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CIM DIFFUSION: THE CASE OF NC-MACHINES IN THE U.S. METALWORKING INDUSTRY

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Foreword

Analysis and forecasting of NC-machine diffusion constitute one of the main activities of the IIASA Project "Computer Integrated Manufacturing" (CIM). Numerically controlled (NC) machines represent the first stage of flexible automation in the metalworking industry. NC-machines were developed in the early 1950's and became available commercially in 1955. Currently, they account for 5% of the total number of machine tools installed. Their share of production output is more than 50% by value.

The author has analyzed past development trends of the U.S. metalworking industry in detail and he estimated the fractional NC-machine penetration by industry and by type of machine tools. The statistical results (and forecasts) are given in this paper.

Subsequent work in this direction will be based on establishing a bridge between two types of data -- production and installation -- to make the forecasts more reliable.

Prof. Robert U. Ayres
Project Leader
Computer-Integrated Manufacturing

Summary

This paper illustrates the first results of the analysis of CIM diffusion processes, produced within the IIASA CIM Project for the case of penetration of NC-machines into the U.S. metalworking industry.

Tendencies in NC-machine production and installation as well as tendencies in relative price changes are analyzed. Five main types of NC-machines and six main metalworking industries were under consideration.

Some logistic type of explorations were made to estimate a potential saturation in these diffusion processes.

1. Introduction

One can observe two important features of modern industrial production: growing variability of products and higher quality demand. The main reasons creating these features and their consequences are the following.

The relative satisfaction of demand for goods of the prime needs has been achieved by growing labor division, leading to demand differentiation. Consumers demanded a wider spectrum of goods with different prices. Thus, the new demand had to be met by new supply, based on batch production instead of mass production. The high degree of labor division became also an obstacle to quality increase and made the cost of intermediate quality control very high. That is why the production had to adopt new technologies, which were capable of increasing a product quality by the use of computerized control.

The interaction of the reasons and consequences is illustrated in Figure 1.

As a result of the end of the 1950's a diffusion of CIM technologies began in the U.S. metalworking industry, and these technologies have played an important role in technological progress in the industry since the end of the 1970's.

2. Machine-tools Population in US Metalworking Industries

The growth of production capabilities as well as technological progress of a whole economy depends on the qualitative development of the machine-building sector or metalworking industries (MWI). There are seven 2-digit industries among them, namely:

- primary metals (SIC-33)
- fabricated metal products (SIC-34)
- nonelectrical (or general) machinery (SIC-35)
- electrical (or general) machinery (SIC-36)
- transportation equipment (SIC-73)
- instruments (SIC-39)
- miscellaneous manufacturing industries (SIC-39).

In 1985 MWI produced 55% of manufacturing or 12% of total GNP [1]. Approximately 48% of manufacturing or 6% of the total gross stock of fixed private capital belonged to this sector [2].

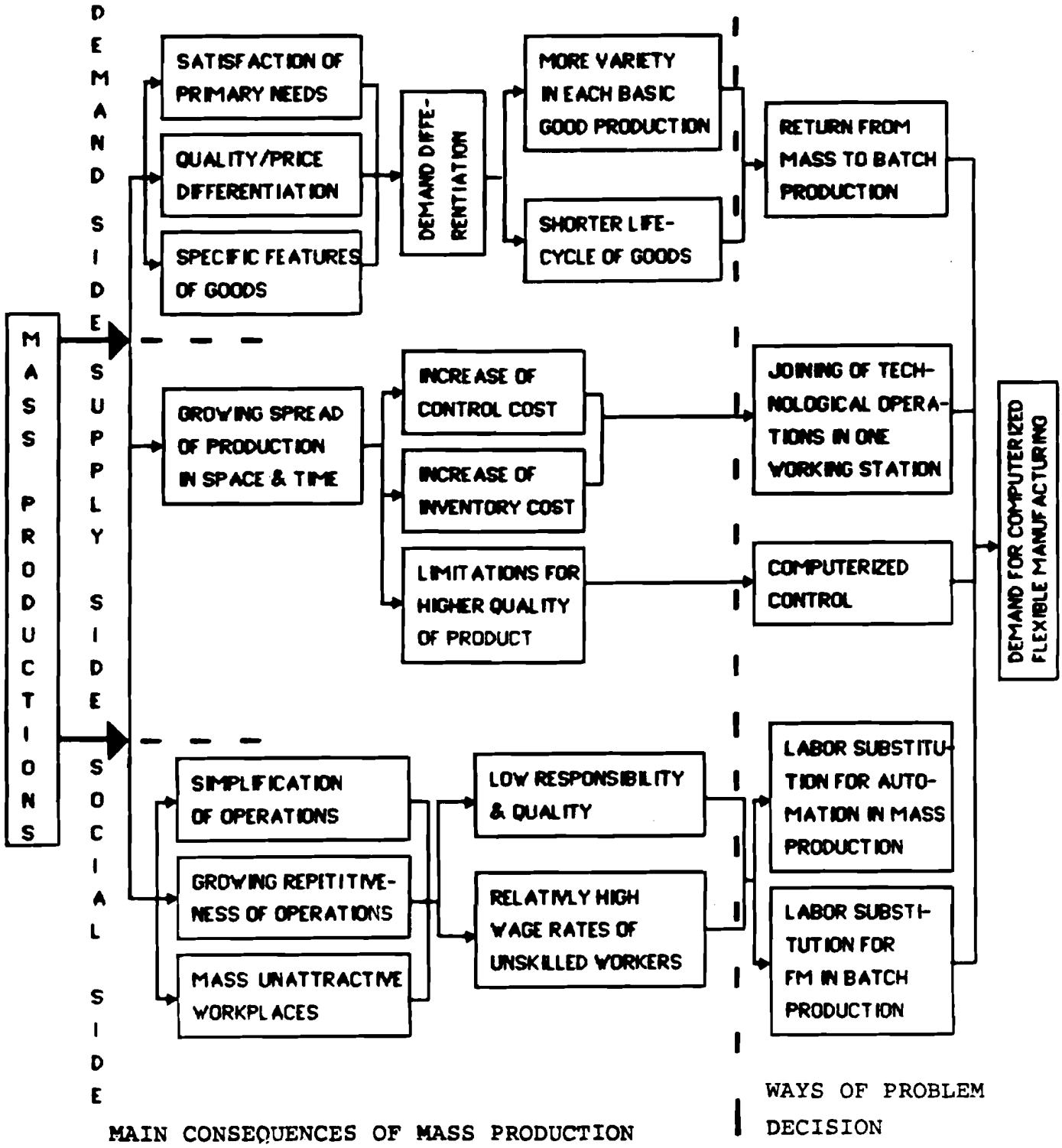

Figure 1. Driving forces of computer integrated flexible manufacturing.

Metalworking industries are a main producer and main consumer of machine-tools in the economy. In 1983 there are 1.7 million metalcutting machines, 0.5 million metalforming machines and 0.9 million other equipment as well as 11 million employees in this sector.

During the last decade the following tendencies in MWI development were observed:

1. Acceleration of intraindustrial structural changes, when traditional equipment production was replaced by electronics and computer production.
2. Enormous decrease of the total machine-tool population -- by 25%.
3. Long-term tendency to older population of machine-tools.
4. Growing diffusion of NC-machines in total-machine tool production and installations.

To prove these tendencies we shall provide some statistical illustrations.

The compound annual growth during the last 15 years for transformers (SIC 3612) was -1.0%, for motors and generators (SIC 3621) it was -0.6%, etc. At the same period (SIC 3674) it was +30.0% for semiconductors. As a result the share of the two first 4-digit industries decreased up to 4% and the share of the third one increased up to 17% of the total electrical machinery shipments.

The same situation took place in nonelectrical machinery where the production of traditional equipment like turbines (SIC 3511), machine-tools (SIC 3541, 3542), textile machines (SIC 3552) moved down, but the compound annual growth of electronic computing equipment (SIC 3573) was about 20% during 15 years [4].

The second, third and fourth tendencies are illustrated in Figure 2, and the third one is described in Table 1.

The following vintage structure of machine-tools is due to long-term trends in machinery development as well as business cycles. The current situation lets us expect a new wave of industrial reequipping, because the average age of the U.S. equipment became higher than in competing countries -- Japan, the FRG, France, the UK.

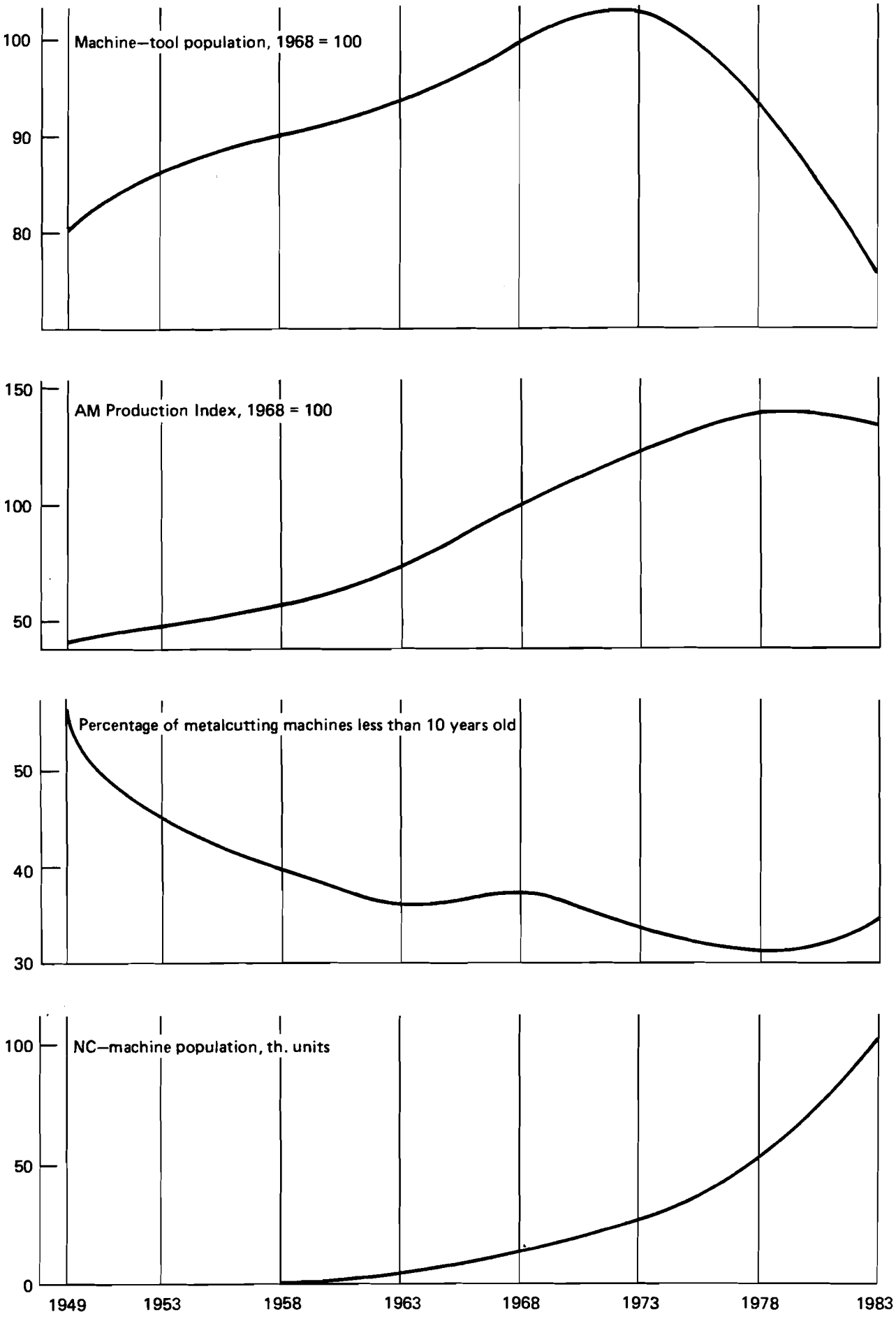

Figure 2. Machine-tools in US metalworking industries. Sources: [3].

Table 1. Vintage structure of metalworking equipment, US MWI [3].

Age	Year	Metalcutting Machines		Metal-forming machines	Joining & Assembl. Equipment	Other Equipment	Total
		Turning	Total				
0-9	1963	33	36	36	53	50	39
	1968	31	37	32	49	53	39
	1973	30	34	31	52	51	37
	1977	27	31	29	52	47	35
	1983	31	34	27	56	51	38
10-19	1963	45	44	41	40	38	42
	1968	41	41	42	39	36	41
	1973	39	38	40	37	36	38
	1977	34	35	36	34	34	35
	1983	33	34	36	30	32	33
20	1963	23	20	23	7	12	19
&	1968	28	22	26	12	11	20
up	1973	31	28	29	11	14	25
	1977	39	34	35	14	19	30
	1983	37	32	37	14	17	28

This led to the fact that the USA lost its competitive positions at world markets and, as a result, after 1977 the USA became a net importer of modern industrial equipment. In 1985 the import/export ratio was 3.8 for machine-tools as a whole, 4.8 for metalcutting machines, and 15.7 for NC machining centers [4].

There is only one way to improve the competitive positions, to increase labor and capital productivity, i.e. to base the new wave of reequipping on the growing substitution for conventional technologies and machines by the principally new ones. Now it is clear that this way in metalworking industries is to be an increasing penetration of flexible computerized technologies in MWI. Conventional metalcutting and metalforming machines are being replaced by NC-machines.

Today the share of NC-machines in total machine-tools populations reaches approximately 5% (in units). The share in production is 6% (in units) and 45% (in value).

The NC-machines diffusion processes were not even in different macroindustries. The penetration shares were higher in 3 industries -- electrical and nonelectrical machineries and transportation equipment. About one half of the total number of metalworking and metalforming machines was allocated in nonelectrical machinery (see Table 2.).

The growth of the NC-machines population was followed by a decrease of the total machine-tools population in all 2-digit industries and MWI as a whole. It led to an acceleration in diffusion share trends, particularly at the beginning of the 1980's.

Within the 2-digit industries there were some leading 3-digit industries and their data are shown in Table 3.

One can find that the most wide-spread types of NC-machines in the US metalworking industries are those displayed in Table 4.

The vintage structure, shown in Table 4, reflects different time-paths of diffusion for the mentioned types of NC-machines. The diffusion process began at the end of the 1950's by drilling NC-machines installation. In 1963 about 40% of all NC-machines installed in MWI were drilling machines, but the highest diffusion share was in the case of boring machines. After 1967-1968 the diffusion processes for boring and drilling machines

Table 2. The shares of NC-machines in machine-tools (metalcutting plus metalforming) population, installed units, 2-digit US metalworking industries [3].

Industry SIC		1963	1968	1973	1976-78	1983
33	T	170	167	163	117	118
	NC	10	198	349	750	2662
	S	0.004	0.12	0.21	0.64	2.26
34	T	634	656	638	632	519
	NC	100	992	2112	5600	14463
	S	0.02	0.15	0.33	0.89	2.79
35	T	952	913	1104	961	805
	NC	1360	6834	15131	29700	52541
	S	0.14	0.75	1.37	3.09	6.52
36	T	329	398	399	339	246
	NC	410	2467	3662	4700	10772
	S	0.13	0.62	0.92	1.39	4.39
37	T	450	364	401	361	303
	NC	820	2713	5053	9100	15284
	S	0.18	0.75	1.26	2.52	5.05
38	T	125	133	164	133	110
	NC	90	363	1309	2500	4874
	S	0.07	0.27	0.8	1.89	4.45
MWI	T	2810	2870	3065	2631	2193
	NC	2800	14190	28564	52850	103308
	S	0.1	0.49	0.93	2.01	4.71

T - total number of machine-tools (in thousands)
NC - number of metalcutting and metalforming NC-machines
S - share of NC in T, %.

Table 3. The shares of NC-machines in machine-tools population, installed units, 3-digit US metalworking industries [3].

Industry (SIC)		1963	1968	1973	1976 -78	1983
1. Ordnance (348)	T	28.9	41.5	42.7	38.8	24.3
	NC	60	600	710	810	810
	S	0.21	1.3	1.67	2.1	3.34
2. Construction, mining, material handling, machinery (353)	T	89.9	85	102.3	89.1	81
	NC	140	740	2130	5900	7640
	S	0.15	0.9	2.09	6.62	9.43
3. Metal-working machinery (354)	T	210.6	249.1	274.5	242.1	202
	NC	480	1750	3360	6920	11800
	S	0.23	0.7	1.22	2.86	5.84
4. Special machinery (355)	T	110.9	120.9	126.3	97.6	80.4
	NC	250	1300	1790	3750	4037
	S	0.22	1.1	1.42	3.84	5.02
5. Office, computing & accounting machines (357)	T	40.6	32.6	39.7	33.2	25.6
	NC	220	290	1080	1250	1890
	S	0.54	0.9	2.71	3.77	7.37
6. Electrical equipment (361,2,4,9)	T	175.8	211	202.6	179.4	127.6
	NC	150	1000	1670	2350	4420
	S	0.08	0.5	0.83	1.31	3.46
7. Radio, communication equipment & electronic components (365,6,7)	T	118.9	159.4	154.2	117.5	93.9
	NC	260	1450	1970	2160	5630
	S	0.22	0.9	1.28	1.83	6
8. Aircrafts & parts (372)	T	212.7	165.1	161.3	139.2	97.7
	NC	790	2480	4130	7400	8780
	S	0.37	1.5	2.56	5.32	8.99

See footnotes to Table 2.

Table 4. Vintage structure of NC-machines by types in US metalworking industry, 1983, % [3].

Type of equipment	0-4 yr	5-9 yr	10-19 yr	20yr & up	Total units in 1983	Plants with, %
NC turning machines	58	28	11	3	33352	26
NC boring machines	29	22	33	17	5064	7
NC drilling machines	21	29	43	8	7993	9
NC milling machines	44	27	22	6	15929	16
NC grinding machines	50	21	22	7	2276	3
NC thermal cutting machines	53	29	8	9	1034	3
NC machining centers	58	26	15	1	24003	19
NC punching & shearing machines	37	29	26	8	6223	8
NC bending & transforming mach.	33	26	27	15	2585	3

stagnated. One of the reasons was their replacement by machining centers.

That is why among the youngest generations of NC-machines turning machines and machining centers dominate.

If we look at Table 5 we can see that the highest diffusion share is observed in the case of turning machines. Moreover, this share is growing permanently from the oldest generation to the youngest one. It is rather high also for boring, thermal-cutting, punching and shearing machines, traveling-wire EDM, but their shares in the total number of NC-machines are relatively small.

The diffusion of NC grinding machines is important too in spite of the rather low share. This importance is due to the high number of this type of machines in MWI. Grinding machines take the first place in the total machine tools population (about 23% in 1983).

The industrial distribution of NC-machines by types shown in Table 5 proves that 50% of them are installed in nonelectrical machinery. But the main consumer of metalforming machines is fabricated metal products. The second user of metalcutting machines is transportation equipment, but the most dynamic industry (electrical machinery) uses only 10% of NC-machines installed in MWI.

3. NC-machines Production and Their Diffusion

The compilation of statistical information about NC-machines production, consumption, prices and their diffusion in total machine-tools production is rather a complicated problem. We had to use several statistical sources [5-8] to construct long-term time-series and even now we are not sure of full compatibility of different sets of statistical data. Nevertheless, almost all data mentioned above have been compiled for the US industry for all types of NC-machines investigated in the previous section.

The shares of NC-machines in total machine-tools production by types are shown in Figure 3. These shares were estimated in units as well as in values. One can see several inexplicable "jumps" in the data trends (after 1968 and at the beginning of the 1980's). Probably they are connected with boundaries inside the time-series due to the use of different statistical sources.

Table 5. Shares of NC-machines in each generation of machine tools, %, US MWI, 1983 [3].

	0-4 yr	5-9 yr	10-19 yr	20yr & up	Total	Share in total no. of NC-machines
Turning machines	37.1	15.5	3.2	0.6	9.1	32.0
Boring machines	30.7	19.4	10.9	4.3	11.1	5.0
Drilling machines	5.6	4.2	3.3	0.6	2.8	8.0
Milling machines	20.7	9.1	4.4	1.4	6.8	15.0
Grinding machines	2.1	0.6	0.4	0.1	0.6	2.0
Thermal cutting machines	28.1	14.9	5.9	11.7	19.5	1.0
Traveling-wire EDM	23.9	15.6	1.3	0.6	10.0	1.0
Machining centers (in sum of drill., mill. & boring mach.)	20.3	5.7	1.8	0.1	4.2	23.0
Total metalcutting	19.2	7.3	3.0	1.0	5.5	9.1
Punching & shearing mach.	24.3	11.7	6.3	2.2	8.6	6.0
Bending & forming mach.	9.1	4.4	2.3	1.5	3.2	3.0
Total metal forming	7.4	3.0	1.4	0.5	1.9	9.0
Total machine tools	17.3	6.4	2.6	0.8	4.7	100.0

Table 6. NC-machines in the metalworking industries, shares, %, 1983 [3].

SIC / Type	25	33	34	35	36	37	38	39	Total
Turning	0.1	2.5	13.0	55.7	8.0	14.8	4.6	1.2	100
Boring	0.4	5.4	9.9	57.9	3.6	17.9	2.2	2.8	100
Drilling	0.7	3.3	14.0	52.6	14.4	9.0	2.8	3.2	100
Milling	0.3	2.7	10.5	49.4	12.4	13.5	7.1	4.0	100
Grinding	1.4	5.6	16.6	41.6	7.5	20.6	3.9	2.8	100
Thermal cutting	0.3	4.2	38.5	38.1	5.9	12.1	1.0	-	100
Machining centers	0.1	1.5	6.9	58.0	11.0	17.2	5.2	0.2	100
Punching & shearing	2.6	1.5	40.0	20.7	16.3	6.0	5.9	7.0	100
Bending & forming	7.6	5.6	38.3	19.1	9.6	16.5	2.7	0.6	100
Total NC-machines	0.6	2.6	14.0	50.9	10.4	14.8	4.7	2.0	100

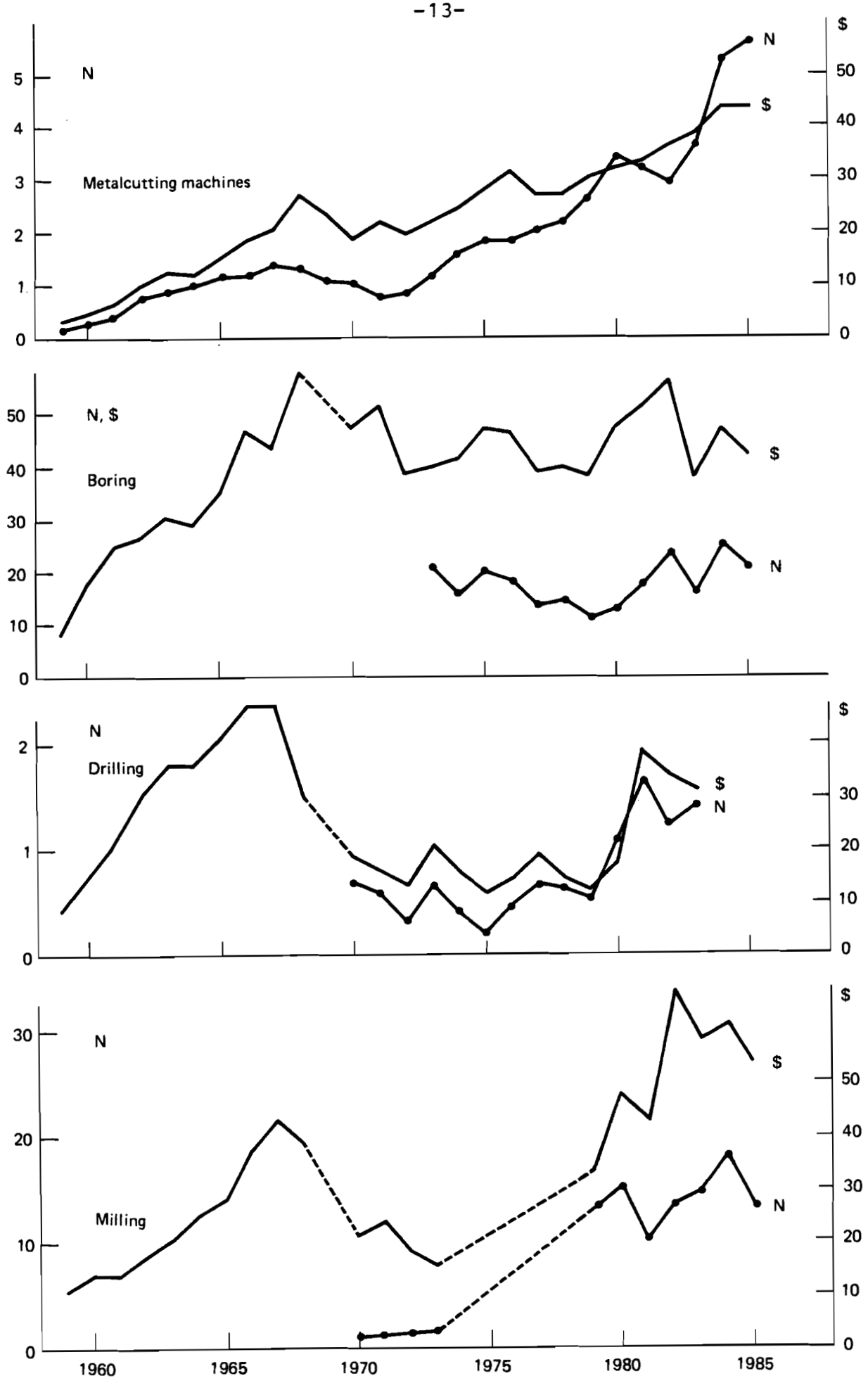

Figure 3. Shares of NC-machines in total machine production, %. N - in units, $ - in values. Estimated on the basis of [5-8]
(to be continued)

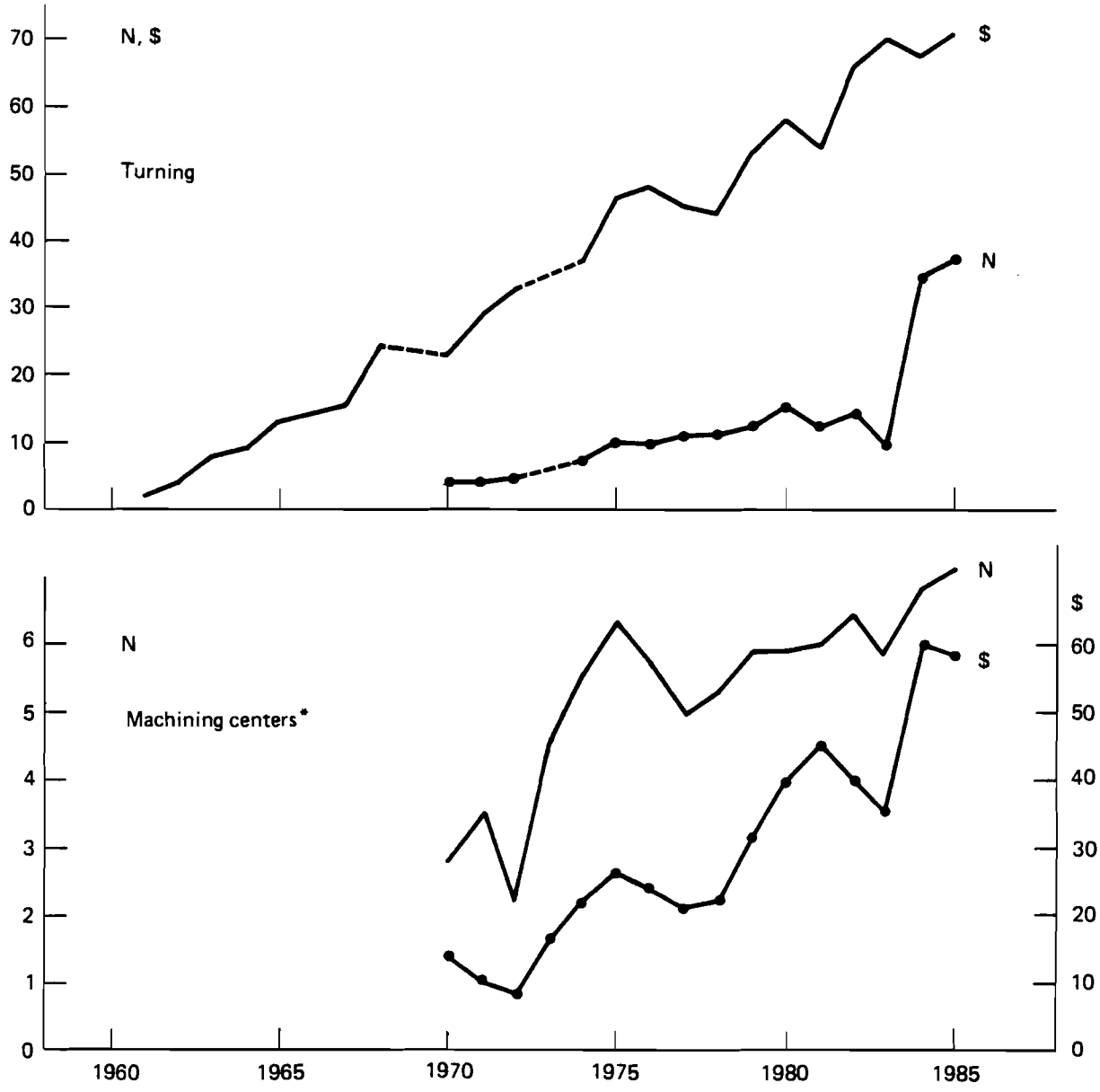

Figure 3. continued

*Machining centers ratio to boring + drilling + milling machines.

The diffusion processes estimated for production differ from the ones based on installation data. For metalcutting machines, one can see that the growth period (1959-1966), which coincided with a period of prosperity in the US industry, was followed by the period of a certain decline (1967-1971). Then the share moved up till 1980, dropped during the recession and went up again in 1983-1985.

In spite of these oscillations for metalcutting machines as a whole, a tendency of growth is obvious both in values and in units. It looks like a straight line for the first case and an accelerating curve for the second one.

But these smooth trends conceal very contradictory movements of the diffusion shares for different types of NC-machines. For the case of boring machines, which demonstrated the highest value of the share at the beginning, one can observe, after the period of a strong growth (1959-1968), a real stagnation of the share, both in units and values.

The forms of the curves for drilling and milling machines are very similar -- rapid growth in 1959-1967, then a decline and growth in the 1980's again. For the case of drilling machines (a very widely spread type of metalcutting machines) the maximum diffusion rate was reached in the middle of the 1960's (2.3%) and at the beginning of the 1980's it was only 1.5%.

NC turning machines started the real diffusion later than the above-mentioned types, but their growth (in values) was strong, stable, and close to a straight line. The observed "jump" in the share dynamics in 1984-1985, measured in units, can be explained by the use of a new statistical source [6]. As a result, NC turning machines became a leader in the diffusion process and their share reached 70% in 1983-1985 (in values) and 35% (in units).

The real expansion of computerized machining centers began in the 1970's. They replaced three types of metalcutting machines -- boring, drilling and milling machines -- combining their functions in one center. The centers appeared first as multifunction machines in the 1960's, and in the 1970's they were 100% computerized.

The ratio of machining centers to boring + drilling + milling machines production reached 70% in values and 6% in

units. This replacement can explain the deceleration in the diffusion share trends for these three types of stand-alone machines.

The analysis of the substitution, or replacement processes called for the use of price dynamics as an explanatory factor.

The dynamics of relative prices for NC metalcutting machines measured as NC-machines to the non-NC-machines price ratio is shown in Figure 4. One can observe a certain long-term oscillation in the movement. The relative prices moved down from the starting point (1954-1958 average) to 1964. Then they went up during the 1965-1971 period and dropped again afterwards. Now the average price of a NC metalcutting machine is 13 times higher than the average price of a non-NC-machine.

One can see the same oscillation in the average unit price of a NC-machine, shown in the same figure.[1] A possible explanation of such an oscillation is a replacement of one generation of NC-machines by another. The first generation of NC-machines based on perforated tapes control dominated at the end of the 1950's and during the first half of the 1960's. The machine cost decreased and its price went down.

In the middle of the 1960's a new generation of NC-machines, based on microprocessor or computerized control, appeared. The high cost of hardware at that time led to a machine price increase. At last a sharp decrease in hardware cost pushed the NC-machine price down in the first half of the 1970's. The price shock in 1981-1982 is probably explained by incompatibility of two sets of statistical information from two different sources. The same explanation holds for the price jumps in 1970-1971.

The incomplete data for the prices of the different types of NC-machines show that relative prices are completely different for each type. The cheapest metalcutting machine is a drilling machine (4000 dollars on average). That is why a rather expensive NC drilling machine is not competitive in many cases and the diffusion rate is one of the lowest among all types of NC-machines.

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[1] In order to recalculate current prices into constant ones we used the price deflator for machines and equipment [9].

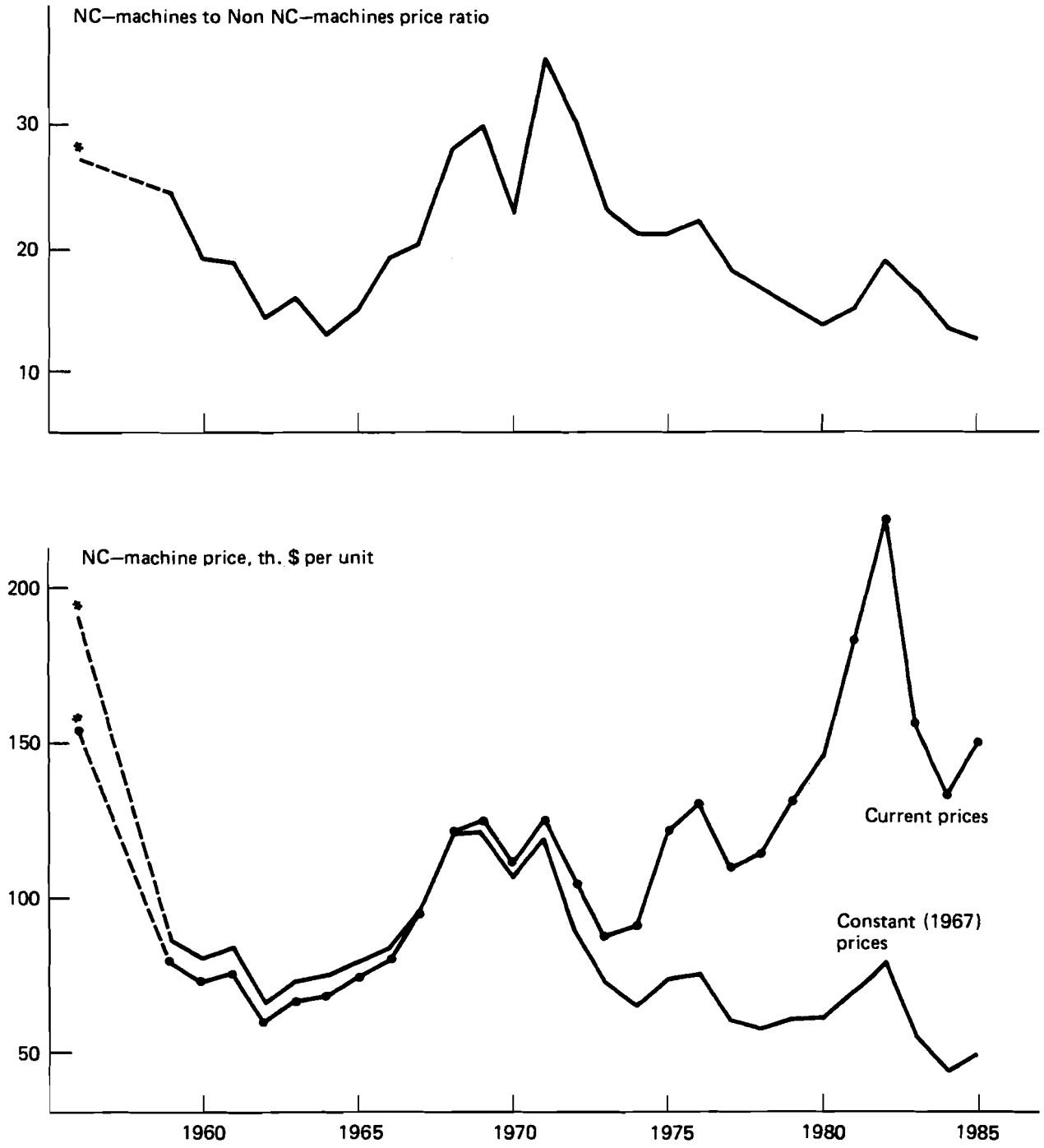

Figure 4. Price trends for NC metalcutting machines, US metalworking industry. Estimated on the basis of [5-8].

*1954-1958 average.

In the case of turning machines the relative price (or NC-price to non-NC price ratio) decreased from 10 at the beginning of the 1970's to 8 at the beginning of the 1980's and to 4 in 1985. This is one of the reasons for the rapid diffusion of NC turning machines.

It is not reasonable to compare the prices of a machining center with the average price of drilling, boring and milling machines because of the high weight of the cheapest drilling machines in the sum and the growing capability of a machining center unit. The price of the unit decreased from $90.000 in 1968 to $80.000 in 1977, to $71.000 in 1982 and to $67.000 (1967 prices) in 1985.

Of course, for a deeper analysis it is necessary to compare NC-machines price dynamics with their productivity trends, but the lack of information about the relative productivity of NC-machines in national and industrial statistics does not permit to do so at the present time.

4. Diffusion Curves and Their Forecasting

The main task of the previous sections was to provide necessary information for diffusion curves fitting and their extrapolation. Now we have different sets of applicable statistical information on the NC-machines diffusion. There are two basic sets: production and installations. Both of them are disaggregated by the metal working industries as well as by types of the machines.

A diffusion process for new technologies can be described as follows:

1. A share of NC-machines, installed, in the total machines installations (in units).
2. A share of NC-machines, produced or shipped, in the total production or shipments of machines (in units and in values).
3. A share of NC-machines consumption[2] in the total number of consumed machines (in units and in values).
4. A share of products, produced with NC-machines use, in

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[2]Consumption = Production - Exports + Imports.

the total production of the metal working industries (in values).

Unfortunately, the official statistical data for the forth case are not published at national economy or industry levels. The third case calls for the international trade statistics, which either is absent, or has limited comparability with the national industrial data (in the case of NC-machines). That is why we shall analyze the diffusion processes by using first and second types of data.

Theoretically these two types of data are to be interconnected by the following equation:

$$IN_t = \delta . IN_{t-1} + PR_t \qquad (1)$$

where:

IN_t - number of machines installed by the end of year t;

PR_t - number of machines produced in year t;

δ - discard rate.

Strictly speaking, consumption must be used instead of production. For the periods when foreign trade was negligible in this field, or when the trade balance was close to zero, the use of production, or shipment data seemed to be reasonable. But for the 1980's the difference between consumption and shipments grows extremely fast. As a result, the main part of NC-machines, installed in this period, originated abroad (see Table 7).

Approximately 80% of the consumed machines were imported and only 15-17% of the produced machines were exported. The imported NC-machines were 2-3 times cheaper than the domestic ones, and 30-40% cheaper than the exported ones. This enormous price difference can be explained by 2 reasons: first, higher cost of production in the USA, and second, US monopoly on the most sophisticated and expensive machines.

Before the 1980's NC-machines international trade had been of no importance, but even for this period we could not connect production with a number of installations by the use of (1). For example, the difference between the numbers of NC metal cutting machines, installed by 1973 and 1968 was 13000, but their total shipments between these two points were only 10000. We think

Table 7. NC machines in 1985 - shipments, consumption, exports and imports [6]

Types of NC-machines	Shipments		Consumption		Exports		Imports		Import/Export ratio		Import/Consumption ratio	
	units	value*	units	value*	units	value*	units	value*	units	value	units	value
Turning	1420	225.2	5500	480.3	245	25.4	4325	280.5	17.7	11.0	0.79	0.58
Mach. centers	1077	214.7	5109	555.1	156	19.3	4188	259.7	26.8	18.6	0.82	0.65
Prices**												
-turning	158.6		87.3		103.7		64.9		-		-	
-mach. centers	199.4		108.7		123.7		85.9		-		-	

*In millions of dollars (exports in producer value, imports in c.i.f. plus import duties).

**In thousands of dollars per unit.

that this is the result of different definitions or samples in different sources of statistical information.

The first approach we used to estimate and forecast the diffusion processes was based on a primitive logistic interpolation and extrapolation through several points available for NC-machines installations.

The estimates, shown in Figure 5, were made for the share of metal cutting and metal forming NC-machines in the total number of machine-tools installed (see Table 2).

Here this rather formal extrapolation predicts a 6% saturation level, which will be reached in the middle of the 90s'. The inflexion point has been passed at the end of the 70s.

The same estimations made for the 2-digit metal working industries (shown in Figure 6) gave different results. The saturation level will be 3.5% for primary metals, 5% for fabricated metal products, 8.7% for non-electrical machinery, 7.7% for electrical machinery, 8.3% for transportation equipment and 9.1% for instruments. These levels will be reached at the end of the century, and the inflexion point is allocated in the middle of the 1980's.

Taking into consideration these estimates as well as the structural forecast of the US MWI (see Figure 7), it is possible to calculate the saturation level for NC-machines in the sector as a whole.

$$\underset{\text{(SIC 33)}}{3.51.0.05} + \underset{\text{(SIC 34)}}{5.07.0.12} + \underset{\text{(SIC 35)}}{8.71.0.26} + \underset{\text{(SIC 36)}}{7.74.0.25} + \underset{\text{(SIC 37)}}{8.32.0.20} +$$

$$+\underset{\text{(SIC 38)}}{9.05.0.12} = 0.18 + 0.61 + 2.26 + 1.94 + 1.66 + +1.09 = 7.7 \qquad (2)$$

The weighted function (2) provides the maximum diffusion share equal approximately to 7% in 2000. This result is slightly higher than the one we have got for MWI earlier. The main impact in the total sum in (2) is provided by nonelectrical machinery. This industry is followed by electrical machinery and transportation equipment.

Then we estimated the diffusion logistic curves for several 3-digit industries which took the leading positions in 2-digit

NCMWI	
1958	0.01
1963	0.10
1968	0.49
1973	0.93
1977	2.01
1983	4.71

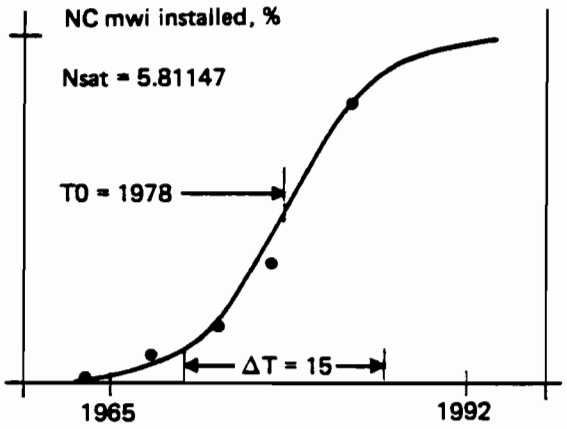
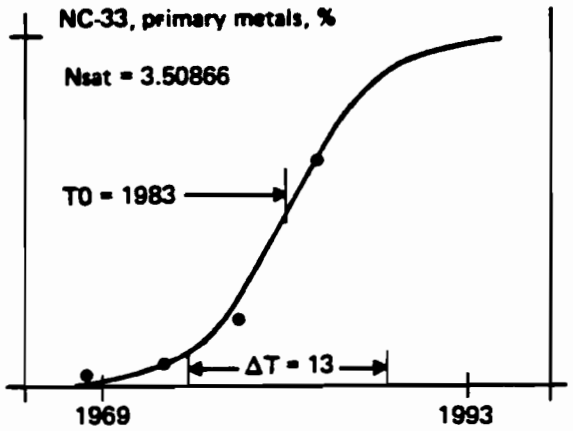


Figure 5. Logistic diffusion of NC-machines installed in US MWI, percentage measured on unit base.

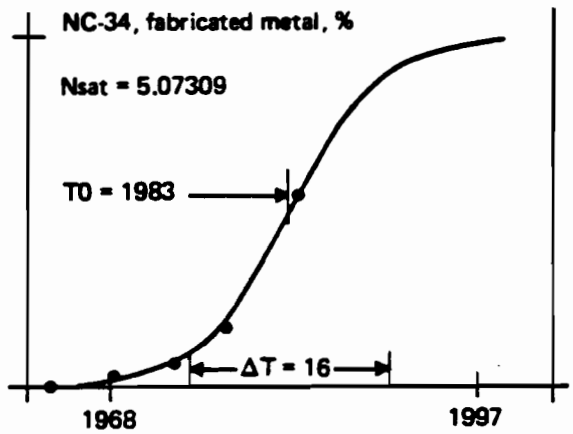
NCPRIMET

1963	0.004
1968	0.118
1973	0.214
1978	0.639
1983	2.259



NCFABRIMET

1963	0.020
1968	0.151
1973	0.331
1977	0.887
1983	2.787



NCNONELMA

1963	0.140
1968	0.749
1973	1.371
1976	3.091
1983	6.524

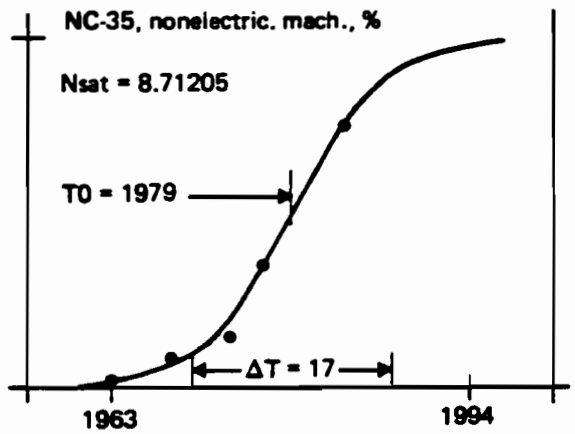
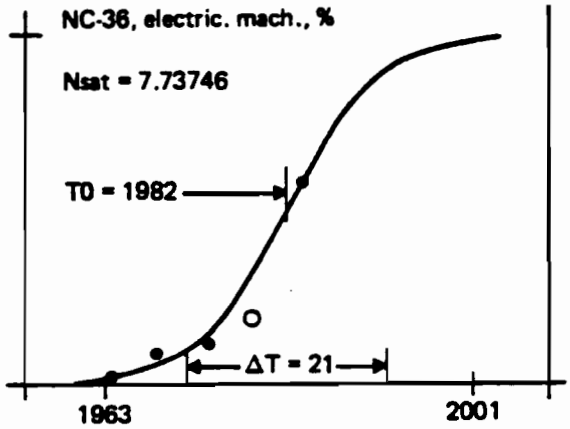


Figure 6. Logistic diffusion of NC-machines in different 2-digit industries (SIC 33-38), percentage measured on unit base

(to be continued)

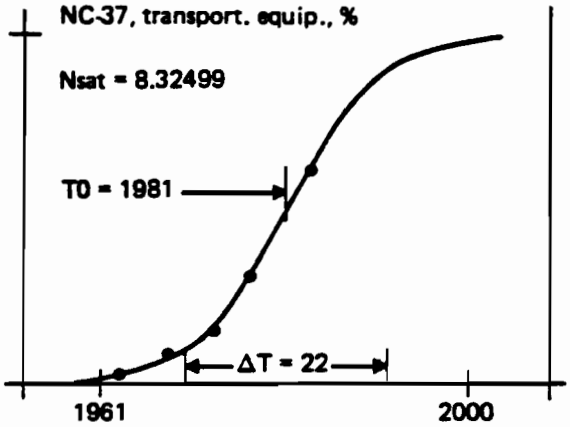
NCELMA

1963	0.126
1968	0.619
1973	0.918
1978	1.386 O
1983	4.385



NCTRANEQ

1963	0.181
1968	0.745
1973	1.260
1977	2.520
1983	5.045



NCINSTR

1963	0.071
1968	0.273
1973	0.797
1978	1.887
1983	4.449

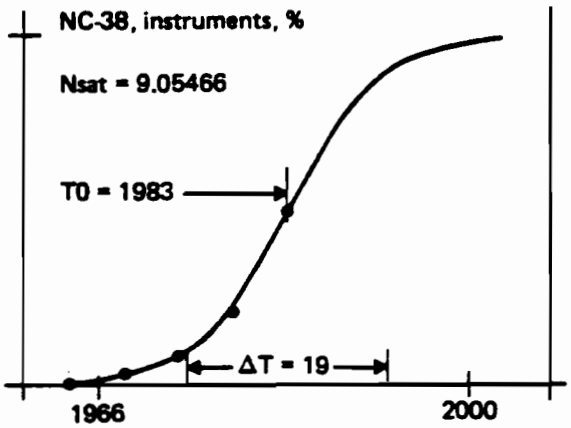


Figure 6. continued

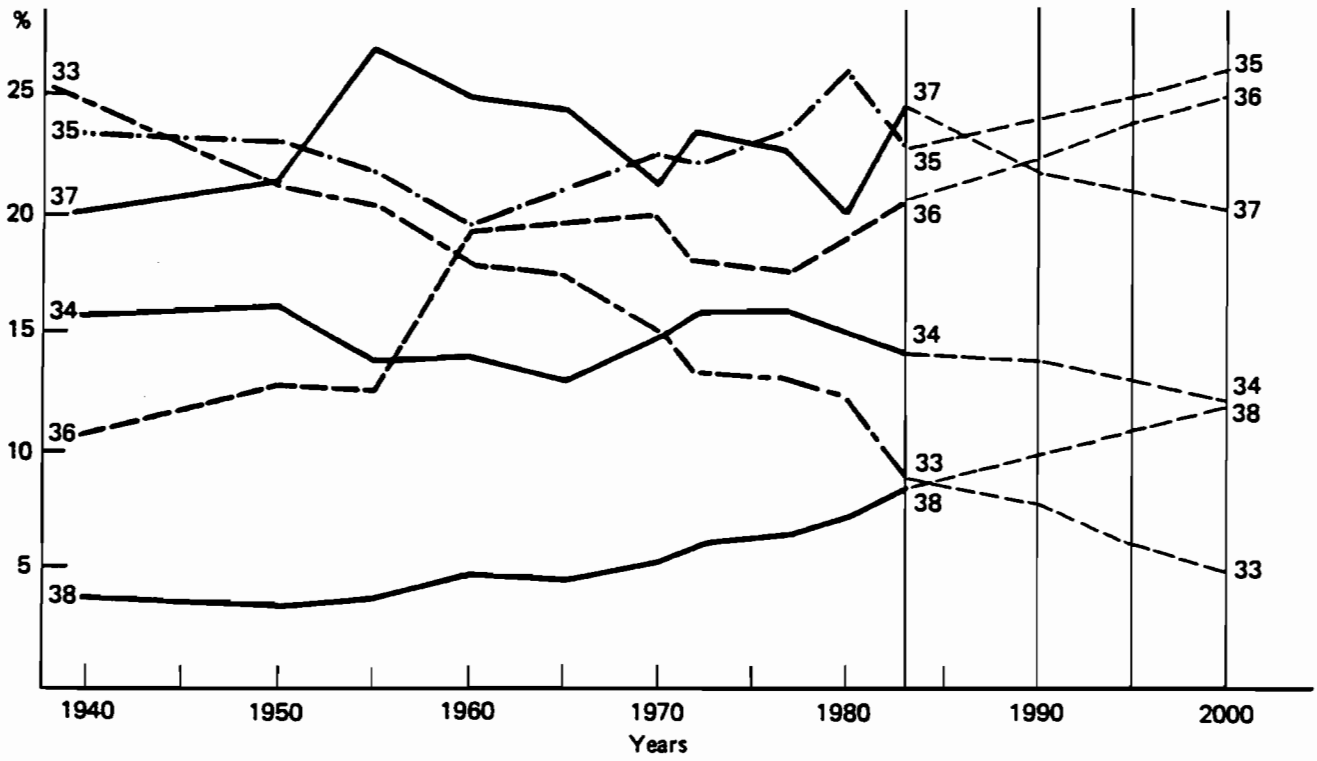


Figure 7. Real and forecast dynamics of metal-working industry structure (SIC 33-38).

industries from the NC-machines diffusion viewpoint. The results, shown in Figure 8, look rather reasonable. The highest saturation level is predicted in a relatively small industry -- engines and turbines -- equal to 20%. The real leaders will be radio, communication equipment and electronic components (SIC 365-367) with the level equal to 15% and office and computing machines (SIC 357) -- 14%.

The same curves estimated for the different types of NC-machines are shown in Figure 9. But for 2 cases -- drilling and grinding machines -- the logistic curves were not fitted. That is why we chose the saturation levels to be reached approximately in 2000. For the case of machining centers in order to estimate the share of their diffusion we use the sum of drilling, milling and boring machines as a denominator.

After that we repeated the procedure described above to forecast NC-machines diffusion in the US MWI. We also estimated real dynamics of shares of each type of machines in the total number of the machine-tools population and extrapolated them up to 2000 (see Figure 10).

$$(16.2.0.17 + 14.4.0.02 + 10.4.0.12 + 4.0.11 + 2.0.18 + 13.8.0.04 + 6.9.0.25).1.089 = (2.83 + 0.29 + 1.25 + 0.44 + 0.36 + 0.51 + 1.72).1.08 = 8.0\% \qquad (3)$$

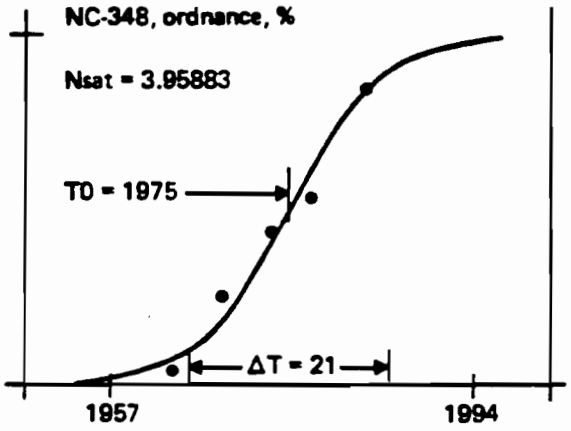
The coefficient 1.08 was used to take other types of NC-machines into consideration and it equals the ratio of the total number of NC-machines to the sum of the mentioned types in 1983.

The result we got in (3), -8%, is rather close to our estimate in (2). The coincidence of these two figures which were reached by the use of two different types of data proves their reliability. However, this saturation level seems to be too low from the economic point of view and its explanation can be the following.

We used only five points for the estimations covering a long period -- 20 years. That is why the results reflect a certain tendency corresponding to the situation in the past which dealt with the previous generations of NC-machines. The current

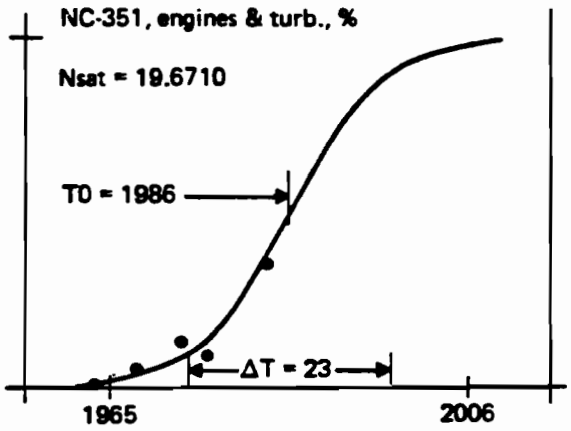
NCORDNANCE

1963	0.207
1968	0.988
1973	1.669
1977	2.095
1983	3.340



NCENTUR

1963	0.174
1968	1.003
1973	2.610
1976	1.914
1983	7.059



NCCONMMH

1963	0.151
1968	0.595
1973	2.085
1976	6.622
1983	9.431

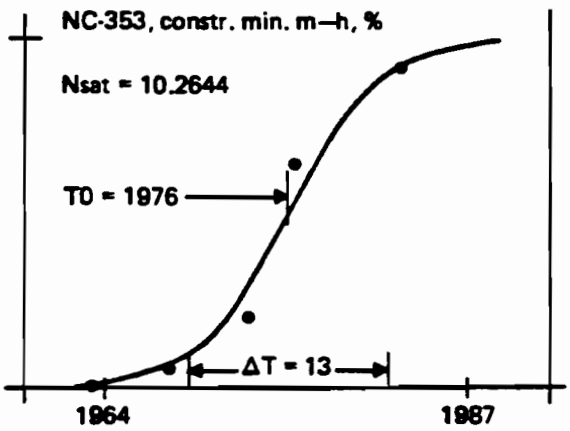
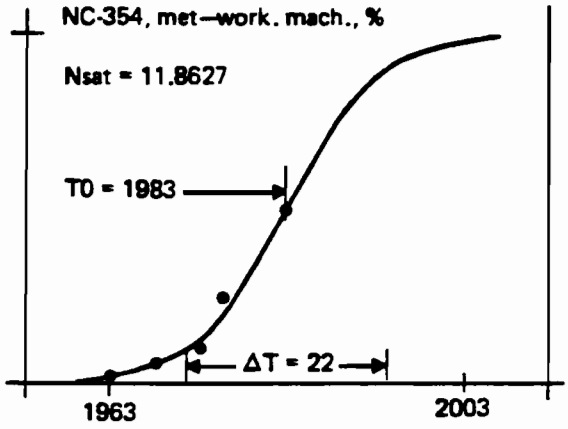


Figure 8. Logistic diffusion of NC-machines in some leading 3-digit industries, percentage measured on unit base

(to be continued)

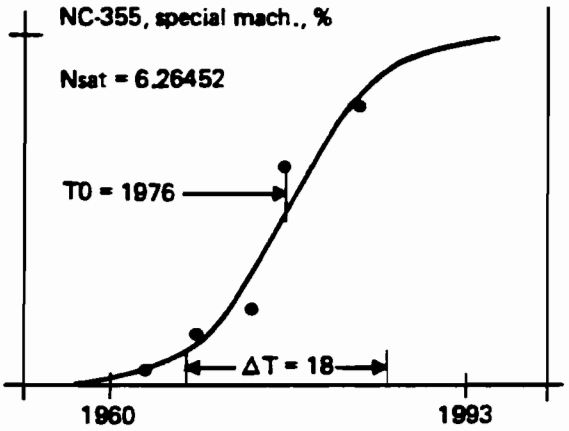
NCMETALWORKING

1963	0.228
1968	0.644
1973	1.223
1976	2.858
1983	5.841



NCSPECIAL

1963	0.221
1968	0.908
1973	1.419
1976	3.842
1983	5.023



NCOFFICE

1963	0.542
1968	0.766
1973	2.714
1976	3.765
1983	7.365

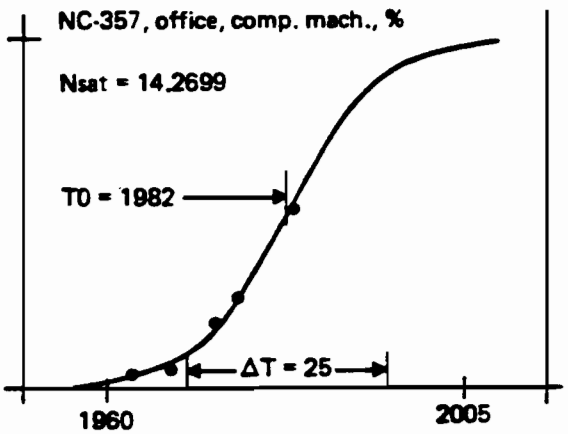
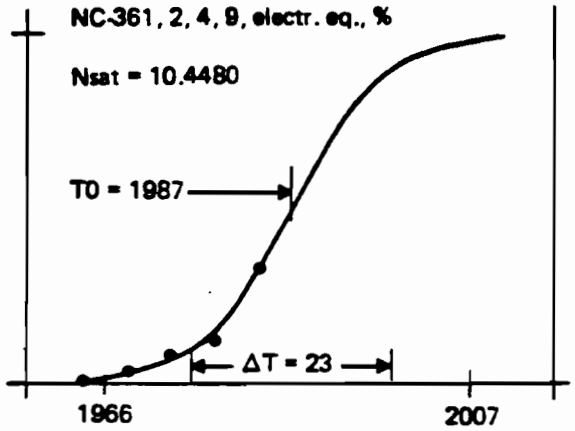


Figure 8. continued

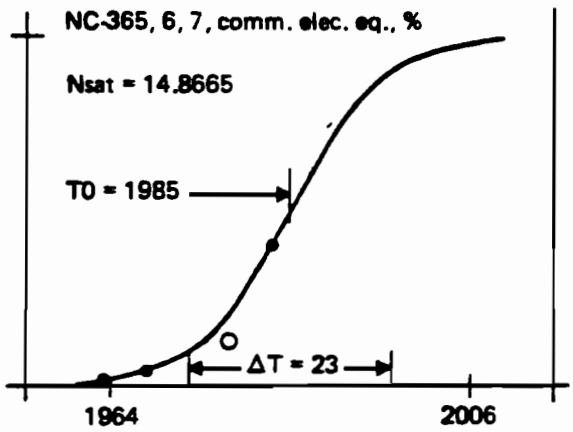
NCELEQ

1963	0.084
1968	0.359
1973	0.826
1978	1.310
1983	3.460



NCCOMEL

1963	0.215
1968	0.717
1973	1.280
1978	1.834
1983	6.000



NCAIRCRAFT

1963	0.370
1968	1.261
1973	2.557
1977	5.316
1983	8.988

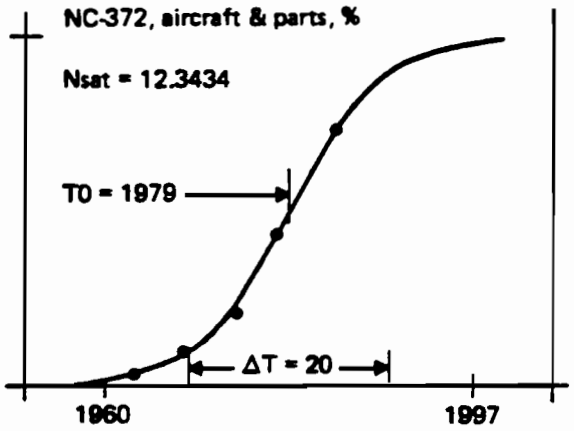
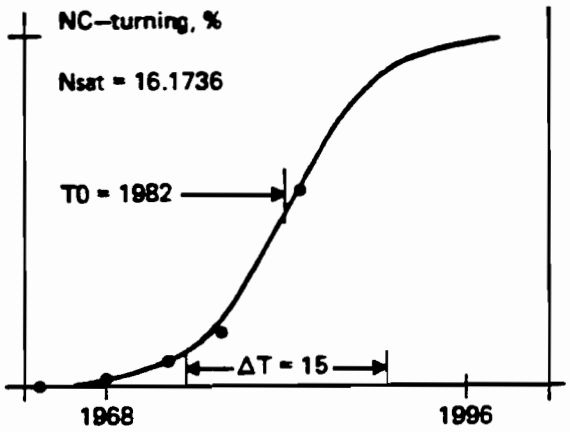


Figure 8. continued

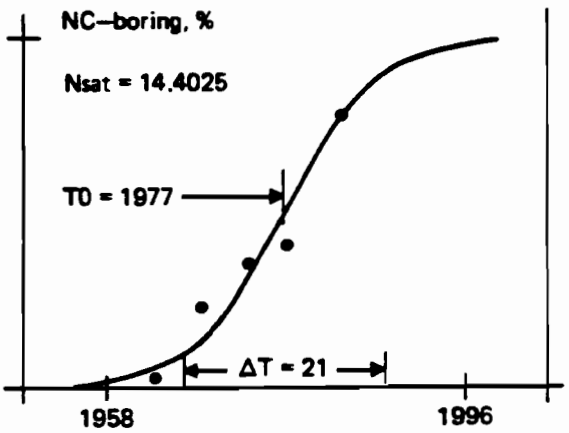
NCTURN

1963	0.050
1968	0.446
1973	1.113
1977	2.534
1983	9.121



NCBOR

1963	0.480
1968	3.396
1973	5.151
1977	5.876
1983	11.123



NCMILL

1963	0.248
1968	0.889
1973	1.756
1977	2.079 O
1983	6.795

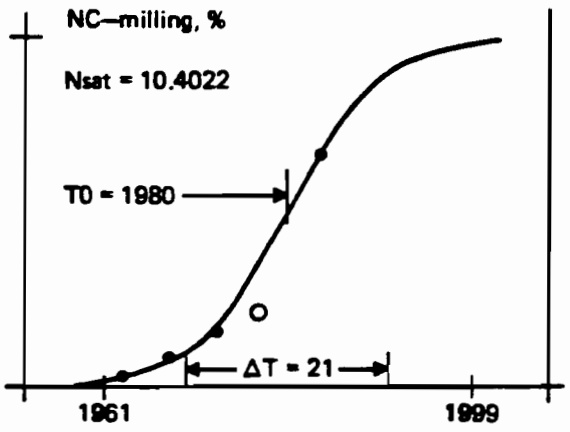
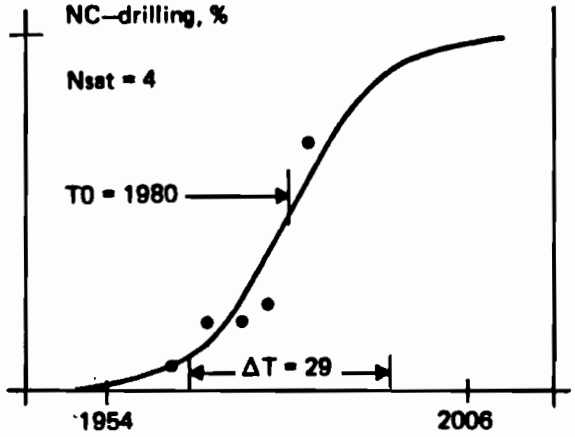


Figure 9. Logistic diffusion of different types of NC-machines in US MWI

(to be continued)

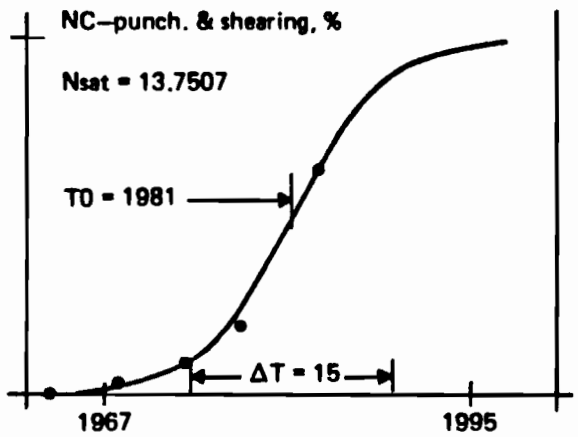
NCDRILL

1963	0.248
1968	0.766
1973	0.809
1977	0.991
1983	2.761



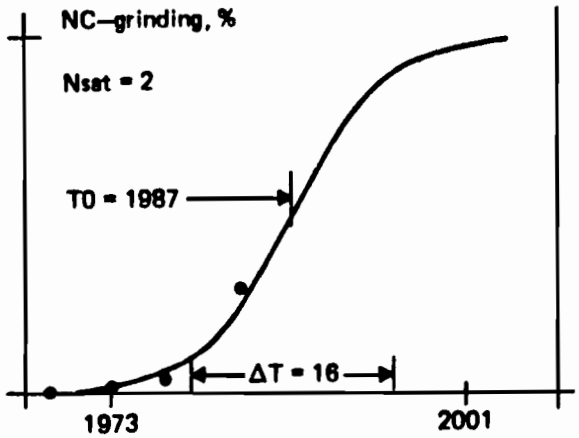
NCPUSH

1963	0.052
1968	0.493
1973	1.156
1977	2.625
1983	8.573



NCGRIND

1968	0.012
1973	0.037
1977	0.073
1983	0.591



MCDRIMIBOR

1963	0.043
1968	0.563
1973	1.109
1977	2.302
1983	5.521

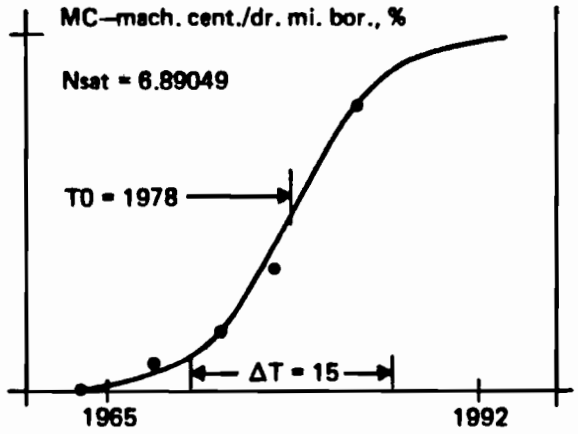


Figure 9. continued

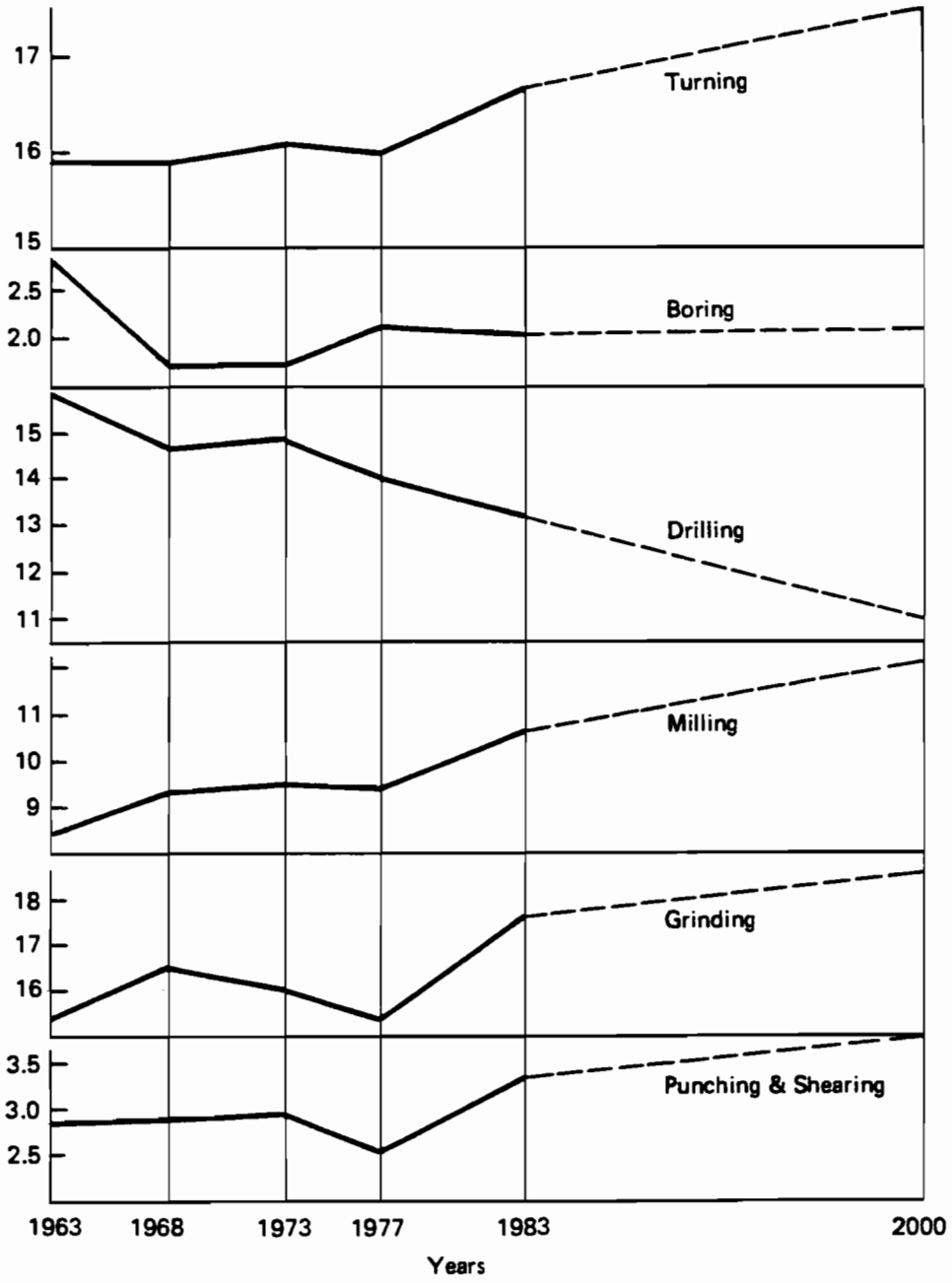


Figure 10. Real and forecasted trends of shares of machines in total machine-tool population, US MWI, %.

generation is based on more sophisticated computerized machines, used partly flexible manufacturing cells or systems.

The results mentioned above can be interpreted as a forecast of the life-cycle movement for the generation of NC-machines which dominated in the 1960's and 1970's. To take into account the new generation, it is necessary to investigate production tendencies.

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