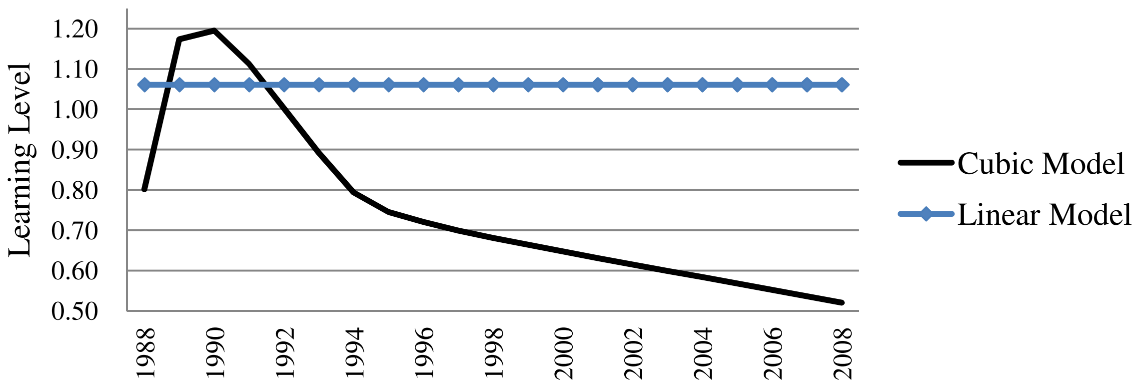


Figure 3. Progress ratio values for the food industry (low-tech).

The chemical industry continued with its learning trend in the last decade towards an outstanding learning level of 0.21 in 2008. This industry benefited the most during NAFTA with an average progress ratio of 0.43 which indicates that the unit production cost in average decreased 57% per doubled production. The chemical industry's contribution to the total manufacturing value increased from 18.20% in 1988 to 32.85% in 2008 as shown in Table 10, an exceptional growth level in line with its observed learning performance during this period.

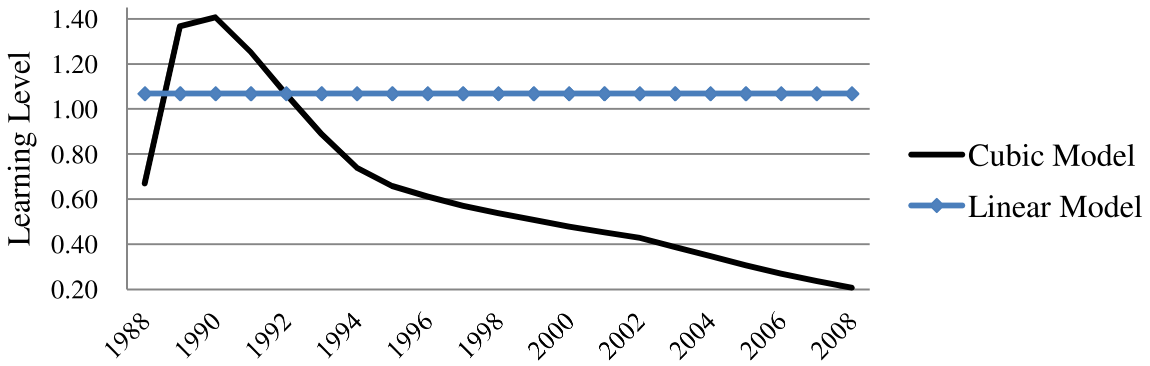


Figure 4. Progress ratio values for the chemical industry (mid-high tech)

The non-metallic and basic metal industries, classified as mid-low tech, show a similar trend in the period under analysis. Both industries, as shown in Figure 6 and Figure 7, overcame their productivity problems early in the 1990's and achieved good learning levels from 1993 onward. The non-metallic industry achieved better improvement levels from 1995 to 2002 compared with the basic metals industry. In 1995, the unit production cost in the non-metallic industry decreased by 28% per doubled production, while in the basic metal industry this cost decreased by only 13%.

In 2002, however, the unit production cost decreased by 38% per doubled production in the non-metallic industry, while in the basic metal this cost decreased by only 32%. These observations indicate that stronger innovation activities were carried out in the non-metallic industry between 1993 and 1999 versus the basic metal industry, but from 2000 to 2005 the basic metal industry carried out stronger innovation activities (Figure 7) than the non-metallic industry. In year 2008 both industries showed similar progress ratio values, 0.54 for the non-metallic industry and 0.55 for the basic metals. Both industries have achieved outstanding learning levels, reaching around 45% unit production cost decreases per doubled production in 2008.

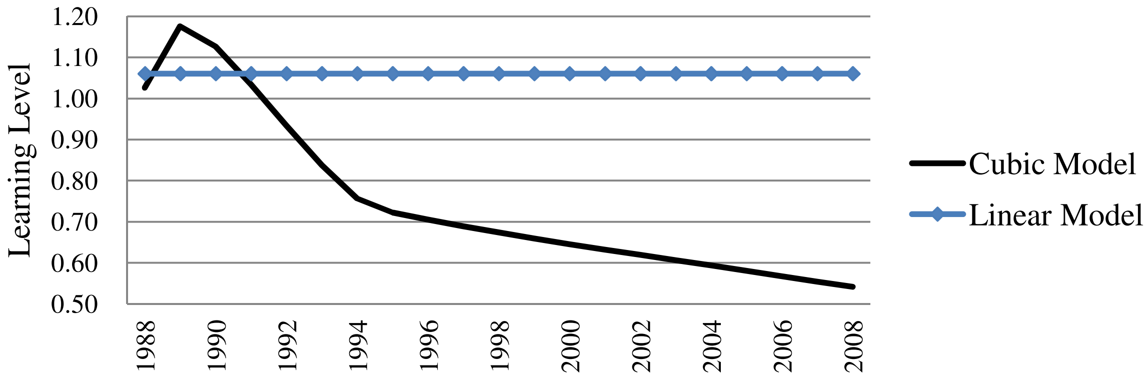


Figure 5. Progress ratio values for the non-metallic industry (mid-low tech)

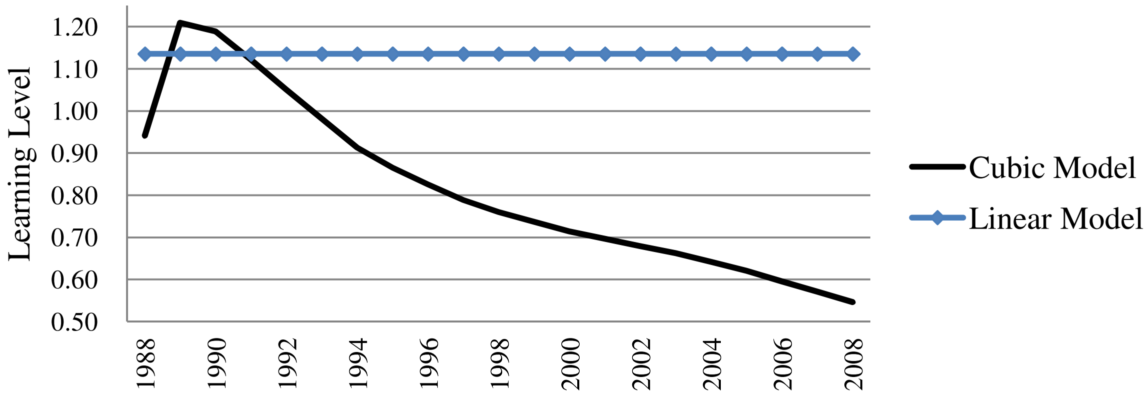


Figure 6. Progress ratio values for the basic metals industry (mid-low tech)

Subsectors in forgetting situations

The expected results for labor-intensive industries, classified as low-tech according to their technological intensity were progress ratio values equal or above 1 (d). Although the calculated values portrayed in Figure 8 show the machinery industry in a forgetting stage, this industry is a high-tech capital intensive industry. The machinery industry did not overcome its productivity problems during the period under analysis, showing a progress ratio of 1.15 in 1994, 1.20 in 2002 and 1.25 in 2008. Unit production costs increased 15% in 1994, 20% in 2002 and 25% in 2008 per doubled production.

The data shown in Table 2 indicates that the machinery industry was actually expanding from 1988 until 2002, but since 2003 the industry has contracted. Because the machinery industry is a high-tech industry, its worsening situation in the learning level reveals a concern for the future of the manufacturing industry in Mexico (Figure 8). In the natural course of development in the manufacturing industry a change is expected in manufacturing specialization moving from labor intensive to capital intensive industries; in other words, moving from low-tech to high-tech industries.

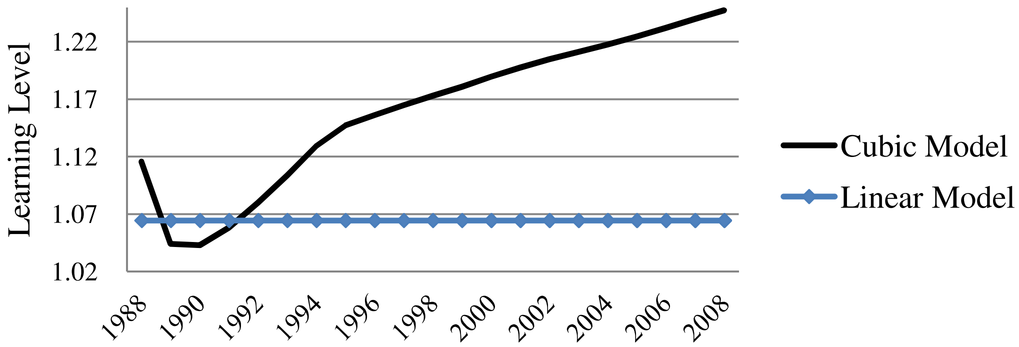


Figure 7. Progress ratio values for the machinery industry (high-tech)

The textile industry has the worst performance among all the Mexican manufacturing sub-sectors (Figure 9). After 1991 and before NAFTA the textile industry suffered serious productivity issues, and the observed progress ratios moved from 1.06 in 1991 to 1.53 in 1994 indicating that the unit production cost increased from 6% to 53% between the mentioned years.

The calculated progress ratio values indicate a chronic situation in the industry, reaching a deteriorated progress ratio of 2.09 in 2008. The textile industry is no longer competitive and no learning is taking place in this industry. NAFTA has not benefited this industry and instead has worsened its performance level. It can be deducted that no new technology has been acquired and implemented in the industry, no innovation activities have taken place, and almost no investment has reached the industry during the period of analysis 1988-2008.

This analysis supports several studies that indicate the textile manufacturing industry in Mexico is not competitive and that the industry has suffered from competitive markets such as China. The industry's contribution to the total manufacturing industry has decreased from 8.92% to 2.60% in 2008.

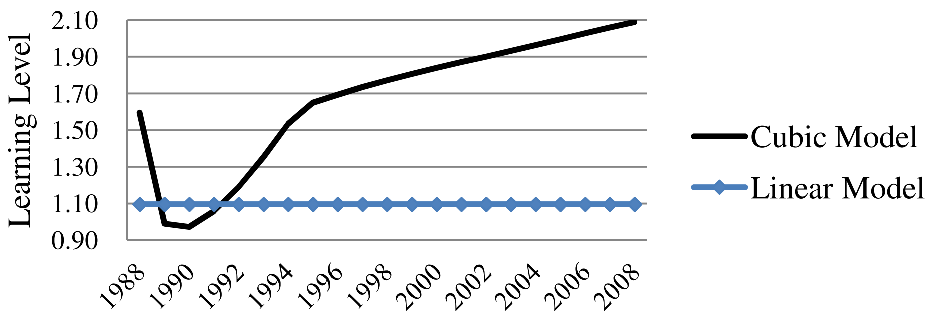


Figure 8. Progress ratio values for the textile industry (low-tech)

The wood industry which includes wood products and furniture, and the paper industry which captures paper, paper products, printing and publishing show an almost similar trend over the period of analysis as depicted in Figure 10 and Figure 11. The wood industry had some improvement in its forgetting level in 1989 and 1990, but after 1991 this situation is worsening though not as bad as the textile subsector.

The unit product cost shows an average increase of 17% per doubled production between 1995 and 2008. The industry's participation in the total production value in the manufacturing industry declined from 3.41% in 1998 to a poor level of 0.61 in 2008 as indicated in Table 10.

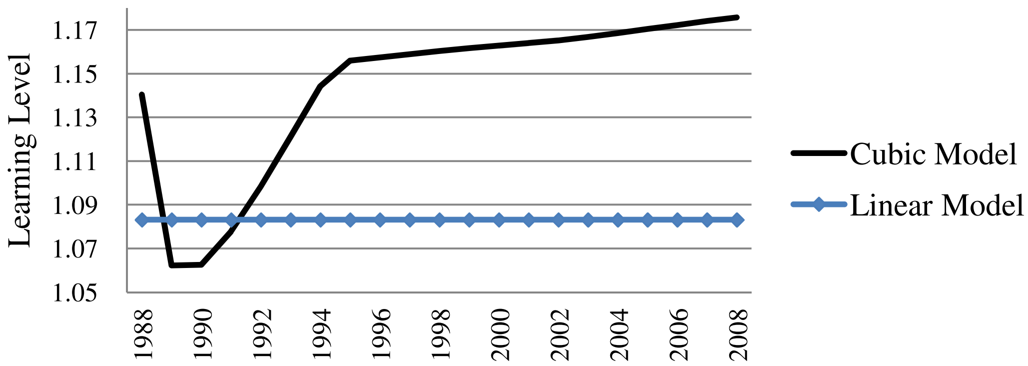


Figure 9. Progress ratio values for the wood industry (low-tech)

The paper industry shows a chronic forgetting level and is the only manufacturing industry that does not show any improvement in any year, but only a worsening level as time goes by. The industry's forgetting level is smaller than the textile industry, and its progress ratio level of 1.26 in 2008 indicates that the unit production cost would increase 26% per doubled production.

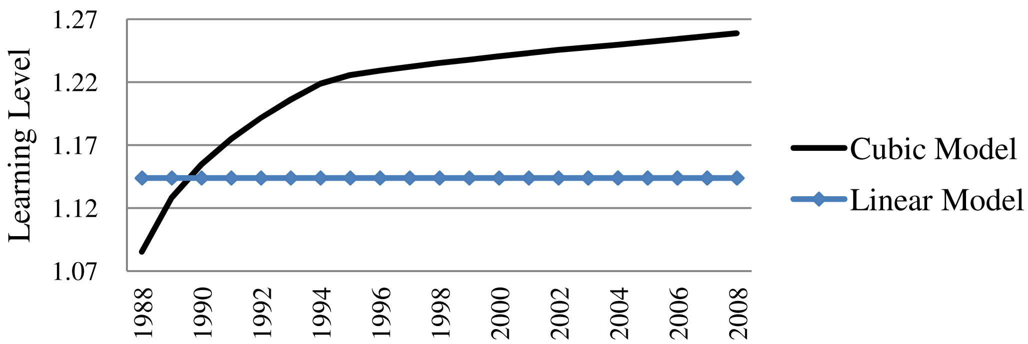


Figure 10. Progress ratio values for the paper industry (low-tech)

NAFTA has negatively impacted the industry and is not a competitive industry. The industry's contribution to the total manufacturing industry decreased from 5.43% in 1998 to 3.23% in 2008; however its current contribution to the whole industry is higher than the contribution of the textile and wood industry together (3.21%), as shown in Table 10.

Manufacturing subsectors by technological intensity

The different policies implemented under the NAFTA agreement have led to a re-structuring of the whole manufacturing industry as observed in Table 10 and Table 11. Labor intensive industries contribute less to the manufacturing industry, with the exception of the food industry, whereas capital intensive industries contribute more, with the exception of the machinery industry.

Table 10 Industry participation in the total manufacturing production value

Year	Chemical %	Machinery %	Food %	Basic Metals %	Non-Metallic %	Paper %	Textiles %	Wood %	Others %
1988	18.20	25.44	24.50	7.67	4.63	5.43	8.92	3.41	1.80
1989	17.22	26.44	24.83	7.20	4.44	5.42	8.87	3.47	2.12
1990	16.59	26.95	25.71	6.72	4.62	5.12	8.68	3.22	2.40
1991	15.48	28.28	27.01	5.52	4.88	4.89	8.54	3.12	2.27
1992	15.01	28.97	27.13	4.98	5.16	4.87	8.30	3.05	2.52
1993	14.80	28.50	27.85	4.82	5.48	4.76	8.22	3.05	2.51
1994	14.67	29.89	27.19	4.92	5.25	4.70	7.82	2.94	2.62
1995	14.90	33.75	24.17	5.94	4.00	4.54	7.46	2.44	2.80
1996	18.16	31.90	25.01	10.19	4.17	4.68	5.05	0.59	0.24
1997	17.88	33.47	23.71	10.29	4.16	4.49	5.12	0.62	0.25
1998	17.65	35.26	23.14	9.15	4.47	4.59	4.85	0.64	0.26
1999	17.43	35.73	23.61	8.18	4.70	4.78	4.66	0.65	0.26
2000	17.34	36.95	23.08	7.95	4.62	4.77	4.45	0.60	0.25
2001	17.68	36.21	24.91	6.90	4.63	4.71	4.16	0.57	0.24
2002	17.83	34.75	26.07	7.09	4.69	4.70	4.06	0.57	0.24
2003	29.79	27.34	22.99	6.29	4.56	3.83	3.79	0.80	0.62
2004	30.58	26.30	22.41	7.83	4.33	3.59	3.59	0.78	0.59
2005	32.01	26.12	21.92	7.51	4.19	3.57	3.34	0.75	0.58
2006	31.68	26.42	21.17	8.67	4.15	3.48	3.16	0.72	0.56
2007	31.27	26.75	21.67	8.78	4.14	3.31	2.88	0.67	0.54
2008	32.85	25.19	21.85	9.29	3.86	3.23	2.60	0.61	0.51

Table 11 Industry production contribution before and after NAFTA[a]

Subsector	Chemical	Machinery	Food	Basic Metals	Non-Metallic	Paper	Textiles	Wood	Others
Average Before NAFTA	16.00%	27.78%	26.32 %	5.97 %	4.92%	5.03 %	8.48%	3.18 %	2.32 %
Average After NAFTA	23.36%	31.15%	23.26 %	8.15 %	4.33%	4.16 %	4.23%	0.79 %	0.57 %

a) The analysis considers the before NAFTA period from 1988 to 1994, and the after NAFTA period from 1995 to 2008

Figure 12 depicts the development path followed by the manufacturing industry, showing that Mexico is moving from a low-tech industry with low value added production activities to a mid-low mid-high tech industry with high value added production activities.

The contribution of low-tech industries to the manufacturing sector decreased from 44.6% in 1988 to 28.81% in 2008, whereas for the mid-high tech industry it increased from 18.20% to 32.85%. The mid-low industry's contribution, however, almost remained the same during this period, moving from 12.30% in 1988 to 13.15% in 2008.

The participation of the high-tech industry in the manufacturing industry shows an expansion from 1998 to 2002, but its contribution level in 2008 is similar to the 1988 level, 25.19% in 2008 versus 25.44% in 1988.

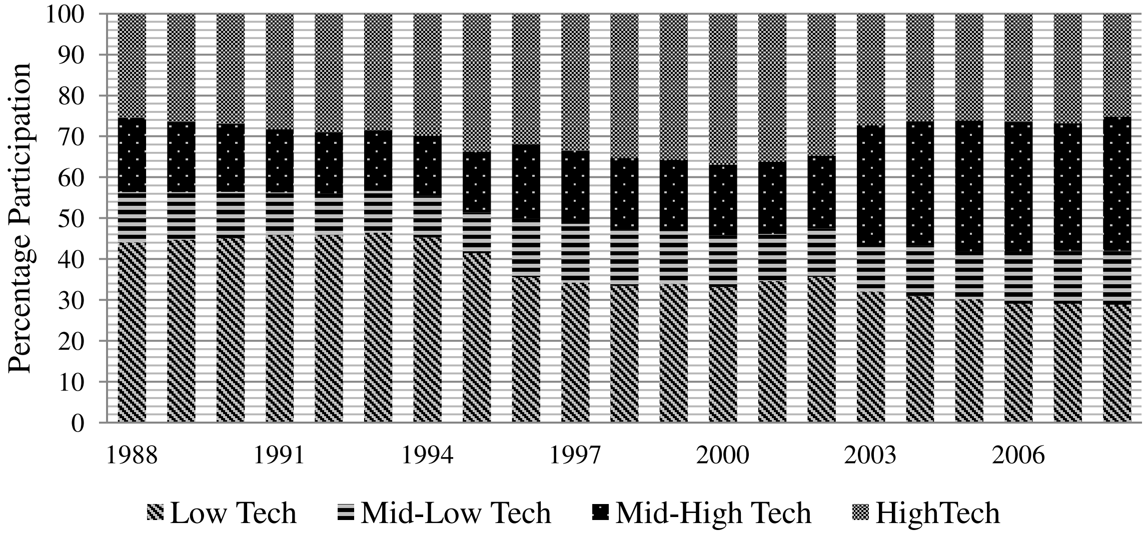
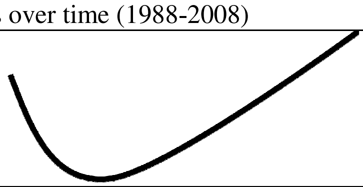
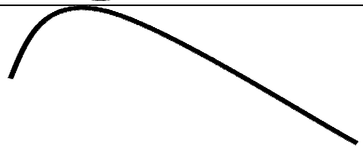
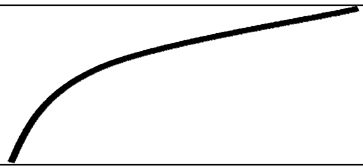


Figure 11. Manufacturing production contribution by technological intensity. Source: INEGI

Patterns of technological learning level

The learning path followed by each industry depends on different internal and external factors. The Mexican subsectors were analyzed and grouped based on the observed learning path during the period 1988-2008. Table 12 shows that the Mexican manufacturing industry can be grouped into three main patterns of learning, two of them with a concave shape and one with a convex shape; the convex shape is further subdivided into two learning paths depending on the estimated progress ratio values.

Table 12 Patterns of technological learning over time

Patterns of learning levels over time (1988-2008)		**Learning Path**	**Industry**
Convex learning path with a minimum		Forgetting at all time	Machinery
		Learning at some beginning periods, but forgetting afterwards	Textile Wood
Concave learning path with a maximum		Forgetting after beginning periods, but learning afterwards	Food Chemical Non-Metallic Basic Metals
Concave learning path with no maximum		Forgetting at all time	Paper

The machinery industry shows no learning but continuous forgetting. However, a more in depth analysis uncovered an interesting finding regarding the actual progress ratio values in the various sub-sectors of the machinery industry; the textile and wood industry follow the same convex learning path, with some learning at the beginning of the period but forgetting afterwards. This is mainly due to the nature of the two latter industries which are labor intensive, low- tech intensity. Also both industries face high competition levels in the global market from cheaper labor countries.

The food, chemical, non-metallic and basic metals industries show a forgetting level after the beginning period, but this tendency is reversed and the industries move towards a learning stage which indicates that productivity issues were overcome and the industries engaged in innovation activities that contributed to lower production cost as production increased. This trend in the progress ratio level is probably the result of structural changes, for instance the FDI law enacted in 1993 and the NAFTA.

The paper industry follows a concave learning path with no maximum; the industry shows continuous forgetting, which indicates that its performance is worsening over time.

Factors contributing to technological learning

The dynamism of technological learning is influenced by different factors that could be either internal or external. This dynamism directly affects the changes in the progress ratio path over time at the firm, industry or national level. The achieved learning level may also vary at different manufacturing locations of a given company.

a) Globalization

Mexico implemented several neoliberal policies early in the 1980's that set the basis for its globalization process. The country gradually opened its economy to the world through various policies, such as adherence to the GATT in 1986. This globalization process has contributed to the development of the manufacturing industry in Mexico as a whole, but it has negatively impacted the labor intensive industries.

b) Foreign direct investment

Mexico re-designed its policy for FDI and eliminated several restrictions in the new FDI law of 1984. The FDI inflows, however, did not increase as expected and Mexico reformed its FDI law in 1993. This reform was in line with the NAFTA agreement that came into effect in 1994. The 1993 reforms had an immediate effect in the FDI inflows in Mexico as shown in Table 2, and around 50% of these inflows were allocated to the industrial sector. The manufacturing industry has benefited from this structural change that directly impacted technological learning in the industry.

c) North America Free Trade Agreement

The NAFTA has been the major contributor to the current condition of the Mexican manufacturing industry, and has influenced the allocation of internal and external resources in the country. The NAFTA, as observed in Table 14, has shaped the technological learning levels in various industries in Mexico. Through the NAFTA, Mexico has been able to consolidate its manufacturing industry and benefit from technological spillovers.

d) Other free trade agreements

Mexico has actively engaged in different free trade agreements not only in the region but globally. The most important free trade agreements besides NAFTA are the free trade agreement between Mexico and the European Union (2007), and the one between Mexico and Japan (2011). The various trade agreements have influenced technological learning in the manufacturing industry, and contributed to the re-structuring of the whole manufacturing industry.

Conclusion

The research findings demonstrate that the cubic model is stronger and provides better insights to the dynamic technological progress and learning effects in the industries compared with the linear model.

The study identified three main patterns of technological learning among the different industries: 1) a convex learning path with continuous forgetting or learning at the beginning but forgetting afterwards, 2) a concave learning path with forgetting after the beginning period but learning afterwards, and 3) a concave learning path with continuous forgetting.

We found that overall the Mexican manufacturing industry is moving from labor intensive industries to capital intensive industries. The calculated progress ratios for the textile, wood and paper put these industries in a forgetting level, while the food industry remains very competitive with a high assimilation capacity. The chemical, non-metallic and basic metals industries show progress ratios around or below 0.5 which indicates that these industries have actively engaged in innovation activities, and are highly competitive.

It was found, however, that the machinery industry was in a forgetting level with a deteriorating performance over time. Given the importance of this industry in terms of its contribution to the total manufacturing industry and its impact on the future development of the Mexican manufacturing industry, further analysis was performed which revealed that the railroad and transport equipment played an important role in the Mexican manufacturing industry and showed an exceptional technological learning path. This case illustrates the need for a more detailed analysis; future studies should aim for an analysis at a 4 digits level.

In order to sustain industrial and economic growth, Mexico should put more emphasis on industries with learning potentials and adjust its technology policy structure. Overall, the focus should be on mid-low and mid-high tech industries, but these policies should be adjusted to correct the stagnant performance of the high-tech industry in the last two decades. Policies should also be enforced to support, rather than neglect the food industry.

The drastic decline of the high-tech contribution to total production demonstrates the weakness of technology policies at the national level that influence the long-run development of the Mexican manufacturing industry. The fact that the high-tech sub-sectors are in a forgetting level and contribute less to the total manufacturing industry has policy implications. Mexico should expand its high-tech national structure beyond its current priority, which appears to be in the railroad and transport equipment subsector. By adjusting the current national policy towards high-tech industries they can improve the design of the current high-tech industrial structure.

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