Original Research Article

INDUSTTRY (ECONOMIC)-WIDE LEARNING: A COMPARATIVE STUDY OF MANUFACTURING AND NON-MANUFACTURING SECTOR IN JAPAN.

ABSTRACT

In knowledge economies, building technological capability is a continuous process, and as well as unarguably key to industrial policy development. Industry (economy)-wide learning has been linked to reduction in unit labor cost and overall production cost of goods and services. In this study, we comparatively studied the learning pattern of Japanese manufacturing and service sector using industrial-level-data. Looking back to almost 4 decades long of financial (on input-output data) we estimated the trend in technological learning using various models and thereafter calculated the annual progress ratios (via production function imputed in loglinear & cubic model), and revealed the dynamic technological learning across the sectors at the aggregate level. This enabled us to identify years with good learning rates which is synonymous to cost saving across the two sectors of the economy. The results show that, while learning was restored and sustained in the service sector of the economy in the last decade, the same cannot be said about manufacturing sector where learning (cost-saving ability) was completely lost. We conclude that (1) as typical of advance economy, Japan is now service-oriented economy with manufacturing playing a complimentary role, (2) the service sector seems to have benefited from IoT (technologies and innovations) to achieve higher productivity at lower cost!

Keywords; *Knowledge-economy, Industry, Learning, Manufacturing, Productivity, Technology, Service*
JEL: L60, L80, O33

I. INTRODUCTION

Japan economy like many OECD economies is driven by knowledge, information and technology. Accumulated knowledge and R&D have long been described as drivers of productivity and economic growth in Japan and many other OECD countries and these have led to the recognition of the role of knowledge (learning) in economic performance, a concept now generally term “knowledge-based economy” [1]! The concise definition of knowledge economy is the production of goods and services based on “knowledge intensive activities and processes that contribute to rapid technical and scientific advances while simultaneously displacing/replacing existing methods and processes [2].

The various form or codification of knowledge (know-what, know-why, know-how and know-who) interacts constantly in the form of inter-industry labor dynamics and academia-industrial collaboration to produce competitive and technically advanced economy. In sum, knowledge-based economy pushes for the need for continuous learning of codified information, the competencies to use this information and the continuous accumulation of this information (tacit knowledge codified as information technologies) which can only be done through “learning” or “learning-by-doing” a process described as paramount to knowledge economy [1] [3].

The concept of learning-by-doing as a contributory factor to the development of knowledge-based economy has been extensively studied by economics and scholars in both manufacturing and service sectors of the economy. The concept began with the seminar work of Arrow (1962), which saw the

unit labor requirement/cost decrease as the knowledge or experience about the production is gained. Recent research on the roles of learning and cost saving as well as the factor determinants of economic/organization/industry-wide learning have been generalized and documented [4] [5], [6].

As agents learned from experience and make complex but informed decisions about what to produce and how to produce goods and services contingent on cost minimization and productivity maximization at the micro-economic levels, the result is reflected on the macro-economic indicators (which often time is accelerated growth and productivity) attributable to economy-wide learning.

The dynamics of industrial/economy-wide learning and the driving force of knowledge-based economy can be illustrated using a continuous circular motion flow diagram (Figure 1). The process almost always begins with the search for quality labor, human resources development, on-the-job training as well as workshops, conferences and collaborations with external economic agents (within the same industry), resulting to huge skill acquisition and accumulated production experience; these combines with intra/inter-industry spillover of new knowledge on production/service techniques plus internal research and development efforts, produce a well-established web of relationship built around the learning economy. Together, the learning and spillover (diffusion) of these technologies with other actors in the chain bring about innovations and technological learning that spur increase in efficiency, productivity enhanced performance which fundamentally transform our *economy* [7]

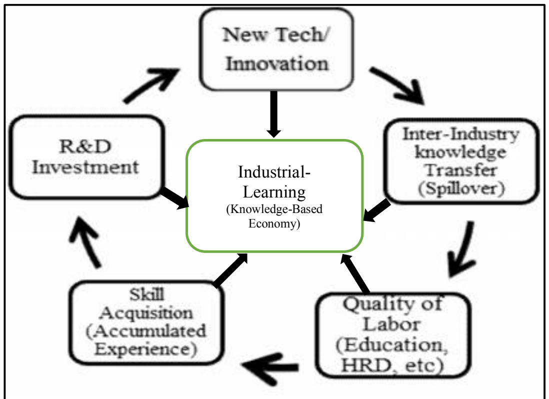

Figure 1: The dynamics of Industry-wide Learning (source: authors)

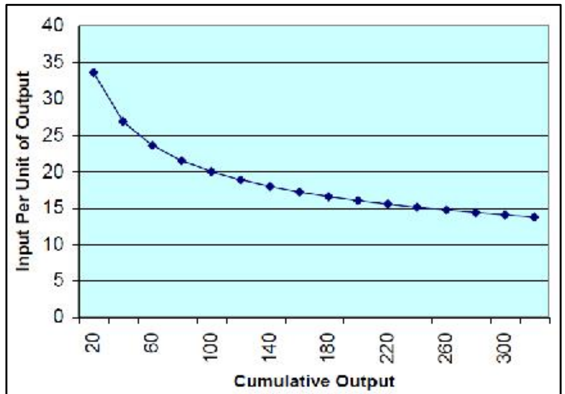

Figure 2: The Learning Curve (Source: Heng, 2010)

Empirically, at the basic unit of production, the effect of the economy/industry-wide learning described in Figure 1 can be capture through the learning curve theorem (Figure 2). As demonstrated by Figure 2, at any given level, the marginal and average cost of production fall sharply as employees and management gain experience with production. While the former (employees) gain experience with the routine of the production tasks and processes including but not limited to; information sharing, the re-engineering and re-designing of machines, the later (management) gain experience with continuous efficiency of production scheduling, supply-chain management and strategic decision making. All of this drastically reduce production cost with cumulative output.

II. RATIONALE OF THE STUDY

Ceteris paribus, cost efficiency/management is almost becoming the most important factor to consider in running an organization or economy. Managers and policy makers are inundated with controlling rising cost of running an economic entity due to inflation and sometimes “economic shocks”. The Japanese economy which grew rapidly during the industrialization or miracle age of Japan, driven in part by knowledge and innovations, has, however, faced a fair share of economy shocks in recent times. Granted, there have been numerous studies speculating the causes and possible solution, this study is an attempt to add to the body of knowledge and the on-going debate. We travelled down memory lane to almost 4 decades of industrial activities to comparatively study learning rates and progress ratio of the two sectors of the economy (manufacturing and non-manufacturing). Given that learning is fundamental to cost reduction and high productivity and the fact that same can be lost, giving way to rising cost of production, we lend ourselves to study learning pattern and the relationship between learning and cost saving in Japan economy.

III. RESEARCH METHOD

In the classical learning curve theorem, the power law equation has been used to estimate the learning effect [8] [9]. The power law (1) states that unit production cost reduced as experience doubles. However, in this study, we utilized the production function (2) imputed into power law (3). This enabled us to separate return to scale effect from learning effect. We will also derive and use the cubic form of (3) which we will represent as (4).

$$C_t = C_1 X_t^{\theta t} \rightarrow lnC_t = \theta_0 + \theta_1 lnX_t \quad (1)$$

$$Y_t = f(L_t, K_t) = AL_t^{\theta 1} K_t^{\theta 2} \rightarrow lnY_t = A + \theta_1 lnL_t + \theta_2 lnK_t + \varepsilon_t \quad (2)$$

$$lnC_t = \theta_0 + \theta_1 lnX_t + \theta_2 lnL_t + \varepsilon_t \quad (3)$$

$$lnC_t = \theta_1 + BlnX_t + C(lnX_t)^2 + C(lnX_t)^3 + \theta_2 lnL_t) + + \varepsilon_t \quad (4)$$

$$P = AE_t^{\alpha} \rightarrow \ln P = lnA + \alpha lnX_t + + \varepsilon_t \quad (5)$$

$$d = 2^{\theta t}, \quad (6)$$

$$B + 2ClnX_t \quad + 3C(lnX_t)^2 \quad (7)$$

X_t *is cumulative experience or production,* Y_t *is value Added,* C_t *is* L/Y_t , $L, K,$ *are labor, capital and wages respectively, and* ϵ_t *is the error term* $(E(\varepsilon_t/\epsilon_t) = 0)$.

Furthermore, we defined a productivity-based learning model whose dependent variable we called "cost efficiency" (computed as cost of goods sold-cgs per sale,) and will be estimated using (5). We assumed that if learning is implicated, the curve of (5) will follow a similar trend as Figure (2) implying that cost reduces with cumulative production experience. We will estimate the progress ratio of (3) using (6) and the progress ratio of (4) using its first derivative (7). Theoretically, learning implies that the coefficient of cumulative output X_t $(\theta_1 \text{ or } \alpha)$ is negative.

IV. RESEARCH OBJECTIVES

In keeping with the rationale of the study, this study will achieve the following objectives;

1. Estimate learning rates across the two sectors of the Japanese economy (manufacturing and non-manufacturing) using various learning models.
2. Estimate and compare annual progress ratios of manufacturing and non-manufacturing sectors using two economic phases (1980-1999) & (2000-2018).

V. DATA SOURCES AND CONSTRUCTION

The data for this study was sourced from Policy Research Institute, an agency of the Japan Ministry of Finance (JMOF). The data was processed from its original form (quarterly) and summarized into annual data, spanning about 4 decades long. Figure 2 describes the process, structure of the data and variable definitions.

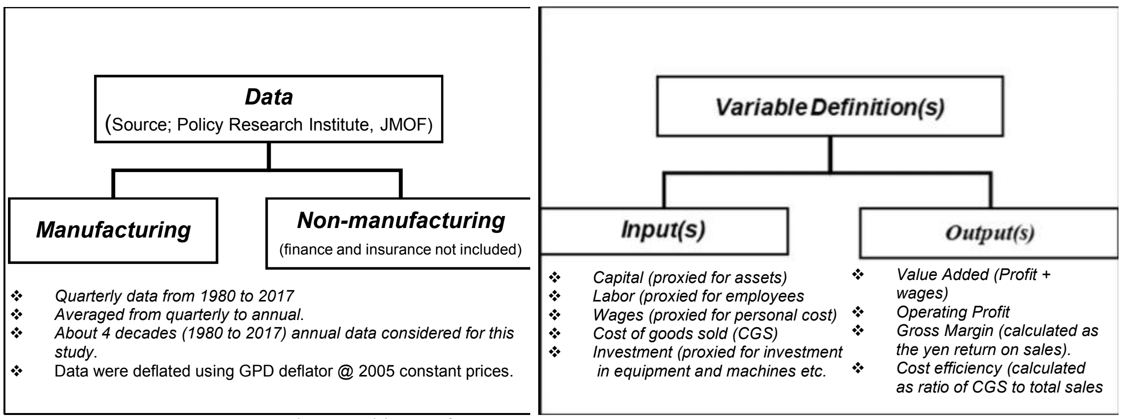

Figure 3: Data Source and Variable Definition (source: authors).

VI. FINDINGS AND DISCUSSION

Basic statistical information of the two sectors of the economy are describe using Table 1. For better inferences, we present this information using a line graph (Figure 4). We begin by looking at labor productivity, capital productivity and total factor productivity in their simplest computational form, ceteris paribus. While labor productivity seems to change course from 2010 onward (growth), the same cannot be said of capital productivity. Total factor productivity roughly estimated using the ratio of total sales to sum total of capital invested plus total cost or wages both decline continuously until the last point of year the considered (2017). This is not unconnected with the many factors which have been documented in literature.

Annual production and gross margin (defined as the yen return on sales) grew rapidly from the 80s to early 2000s for the manufacturing sector. There seems to be a huge shock between 2002 to 2011 which affected the growth considerably. One chief explanatory reason for this phenomenon is cost inefficiency or growing cgs relative to sales and other revenue generation activities. We blame this on both internal and external factors; the former being that at this time, the Japanese economy has already been hit with economic shocks occasioned by failing financial institutions, and the latter is directly connected with the impact of global financial crises (lemma shock) of early 2000s and rising of other Asian market (competition) such as China. The manufacturing sector, however seems to have brazed up as evidenced from 2011/2012 onward.

The non-manufacturing sector (service sector excluding finance and insurance) on other hand seems to be resilient to the crises as demonstrated by their continuous and steady growth in unit production and gross margin. Again, we conjectured that this is most likely connected with efficient cost management, maturation of economy, among others. The regression results on Appendix A shows that wages (proxied for quality of labour) and Investment in machines, software and equipment are good predictors of output in both sectors.

Table 1: Summary Statistics (unit:1Billion yen≈10millionUSD)

	Var.	Value Add.	Sale	Assets	Op. Profit	Labor	Invest	GM
Manuf.	Mean	3,778.75	30,237.20	55,790.69	1,016.15	289,312.10	1,036.99	20.13
	SDEV.	914.48	6,566.19	21,749.69	264.57	56,235.34	301.33	2.52
	Min	1,729.28	14,849.77	13,189.42	590.61	175,673.00	474.90	15.31
	Max	4,826.70	38,192.98	84,365.50	1,605.59	360,942.00	1,658.75	23.84
Non-manuf.	Mean	2,409.39	21,038.67	39,195.09	643.31	195,066.50	667.45	20.13
	SDEV.	678.25	4,911.96	16,157.67	189.21	53,853.86	208.24	3.43
	Min	897.34	9,678.39	8,048.47	300.33	95,467.00	267.14	14.01
	Max	3,116.90	27,018.18	61,638.92	1,081.20	265,554.00	1,029.85	24.98
Total	Mean	3,778.75	30,237.20	55,790.69	1,016.15	289,312.10	1,036.99	20.13
	SDEV.	914.48	6,566.19	21,749.69	264.57	56,235.34	301.33	2.52
	Min	1,729.28	14,849.77	13,189.42	590.61	175,673.00	474.90	15.31
	Max	4,826.70	38,192.98	84,365.50	1,605.59	360,942.00	1,658.75	23.84

Source: authors estimation base on original data

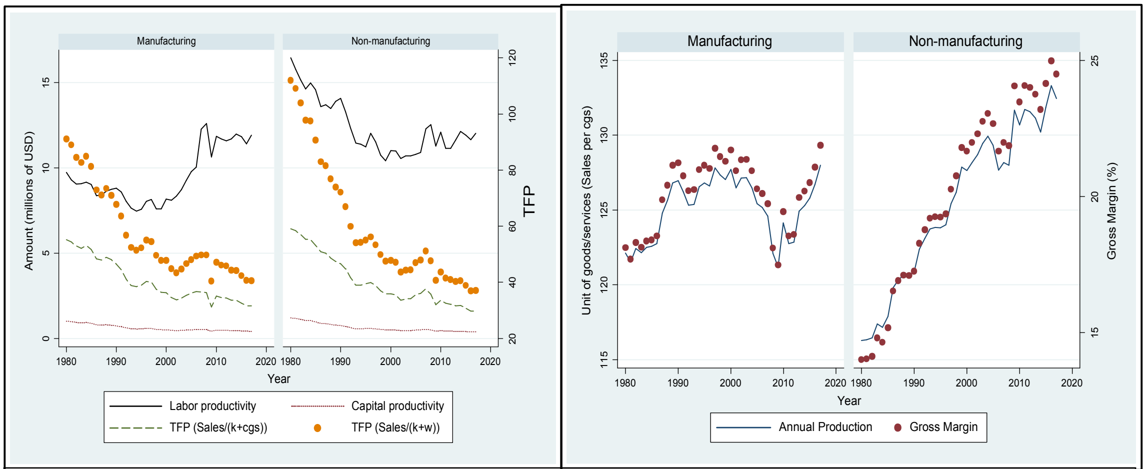

Figure 4: Productivity & Gross Margin of Manufacturing and Non-manufacturing Sectors in Japan

To understand the extent and nature of learning across these two sectors of the economy we perform the first part of the productivity base learning model represented by equation 5. As mentioned earlier, the underlying principle is that if learning occurred, then cost relative to sales will decrease with cumulative output (unit production and /or gross margin in our case). We represent our result using a line graph (Figure 5). First, we noticed a striking resemblance of the theoretical learning curve (Figure 2) and our empirical estimation result (Figure 5). For the manufacturing, cost per output decreases with cumulative output in both definition (gross margin and unit production) from the start of the production activities and continued that way to 2010 (with slight shock between 2006 and 2009). This learning was lost substantially between 2012 and 2013/14.

The non-manufacturing sector, however, shows a sustained learning pattern in relation to cost per output. Granted there are few shocks observed in 2008/9 and 2013/14, the overall learning pattern was good in the service sector. We said this without loss of generality because the variable treated as “cost” refer to cost of goods sold which is reflective of day-to-day running/operational cost and irrespective of the sector, economic agents have greater flexibility on its management and control. As a result, managerial decisions, optimal resource use and efficiency of the production process are reflected on the cost structure of economic entities.

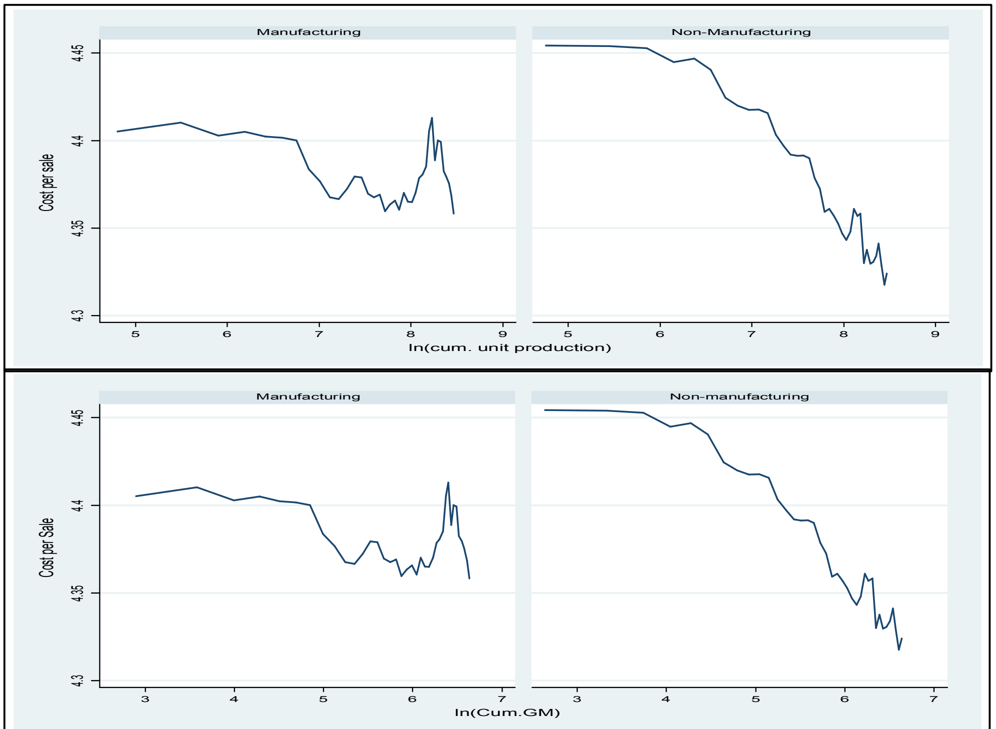

Figure 5: Cost per unit output versus cumulative output (source: authors)

The magnitude (learning coefficient) of the learning estimated from the various learning models described in section 3 are presented on Table 2. We begin with the linear and productivity model of industry-wide learning. For each proposed learning models (DV) we deliberately used various (economic) output (cumulative sales, cumulative operating profit, cumulative gross margin and cumulative unit production) to check (1); which output best capture the learning behavior (2); whether other non-conventional outputs such as cumulative; sales, profit and gross margin contain as much learning information as the conventional learning variable; cumulative unit production. The results show that irrespective of the learning model employed and irrespective of the output, there are evidence of economic wide learning in both manufacturing and non-manufacturing sector as exemplified by the progress ratios on Table 2.

These results show that on the average cost reduced by 3.1% and 15.8% respectively of its previous value when output (unit production, sales, gross margin and operating profit) doubles for manufacturing and non-manufacturing sector (column 6 & 9).

The productivity base learning (5) shows a higher rate of learning and suggest that on average, 15.6% and 19.4% cost will be saved due to productivity achieved through accumulated experience with improved sales strategies (advertising etc.), improved quality of goods and services, strategic decision making leading to higher profits and efficient cost management leading to higher return on sales in manufacturing and non-manufacturing sector respectively. We have established quantitatively via progress ratio that (1); there is evidence of learning in both sectors of the economy (2); non-manufacturing sector seems to have better learning rates than manufacturing sector. However, the next task will be to show how this learning is dynamically sustained or lost along the years. This will be addressed in the next section.

Table 2: The Linear Learning Estimation (Progress Ratio)

Models	DV	IV	Manufacturing			Non-Manufacturing			Economy-wide		
			Coef.	D	AvG (6)	Coef.	d	AvG (9)	Coef.	d	AvG (12)
3	Labor Per value Added ln(L/Yt)	lnXs	-0.0419	0.9714	0.969	-0.2594	0.8355	0.841	-0.0889	0.9402	0.940
		lnXp	-0.0506	0.9656		-0.2613	0.8343		-0.0960	0.9356	
		lnXgm	-0.0493	0.9664		-0.2395	0.8471		-0.0879	0.9409	
		lnXop	-0.0408	0.9721		-0.2390	0.8473		-0.0824	0.9445	
3	Value Added (lnYti)	lnXs	-0.1110	0.9259	0.926	-0.0220	0.9849	0.986	-0.0945	0.9366	0.938
		lnXp	-0.1073	0.9283		-0.0197	0.9865		-0.0929	0.9376	
		lnXgm	-0.1105	0.9262		-0.0194	0.9866		-0.0749	0.9494	
		lnXop	-0.1152	0.9233		-0.0220	0.9849		-0.1064	0.9289	
5	Productivity (lnRC)	lnXs	-0.2284	0.8536	0.844	-0.2910	0.8174	0.806	-0.2287	0.8534	0.832
		lnXp	-0.2700	0.8293		-0.3604	0.7789		-0.3160	0.8033	
		lnXgm	-0.2621	0.8339		-0.3297	0.7957		-0.2980	0.8134	
		lnXop	-0.2202	0.8585		-0.2630	0.8333		-0.2238	0.8563	
5	Cost Efficiency (lncm)	lnXs	-0.0051	0.9965	0.997	-0.0152	0.9895	0.988	-0.0188	0.9870	0.986
		lnXp	-0.0061	0.9958		-0.0155	0.9893		-0.0231	0.9841	

lnXgm	-0.0060	0.9959		-0.0189	0.9870		-0.0224	0.9846	
lnXop	-0.0049	0.9966		-0.0190	0.9869		-0.0189	0.9870	

X is cumulative, s, p, gm, and op represent sale, unit production, gross margin and operating profit respectively. cm=cgs/sale, RC=sale/(K+W)

VII. ANNUAL LEARNING RATE AND PROGRESS RATIOS

In this section, we focused on the dynamics of industry-wide learning as time elapses. With the assumption that learning is not constant and events such as economic shocks, poor production schedules, poor supply chain management, inter- industry labor migration and quality of labor can alter the learning system, we divide our study into two economic phases (1980-1999 & 2000-2017) and estimated the annual learning rates and progress ratios for both sectors of the economy (Appendix C). We represented the result using line graph for ease of discussion (Figure 6). The result shows rapid learning in the early 80s to the late 90s (about one and half decades long) for manufacturing sector implying cost reduction for each doubling of output in the first economic phase. This learning trend was completely lost from the late 90s and was never recover two decades later (late 90s to 2017) as shown in the 2nd economic phase of the study. This implies rising cost of production in the manufacturing sector between the late 90s and 2017.

The non-manufacturing sector on the other hand also show learning trend in the first study phase, about a decade long (early 80s and early 90s). The learning trend was, however, lost between the late 90s and 2008/9. Impressively, learning was restored from 2010 to 2017. Again, this implies continuous reduction in the cost of production of goods (services) as experience is gained. The trend shows that learning was getting better towards the end of the study period!

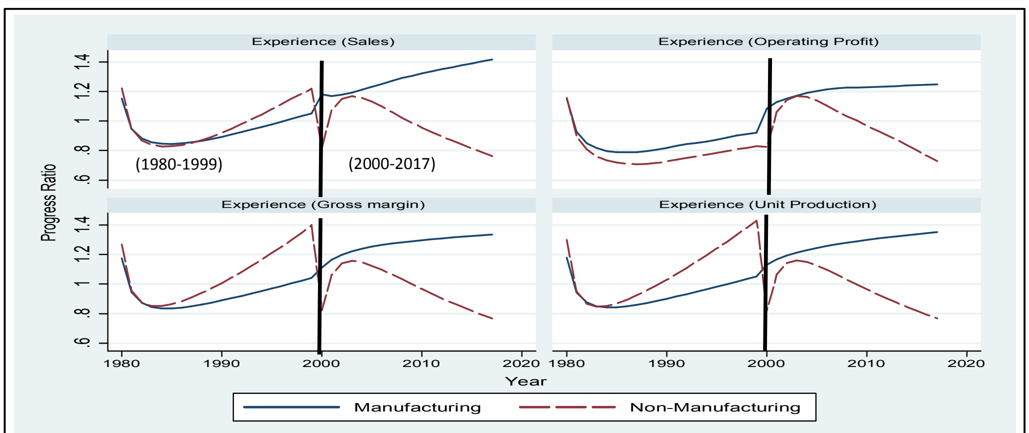

Figure 6: Estimated Annual Progress Ratio Using Cubic Learning Model (source: authors)

We reproduced another line graph using the average (Figure 7). Quantitatively; we observed the following from the progress ratio of the non-manufacturing; cost reduced to about 96% of its previous value in 2010 implying that about 4% cost was saved at each doubling of output. In 2011, the progress ratio was 93% implying 7% cost saved and by 2017 the progress ratio was 76% suggesting that 24% cost saved when output doubles. These results seem to shed light on what other studies have noted about the increasing role of the non-manufacturing sector in Japan and how ‘it is playing an important role in the recovery of the Japanese economy’. It has been noted that Japan is largely becoming service-oriented and that this sector now accounts for about 70% of the GDP and is projected to increase in the years to come [10].

For the years marked with poor learning (late 90s and 2008/9), we blame this on economic shocks and other factors outside the scope of this study. The inability of the manufacturing industries to recover (show learning trend) in the second phase was somewhat a puzzle. Nevertheless, we believe the reasons are connected with (1); activities or investment that disrupt learning and cause rising cost per unit output. (2); stifle competition from rising Asia markets (China), as well as the slowdown in emerging economies and perhaps the yen’s appreciation which gave rise to sluggish industrial productions [11], and (3) growing oversea or offshore production, a practice where Japanese manufacturers continues to shift their production base to oversea in search of market and cheap labor, thereby breaking employment and technological clusters [12].

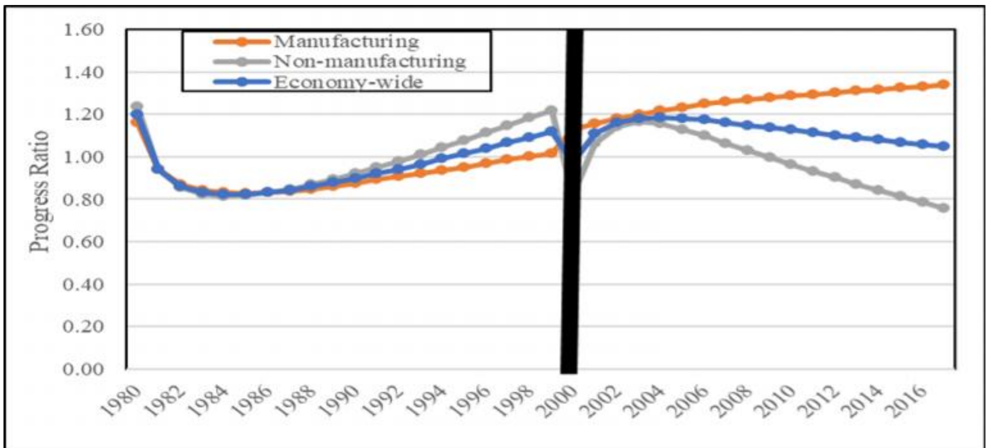

Figure 7: Average Estimated Annual Progress Ratio Using Cubic Learning Model

Quadrant I (1980-1999) Quadrant II (2000-2017)

VIII. CONCLUSION

In keeping with our objectives, we have empirically measured the economy-wide learning in Japan using data from the two most important sectors of Japanese economy (manufacturing and non-manufacturing). For robustness, we used various learning models and compared the results. We also control for return to scale effect by using a production function imputed in a power function. The novelty of our research is the introduction of additional outputs (defined in terms of financial ratios). The results show evidence of declining productivity (TFP and capital) with slight growth in labor productivity in recent years.

Linear learning models shows presence of learning throughout the study period implying unit cost reduction. Learning was affected by factors such as time and economic shocks (not indefinitely). Annual progress ratios show evidence of learning in the first economic phase. This implies cost reduction at doubling of production. Annual progress ratios were greater than one in entirety of the second economic phase for manufacturing sector, implying rising cost of productions. Annual progress ratios show presence of learning (from 2010 to 2017) for the service sector in the second economic phase, implying cost reduction through learning and recovering from economic shocks. This result shows that the service sector is playing a vital role in the development and a recovery of the Japanese economy as demonstrated by other studies. Furthermore, we observed that, other than the traditional cumulative output often used as a proxy for experience, other output such as cumulative gross margin, cumulative operating profit, and cumulative sales/cgs *contain* as much information to capture learning behavior of economic entities.

IX. POLICY IMPLICATION

As documented in this study, there is disparity between the contribution of manufacturing and non-manufacturing sectors to the overall Japan economy in recent time, from the viewpoint of industry-wide learning. With many policies already in place to restore Japan sluggish economy growth, and many more to come, our study has lent its voice to this on-going debate and reveal a gray area where managers and policy makers can tap into; i.e. revisiting the rising cost of unit production occasioned by poor learning in the manufacturing sector and working out modalities for total overhauling of the processes with a view to eliminating unproductive activities/economic units (free-riders) and leading up to cost effective and lean production activities.

X. References

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Appendix A. Summary of Regression Analysis on Major Variables

	Manufacturing.				Non-Manufacturing.				Industry-wide			
Lnyt	Coef.	Std. Err.	t	P>t	Coef.	Std. Err.	T	P>t	Coef.	Std. Err.	t	P>t
Lnl	-1.1711	0.3673	-3.1900	0.0030	-0.2255	0.0647	-3.4800	0.0010	0.1158	0.0380	3.0500	0.0030
Lnw	1.1830	0.1466	8.0700	0.0000	0.6638	0.0495	13.4200	0.0000	0.7366	0.0597	12.3300	0.0000
lnInv	0.2121	0.0644	3.2900	0.0020	0.2637	0.0239	11.0400	0.0000	0.2195	0.0413	5.3200	0.0000
lnXs	-0.1110	0.0601	-1.8500	0.0740	-0.0220	0.0162	-1.3600	0.1850	-0.0945	0.0330	-2.8600	0.0060
Time	0.0093	0.0052	1.7900	0.0820	0.0136	0.0014	9.3900	0.0000	0.0095	0.0026	3.6100	0.0010
_cons	17.7378	5.1428	3.4500	0.0020	4.8953	0.8600	5.6900	0.0000	-0.0928	0.4200	-0.2200	0.8260
Adj R2	0.9184				0.9977				0.9782			
Root MSE	0.0676				0.0175				0.0601			
lnl	-1.2009	0.3688	-3.2600	0.0030	-0.2283	0.0653	-3.5000	0.0010	0.0236	0.0665	0.3600	0.7240
lnw	1.1699	0.1457	8.0300	0.0000	0.6552	0.0482	13.5900	0.0000	0.7677	0.0809	9.4900	0.0000
lnInv	0.2137	0.0651	3.2800	0.0020	0.2644	0.0242	10.9200	0.0000	0.1750	0.0392	4.4700	0.0000

lnXgm	-0.1105	0.0636	-1.7400	0.0920	-0.0194	0.0166	-1.1700	0.2500	-0.0749	0.0381	-1.9700	0.0530
time	0.0080	0.0048	1.6800	0.1030	0.0134	0.0015	9.1200	0.0000	0.0079	0.0030	2.6600	0.0100
_cons	17.6537	5.1748	3.4100	0.0020	4.8400	0.8647	5.6000	0.0000	0.7824	0.7303	1.0700	0.2880
Adj R2	0.9175				0.9977				0.9976			
Root MSE	0.0680				0.0175				0.0177			
lnl	-1.1704	0.3666	-3.1900	0.0030	-0.2226	0.0648	-3.4400	0.0020	0.0904	0.0402	2.2500	0.0280
lnw	1.1982	0.1496	8.0100	0.0000	0.6647	0.0500	13.3000	0.0000	0.7825	0.0697	11.2200	0.0000
lnInv	0.2119	0.0643	3.3000	0.0020	0.2634	0.0239	11.0300	0.0000	0.2067	0.0398	5.1900	0.0000
lnXop	-0.1152	0.0612	-1.8800	0.0690	-0.0220	0.0166	-1.3300	0.1940	-0.1064	0.0373	-2.8500	0.0060
time	0.0101	0.0055	1.8300	0.0760	0.0138	0.0016	8.8500	0.0000	0.0111	0.0032	3.4800	0.0010
_cons	17.4706	5.1420	3.4000	0.0020	4.8008	0.8599	5.5800	0.0000	0.0074	0.4305	0.0200	0.9860
Adj R2	0.9187				0.9976				0.9781			
Root MSE	0.0675				0.0176				0.0602			
lnl	-1.2003	0.3693	-3.2500	0.0030	-0.2301	0.0654	-3.5200	0.0010	0.0153	0.0614	0.2500	0.8040
lnw	1.1604	0.1439	8.0600	0.0000	0.6552	0.0480	13.6400	0.0000	0.7744	0.0745	10.4000	0.0000
lnInv	0.2137	0.0652	3.2800	0.0030	0.2646	0.0242	10.9400	0.0000	0.1880	0.0391	4.8000	0.0000
lnXp	-0.1073	0.0626	-1.7200	0.0960	-0.0197	0.0164	-1.2000	0.2380	-0.0929	0.0389	-2.3900	0.0200
time	0.0075	0.0045	1.6500	0.1090	0.0133	0.0014	9.5600	0.0000	0.0088	0.0028	3.1000	0.0030
_cons	17.9004	5.1743	3.4600	0.0020	4.9100	0.8663	5.6700	0.0000	1.0528	0.7338	1.4300	0.1560
Adj R2	0.9173				0.9976				0.9774			
Root MSE	0.0681				0.0176				0.0611			

Inv=investment in equipment and machines (a proxy for R&D and technology), (source: authors)

*Appendix B: Learning Coefficients Estimated with Linear Models**

	Manuf.				Non-Manuf.				Industry-wide			
(L/Q)	Coef.	Std. Err.	t	P>t	Coef.	Std. Err.	t	P>t	Coef.	Std. Err.	t	P>t
lnXs	-4.19E-02	2.23E-02	-1.880	0.069	-2.59E-01	5.75E-02	-4.510	0.000	-8.89E-02	2.10E-02	-4.240	0.000
R2	0.420				0.367				0.271			
Root MSE	0.137				0.121				0.153			
lnXgm	-4.93E-02	2.57E-02	-1.920	0.063	-2.39E-01	6.70E-02	-3.580	0.001	-8.79E-02	2.02E-02	-4.360	0.000
R2	0.422				0.268				0.279			
Root MSE	0.136				0.130				0.152			
lnXop	-4.08E-02	2.15E-02	-1.900	0.066	-2.39E-01	5.69E-02	-4.200	0.000	-8.24E-02	1.92E-02	-4.300	0.000
R2	0.421				0.335				0.275			
Root MSE	0.136				0.124				0.153			
lnXp	-5.06E-02	2.65E-02	-1.910	0.065	-2.61E-01	6.76E-02	-3.870	0.000	-9.60E-02	2.18E-02	-4.400	0.000
R2	0.421				0.299				0.282			

Root MSE	0.136				0.127				0.152			
Productivity												
lnXs	-2.28E-01	1.25E-02	-18.340	0.000	-2.91E-01	1.19E-02	-24.470	0.000	-2.29E-01	1.38E-02	-16.550	0.000
R2	0.903				0.943				0.787			
Root MSE	0.079				0.081				0.136			
lnXgm	-2.62E-01	1.51E-02	-17.370	0.000	-3.30E-01	1.41E-02	-23.330	0.000	-2.98E-01	1.09E-02	-27.300	0.000
R2	0.893				0.938				0.910			
Root MSE	0.083				0.084				0.089			
lnXop	-2.20E-01	1.17E-02	-18.870	0.000	-2.63E-01	9.80E-03	-26.840	0.000	-2.24E-01	1.14E-02	-19.720	0.000
R2	0.908				0.952				0.840			
Root MSE	0.077				0.074				0.118			
lnXp	-2.70E-01	1.60E-02	-16.910	0.000	-3.60E-01	1.68E-02	-21.390	0.000	-3.16E-01	1.26E-02	-25.010	0.000
R2	0.888				0.927				0.894			
Root MSE	0.085				0.091				0.096			
lncm												
lnXs	-5.10E-03	2.11E-03	-2.420	0.021	-1.52E-02	7.88E-03	-1.930	0.062	-1.88E-02	3.01E-03	-6.240	0.000
R2	0.420				0.919				0.531			
Root MSE	0.013				0.012				0.022			
lnXgm	-5.95E-03	2.43E-03	-2.450	0.019	-1.89E-02	7.83E-03	-2.420	0.021	-2.24E-02	2.48E-03	-9.000	0.000
R2	0.423				0.923				0.659			
Root MSE	0.013				0.012				0.019			
lnXop	-4.94E-03	2.03E-03	-2.440	0.020	-1.90E-02	7.36E-03	-2.580	0.014	-1.89E-02	2.59E-03	-7.280	0.000
R2	0.422				0.924				0.583			
Root MSE	0.013				0.012				0.021			
lnXp	-6.11E-03	2.51E-03	-2.440	0.020	-1.55E-02	8.32E-03	-1.870	0.070	-2.31E-02	2.84E-03	-8.120	0.000
R2	0.422				0.918				0.622			
Root MSE	0.013				0.013				0.020			

**Other variables omitted for concise presentation of the relevant statistics (source: authors)*

Appendix C: Progress Ratio Estimated from Cubic learning Coefficient[†]

	Manufacturing				Non-Manufacturing				Average		
Year	Sales	Profit	GM	Prod.	Sales	Profit	GM	Prod.	Manuf.	Non-Manuf.	Eco-wide
					Phase I						
1980	1.151	1.151	1.17	1.178	1.22	1.157	1.27	1.298	1.16	1.24	1.20
1981	0.947	0.927	0.95	0.945	0.949	0.896	0.96	0.95	0.94	0.94	0.94
1982	0.883	0.85	0.87	0.875	0.869	0.808	0.88	0.867	0.87	0.86	0.86
1983	0.857	0.817	0.85	0.85	0.838	0.76	0.85	0.847	0.84	0.82	0.83
1984	0.846	0.797	0.84	0.842	0.828	0.733	0.85	0.851	0.83	0.82	0.82
1985	0.844	0.789	0.84	0.844	0.829	0.719	0.86	0.869	0.83	0.82	0.82
1986	0.848	0.788	0.84	0.85	0.838	0.711	0.88	0.893	0.83	0.83	0.83
1987	0.855	0.789	0.85	0.86	0.852	0.708	0.91	0.923	0.84	0.85	0.84
1988	0.865	0.795	0.86	0.872	0.87	0.71	0.94	0.956	0.85	0.87	0.86
1989	0.877	0.806	0.88	0.886	0.892	0.716	0.97	0.992	0.86	0.89	0.88
1990	0.892	0.819	0.89	0.901	0.918	0.726	1.01	1.029	0.88	0.92	0.90

1991	0.909	0.833	0.91	0.916	0.948	0.738	1.04	1.069	0.89	0.95	0.92
1992	0.926	0.843	0.92	0.932	0.98	0.75	1.08	1.11	0.91	0.98	0.94
1993	0.943	0.852	0.94	0.948	1.011	0.761	1.12	1.152	0.92	1.01	0.97
1994	0.96	0.862	0.95	0.965	1.044	0.773	1.17	1.196	0.93	1.05	0.99
1995	0.977	0.873	0.97	0.982	1.079	0.784	1.21	1.24	0.95	1.08	1.01
1996	0.996	0.887	0.99	0.999	1.115	0.796	1.25	1.286	0.97	1.11	1.04
1997	1.015	0.901	1.01	1.016	1.151	0.809	1.3	1.332	0.99	1.15	1.07
1998	1.033	0.911	1.02	1.034	1.185	0.818	1.35	1.38	1.00	1.18	1.09
1999	1.05	0.922	1.04	1.051	1.218	0.83	1.4	1.429	1.02	1.22	1.12
Phase II											
2000	1.181	1.084	1.11	1.131	0.816	0.824	0.82	0.821	1.13	0.82	0.97
2001	1.167	1.126	1.17	1.167	1.073	1.06	1.06	1.064	1.16	1.06	1.11
2002	1.178	1.152	1.2	1.193	1.15	1.141	1.14	1.143	1.18	1.14	1.16
2003	1.194	1.172	1.22	1.213	1.167	1.168	1.16	1.16	1.20	1.16	1.18
2004	1.212	1.189	1.24	1.23	1.157	1.163	1.15	1.149	1.22	1.15	1.19
2005	1.231	1.202	1.25	1.245	1.132	1.138	1.12	1.126	1.23	1.13	1.18
2006	1.251	1.213	1.27	1.258	1.098	1.104	1.1	1.096	1.25	1.10	1.17
2007	1.272	1.221	1.28	1.27	1.059	1.065	1.07	1.064	1.26	1.06	1.16
2008	1.291	1.225	1.28	1.28	1.022	1.032	1.03	1.031	1.27	1.03	1.15
2009	1.305	1.226	1.29	1.29	0.989	1.003	1	0.997	1.28	1.00	1.14
2010	1.321	1.229	1.3	1.299	0.955	0.968	0.97	0.964	1.29	0.96	1.13
2011	1.336	1.232	1.3	1.308	0.924	0.935	0.93	0.932	1.29	0.93	1.11
2012	1.35	1.234	1.31	1.316	0.896	0.904	0.9	0.902	1.30	0.90	1.10
2013	1.363	1.237	1.32	1.324	0.869	0.872	0.87	0.873	1.31	0.87	1.09
2014	1.377	1.24	1.32	1.331	0.841	0.838	0.85	0.845	1.32	0.84	1.08
2015	1.39	1.242	1.33	1.338	0.815	0.8	0.82	0.819	1.33	0.81	1.07
2016	1.403	1.244	1.33	1.345	0.789	0.764	0.79	0.793	1.33	0.78	1.06
2017	1.416	1.247	1.34	1.352	0.763	0.729	0.77	0.769	1.34	0.76	1.05

[†]*Cubic learning rates calculated from the estimated cubic coefficients (model 4) and thereafter the annual progress ratio is calculated recursively (steps not show here), (source: authors)*