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U.S. Productivity and Electronic Business Processes in Manufacturing

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Abstract

Recent studies argue that the use of information technology is a significant source of U.S. productivity growth. Official U.S. data on this use have been scarce. New official data on the use of electronic business processes (business processes such as procurement, payroll, inventory, etc., conducted over computer networks) in the manufacturing sector of the United States were recently released. Preliminary estimates based on these data are consistent with some results in the literature. However, they also raise questions requiring additional detailed micro data analysis.

Disclaimer: This paper reports the results of research and analysis undertaken by the authors. It has undergone a more limited review than official publications. Opinions expressed are those of the authors and do not necessarily represent the official position of the U.S. Census Bureau. This report is distributed to inform interested parties of research and to encourage discussion

1. Introduction

The strong economic performance of the United States in the late 1990s economy generates vigorous interest in role of computers. Many studies took up the challenge of Solow's 1987 paradox that "you can see the computer age everywhere except in the productivity statistics." Linkages between computers and economic performance are found (for example, in Oliner and Sichel 2000; Jorgenson and Stiroh 2000; Jorgenson 2001; and Triplett and Bosworth 2000), at least for some sectors of the U.S. economy, particularly the surge of productivity growth in the late 1990s. However, it remains unclear just how computers affect productivity. Official statistics provided scant information about how computers are used. The Census Bureau initiated an e-business measurement strategy (Mesenbourg 2001) to begin addressing these data gaps. New data on the use of computer networks and e-business processes in manufacturing were released in June 2001. This paper describes those new data. It also presents the first research results using these data by modeling the use of computer networks in the manufacturing sector and exploring how this basic measure of electronic threshold relates to the differential industry productivity gains found in other studies.

2. Productivity and Computer Use: Many Questions and a Few Answers

While productivity research generally finds an important role for computers in the growth of output and productivity in the U.S, it does not fully explain how that effect occurs. The use of e-business processes (business processes such as procurement, payroll, inventory, etc., conducted over computer networks) is one possibility. However, data to assess the role of e-business processes has been limited.

Productivity growth and concentration. Illustrative estimates of output and productivity growth in the U.S. are given in Table 1. The first three columns, taken from Jorgenson and Stiroh 2000, show output growth, a broad measure of productivity growth, and average labor productivity growth between 1958 and 1996. Both measures of productivity growth are low in industries outside of manufacturing. Within manufacturing, growth rates are far higher for two industries in the U.S. Standard Industrial Classification System (SIC): Industrial Machinery and Equipment (SIC

Table 1: Illustrative Recent Estimates of Output and Productivity Growth for U.S. Selected Industries[1]

SIC Industry – description	Period								
	1958 - 1996[2]			1960 - 73[3]		1973-97[3]		1987-97[3]	
	Output	Broad Productivity	Average labor productivity	Multifactor productivity	Labor productivity	Multifactor productivity	Labor productivity	Multifactor productivity	Labor productivity
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
All Manufacturing				**2.5**	**3.3**	**2.0**	**2.7**	**2.4**	**2.9**
Durable goods industries				**3.1**	**3.7**	**2.0**	**2.4**	**2.4**	**2.5**
24 – Lumber and Wood products	2.241	-0.020	1.551						
25 – Furniture and fixtures	2.909	0.562	1.785						
32 – Stone, clay, and glass	1.860	0.414	1.302						
33 – Primary metals	1.139	0.224	1.514						
34 – Fabricated metals	2.280	0.648	1.881						
35 – Industrial machinery and equipment	4.786	1.461	3.154						
36 – Electronic and electric equipment	5.457	1.975	4.078	-0.9	0.2	4.6	5.8	7.3	8.7
371 – Motor Vehicles	3.361	0.242	2.279						
37 x 371 – Other transportation equipment	1.306	0.183	0.999						
38 – Instruments	5.226	1.121	2.568						
39 – Miscellaneous	2.530	0.821	2.079						
Nondurable goods industries				**2.6**	**3.6**	**1.2**	**2.1**	**0.5**	**1.3**
20 – Food products	2.201	0.535	1.594						
21 – Tobacco products	0.428	-0.200	0.881						
22 – Textile mill products	2.227	1.230	2.536						
23 – Apparel and textiles	2.027	0.804	2.013						
31 – Leather products	-2.056	0.285	2.078						
26 – Paper products	2.891	0.416	1.963						
27 – Printing and publishing	2.513	-0.445	0.145						
28 – Chemical products	3.471	0.584	2.018						
29 – Petroleum refining	2.211	0.327	0.796						
30 – Rubber and Plastic	5.171	1.043	1.936						
Services	**4.343**	**-0.190**	**0.920**	**1.6**	**2.2**	**0.2**	**.04**	**0.5**	**0.7**
Finance, Insurance, and Real Estate	**3.423**	**-0.176**	**0.664**	**-0.6**	**1.3**	**-0.9**	**0.5**	**-0.5**	**1.6**
Total Private Sector	--	--	--	**1.7**	**2.5**	**0.5**	**0.9**	**0.9**	**1.1**

[1] Definitions of productivity measures differ slightly between Jorgenson and Stiroh 2000 and Triplett and Bosworth 2000. Also, both studies report additional estimates not replicated in this table. "—" indicates statistic not reported in original publication. All data are on a U.S. Standard Industrial Classification (SIC) basis.

[2] Jorgenson and Stiroh 2000.

[3] Triplett and Bosworth 2000.

35), and Electronic and Electric Equipment (SIC 36). Columns 4 through 9 are taken from Triplett and Bosworth 2000. Recent growth in both productivity measures can be seen by comparing data for 1973 – 1997 (columns 6 and 7) with data for 1987 – 97 (columns 8 and 9). Productivity growth is far higher in manufacturing than in other industries during either period, and is particularly pronounced for Electronic and Electric Equipment. That industry's multifactor productivity growth of 7.3 percent between 1987 and 1997 far exceeds the rate of 2.4 percent for durable goods manufacturing, 2.4 percent (also) for all manufacturing industries, 0.5 percent for services, -0.5 percent for finance, insurance, and real estate, and 0.9 percent for the private sector as a whole.

This concentrated productivity growth is not completely expected. Computers are an intermediate input to production processes in many industries, so labor productivity gains through capital deepening might be expected in industries that *use* computers, including manufacturing and also industries such as retailing, wholesaling, and logistics. More recent studies, such as Stiroh 2001and Nordhaus 2001, find the productivity increase more widespread. However, Stiroh 2001 still finds that the gains are higher in durable goods manufacturing than in nondurable goods manufacturing, and singles out SIC 35 and SIC 36 as two manufacturing industries of three industries whose productivity growth markedly accelerated in the late 1990s.

<u>E-business processes.</u> The literature on the Solow paradox addresses whether the use of computers affects productivity, but does not fully explain how this effect occurs. Computer capital, often called IT or information and communications technology (ICT), may be used to streamline business processes such as order taking, inventory control, accounting services, and tracking product delivery. When these computers are linked into networks, they form the basis for electronic business processes. The U.S. Census Bureau's e-business measurement strategy (Mesenbourg 2001) defined three primary components of the digital economy – supporting infrastructure, electronic business processes (how business is conducted), and electronic commerce transactions (selling goods and services online). Both electronic business processes and electronic commerce transactions rely on computer-mediated networks. This reliance on computer networks, and the benefits they can provide, is the "bottom line" difference between electronic and other kinds of business. Adopting e-business processes can change the way companies conduct these processes and their businesses. Brynjolfsson and Hitt 2000 argue that the effect of organizational changes generated by IT may rival the effects of changes in the production process. The surge of interest in supply chains exemplifies this potential for organizational change. Many core supply chain processes are widely cited as examples of successful e-business processes that, in turn, are expected to shift the location of the process among actors in the supply chain.

Many countries share U.S. interest in assessing the pervasiveness of ICT use among businesses and its effect on their economic performance. Some cross-country comparisons, e.g. Schreyer 2000, find a clear role for ICT in the U.S. and other G7 countries. Official statistical surveys of the business use of ICT (including the use of a few e-business processes) have been initiated in many countries (e.g., Canada, Australia, Denmark, Finland, Norway, and France, among others). International collaborations include the Nordic countries, which established a working group on ICT statistics, and the OECD's Working Party on Statistics for the Information Society, which is developing a model survey on ICT use by businesses (Boegh-Nielsen 2001). Assessments of the effects of the ICT measured in these surveys are, of course, just beginning.

<u>Data Gaps.</u> While some official U.S. data on computers and other IT components have been available, the amount of detail has been limited. For example, the U.S. Census Bureau's Annual Capital Expenditure Survey (ACES) for 1998 was the first time detailed information on investment spending for IT was collected from a national sample of U.S. businesses. A limited number of tabulations from this data have been published. Although the published tabulations do not present detail by industry and types of IT capital, additional information is available in the form of special tabulations. Detailed IT spending data will be collected again in the 2003 ACES.

Official data on the use of e-business processes also have been very limited. Table 2 below shows information from the Census Bureau's Survey of Manufacturing Technology conducted for 1988 and 1993. Information was collected only for the five major industry groups in manufacturing that were thought to be primary users of such technology. This data gap limited studies of e-business processes to the five manufacturing industries in the SMT (e.g., McGuckin *et al*, 1996), to relatively small samples drawn from proprietary data sets (e.g., 600 firms in Brynjolfsson and Hitt 2000), or to case studies (e.g., Dedrick and Kramer 1999). Local area networks (LANs) and inter-company computer (ICNs) networks were used by in all five industries, not just in SICs 35 and 36. Usage rates differed among these industries. In both years, Electronic and other Electric Equipment and Instruments and Related Products had the highest LAN rates, while Transportation Equipment had the highest ICN rates.

Table 2: Selected Statistics on Communication Technology Use from the Surveys of Manufacturing Technology for 1988 and 1993

Year and Major SIC Group	Local Area Network for:		Inter-company computer network
	Technical data	Factory use	
	Percentage of establishments using in operations		
1988			
Fabricated metal products (34)	13.4	11.6	14.9
Industrial machinery and equipment (35)	18.5	16.3	12.4
Electronic and other electric equip. (36)	24.9	21.1	16.2
Transportation equipment (37)	22.0	18.7	21.7
Instruments and related products (38)	25.8	21.3	13.8
1993			
Fabricated metal products (34)	20.1	14.5	16.7
Industrial machinery and equipment (35)	29.4	21.0	15.4
Electronic and other electric equip. (36)	37.1	30.5	21.9
Transportation equipment (37)	28.0	23.9	23.4
Instruments and related products (38)	40.7	30.0	15.3

3. New Data on E-Business Processes in U.S. Manufacturing

The analytical framework that the U.S. Census Bureau developed for measuring e-business (Atrostic, Gates, and Jarmin 2000) identified the absence of data on e-business processes as a key data gap. That framework also noted that collecting information on business processes presents challenges because it is a relatively new activity for statistical organizations. The U.S. Census Bureau's e-business measurement program (Mesenbourg 2001) addressed this gap through a supplement to the 1999 Annual Survey of Manufactures (ASM). The Computer Network Use Supplement (CNUS) surveyed some 50,000 manufacturing plants on their use of on-line purchasing and ordering in 1999, the types of information (design specifications, product descriptions, demand projections, orders, inventory, production schedules, and so on) manufacturers are sharing online with suppliers and customers, as well as their use of about 25 specific e-business processes in mid-2000. In June 2001, the U.S. Census Bureau released the first official statistics on the use of e-business processes (*E-stats*, at www.census.gov/estats). The statistics are based on responses of more than 38,000 U.S. manufacturing plants, with a response rate of 82 percent. All CNUS data are on a North American Industrial Classification System (NAICS) basis.

Most manufacturing plants responding to the CNUS were "wired" in mid-2000, with nearly 90 percent of respondents reporting a computer network in place. "Computer network" includes both open networks such as the Internet, and proprietary networks running systems such as Electronic Data Interchange (EDI). Responding plants that reported on-line purchasing (e-purchases) or accepting orders on-line (e-shipments) were asked what was their primary network for making each type of transaction. One-third of responding plants used the Internet as their primary network for accepting online orders. These plants accounted for only 5 percent of e-shipments at responding plants, while plants primarily using EDI networks accounted for two-thirds of e-shipments, as shown in Table 3.

The *E-stats* report also presents statistics on several e-businesses processes that appear closely related to the commercial activities of accepting and placing orders online. Only half of manufacturing plants reporting a network present also reported that they accepted and/or placed orders online. These new statistics show that research focusing on commercial transactions occurring online would omit uses of computer networks at roughly half of the plants reporting they use such networks.

Table 3: Most Frequently Used Network to Accept Orders by Responding Manufacturing Plants in 2000

Counts/E-commerce shipments	Total	Internet	EDI Network	Other Networks	Unknown
	All responding plants				
Number of plants	38,985	4,185	6,621	1,637	26,542
E-commerce shipments ($billion)	393.8	21.1	260.0	104.6	8.1
	Responding plants that accept orders online				
Number of plants	12,069	3,906	6,435	1,277	451
E-commerce shipments ($billion)	385.8	19.3	257.0	102.9	6.6
	Percentages for plants that accept orders online				
Number of plants	100.0	32.4	53.3	10.6	3.7
E-commerce shipments	100.0	5.0	66.6	26.7	1.7

Notes:

These data are calculated from responses to the survey. No weighting is used to create population estimates. No imputation or adjustment for nonresponse has been made. See the e-stats report for additional discussion.

All respondents were instructed to choose only one network as the most frequently used network. All e-commerce shipments of the respondent were assigned to that network. Details may not add to totals due to rounding. "Other networks" includes Intranet, Extranet, and "Other" responses. "Unknown" includes inconsistent reporting, and item nonresponse.

Source: Tables 4A and 4B, "Manufacturing 1999 and mid-2000," E-Stats: June 8, 2001, U.S. Department of Commerce, Bureau of the Census. www.census.gov/estats

4. First Insights on E-Business Processes and Productivity

The research literature generally defines industries and subsectors as "high tech" or computer-using on the basis of the composition of their capital investment and stocks. Business' uses of e-business processes provide additional dimensions for defining these terms. While CNUS clearly has the potential to provide new and exciting information, the *E-stats* report is limited to statistics about the use of only a few e-business processes. Also, the reported statistics are for survey respondents only, with no adjustment made for non-respondents to the CNUS. Because the ASM uses a probability-proportionate-to-size sample design, which results in a sample primarily comprised of larger manufacturing plants, the respondents are likely to be more representative of the larger plants in manufacturing than of the entire manufacturing population. In this section, we model the manufacturing population and give model-based estimates of two e-business processes.

We begin this first analysis of the use of e-business processes in U.S. manufacturing industries and their relationship to productivity growth by exploring two simple questions on the CNUS: 1) Do plants have a computer-mediated network in place? 2) Do plants use fully integrated Enterprise Resource Planning (FIERP) software?[4] We chose the first question because it indicates that a plant has crossed the technology threshold. Having a computer network implies there is more than one computer at the plant, or the plant communicates with other locations. Plants with networks are poised to participate (if not already participating) in e-business processes. We wanted to find how common networks were in various manufacturing subsectors, particularly outside the five for which data were collected in the earlier SMTs. In addition, we wanted to see whether this basic threshold effect seemed related to the differential industry productivity gains found in other studies. We chose the second question because it indicates a much deeper commitment to development of IT use. It goes beyond indicating potential to indicate an intensity of development that might be significant if the network presence threshold was too commonly crossed to be distinctive or explanatory.

Modeling methodology. To turn data from CNUS supplement respondents into estimates for the entire manufacturing sector, we applied a simple model of the relationship between CNUS respondents and the manufacturing population as estimated in the Census Bureau's County Business Patterns program. We used this approach to calculate the estimates shown in the first six columns of Table 4. The first two columns present the proportion of plants in each NAICS manufacturing subsector that have a network in use, and the proportion of that subsector's employment at such plants. The third column shows the proportion of plants in each subsector that use FIERP software. The next three columns show the distribution across manufacturing subsectors of plants with networks, employment at plants with networks, and plants with FIERP software. The final two columns provide,

[4] The more technically knowledgeable IT professionals we spoke with during survey preparation noted that asking about "fully integrated ERP" was quite different from asking about "ERP." FIERP is present when ERP software that is applied to separate business processes such as payroll and procurements is integrated into a single system.

for reference, the distribution across manufacturing subsectors of all plants, and all employment, in 1999. The manufacturing subsector estimates in Table 4 depend on assumptions about non-respondents. The assumption in these estimates is conservative -- that nonrespondents were considerably less likely than respondents to have networks.

Computer network. Most respondents to the CNUS – over 90 percent – had a computer network, and many had more than one. That proportion drops substantially in our estimates for the entire manufacturing sector, but remains pervasive, with just over half – 52 percent – of manufacturing plants having one or more networks in use, and networks are common in all subsectors (see the first column of Table 4). Networks are slightly more common in NAICS Nondurables subsectors (54 percent of plants) than in NAICS Durables subsectors (51 percent) but the percent of employment at plants with networks is almost identical – 76 percent in NAICS Nondurables and 75 percent in NAICS Durables. The lowest percentages of plants with networks are in Apparel (27 percent) and Furniture (35 percent). The highest are in Chemicals and Electrical equipment (both 71 percent). Each of these extreme estimates appears in both Nondurables and Durables. Aside from these four extreme values, there is surprising homogeneity across the remaining 17 subsectors, within and between Durable and Nondurables.

The pervasiveness of plants with networks across NAICS manufacturing subsectors suggests that computer networks alone are unlikely to be sources of the differences in productivity growth in Table 1. (However, such comparisons 3 are not precise because data in Table 1 are based on the SIC while data in Table 4 are based on NAICS.) "High tech" may require more than the presence of computer networks, let alone the mere presence of computers. It seems quite doubtful that the threshold represented by the absence or presence of a computer network at a manufacturing plant will be a significant factor in explaining differences in industry-level productivity growth.

Fully Integrated Enterprise Software (FIERP). The increased intensity of IT usage signaled by the use of fully integrated ERP software would appear to hold more promise as definition of "high tech" and a source of differential productivity growth. This intensity is not as common as network presence – only 8 percent of plants have FIERP software compared to 52 percent with networks. The use of FIERP software is more common in Durables subsectors (9 percent of plants) than in Nondurables (7 percent), and differences in FIERP software usage among subsectors seem more substantial than the differences in network presence. For example, the two manufacturing subsectors with the largest percentages of FIERP usage are both in the Durables area – Electrical equipment (18 percent) and Transportation equipment (17 percent). However, the Chemicals subsector, in Nondurables, has the third-highest use of FIERP (16 percent).

While FIERP usage may be one definition of "high tech," it too is distributed differently from industry productivity growth rates. The Transportation equipment subsector is especially intriguing. Transportation equipment was found to account for the largest shares of e-commerce shipments and online purchases in the *E-stats* report, and we find it to be the second-highest user of fully integrated ERP software. This finding is consistent with estimates from the 1988 and 1993 Surveys of Manufacturing Technology, in which Transportation Equipment had the highest use of inter-company computer networks, followed (and followed more closely in 1993 than in 1988) by Electronic and other Electric equipment. Yet illustrative estimates from the literature, as in Table 1, do not find Transportation equipment to be an industry with high productivity growth. Some of the difference may be due to differences in the definition of Transportation equipment in the SIC and in NAICS. If differences in how IT is used are a major source of differences in productivity growth, opportunities remain for further investigation about how use should be measured.

Table 4: Selected statistics on the use of electronic business processes for NAICS manufacturing subsectors: 1999-2000 [5]

NAICS3 subsector code - description	Percentage of plants that have one or more networks in use[6]	Percentage of subsector employment at plants with network in use[6]	Percentage of plants that have fully integrated ERP software in use[6]	Percent distribution of:				
				Plants with networks	Employment at plants with networks	Plants with fully integrated ERP software in use	All manufacturing plants	Employment at all manufacturing plants
All Manufacturing	**52.0**	**75.5**	**8.2**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Durable goods industries	**50.9**	**75.2**	**9.0**	**60.2**	**60.3**	**67.6**	**61.5**	**60.5**
321 – Wood products	43.5	69.9	2.9	4.1	3.4	1.7	4.9	3.7
327 – Nonmetallic mineral products	42.3	70.7	4.8	3.7	3.0	2.7	4.6	3.2
331 – Primary metals	57.2	82.8	13.0	1.8	3.9	2.6	1.6	3.5
332 – Fabricated metal products	51.0	74.7	8.8	16.9	11.2	18.6	17.3	11.3
333 – Machinery	68.0	80.9	13.9	10.9	9.3	14.3	8.4	8.7
334 – Computer and electronic products	59.4	70.6	14.7	5.5	8.3	8.7	4.8	8.9
335 – Electrical equipment, and relat ed	71.2	80.3	17.8	2.7	3.8	4.3	2.0	3.6
336 – Transportation equipment	57.2	78.1	17.0	4.0	9.3	7.5	3.6	9.0
337 – Furniture and related products	35.3	68.5	3.3	3.8	3.5	2.3	5.6	3.9
339 – Miscellaneous	40.3	72.5	4.7	6.8	4.5	5.0	8.7	4.7
Nondurable goods industries	**53.7**	**76.0**	**6.8**	**39.8**	**39.7**	**32.4**	**38.5**	**39.5**
311 – Food products	49.1	74.6	7.5	7.0	9.2	6.9	7.4	9.3
312 – Beverage and tobacco	50.4	73.8	6.3	0.7	1.0	0.6	0.8	1.0
313 – Textile mills	56.6	79.7	6.3	1.4	2.4	1.0	1.3	2.3
314 – Textile product mills	47.8	70.2	3.2	1.8	1.3	0.8	2.0	1.4
315 – Apparel	27.1	57.7	3.2	2.4	2.8	1.8	4.6	3.6
316 – Leather and allied products	45.7	69.8	4.6	0.4	0.5	0.3	0.5	0.5
322 – Paper	68.7	84.5	11.6	2.2	4.0	2.3	1.6	3.6
323 – Printing and related activities	56.2	75.8	2.4	12.2	5.3	3.3	11.3	5.3
324 – Petroleum and coal products	50.5	80.0	10.3	0.6	0.7	0.8	0.6	0.7
325 – Chemicals	71.1	80.3	15.7	5.1	5.5	7.2	3.8	5.2
326 – Plastics and rubber products	66.1	80.8	13.0	5.9	7.0	7.4	4.6	6.6

[5] Based on imputed usage rate for survey nonrespondents that is 1/10th the rate of respondents in the same NAICS3 and employment-size class. That is, if 40% of respondents reported a network in use, 4% of nonrespondents were assumed to have a network in use. Also based on the ratio of sample plants and their employment to all plants and employment in the same NAICS3 by employment-size class as described in the Census Bureau's County Business Patterns statistics. If nonrespondents were imputed at same usage rate, the percentage of plants with a network would be 64.7, the percentage of employment at plants with networks would be 91.0, and the percentage of plants with fully integrated ERP software in use would be 9.8 for all manufacturing.

[6] There are no estimates of the measurement error associated with these values. The estimates are not official Census Bureau statistics, and are intended only as preliminary indicators that can serve to focus discussion and research that may lead to the development of future official estimates.

5. Conclusions and Next Steps

Newly available data on the use of e-business processes from the U.S. Census Bureau's e-business measurement program were used to model two new and preliminary indicators of the use of e-business processes in manufacturing: the use of computer networks, and of fully-integrated enterprise resource planning software. The indicators add to the information available about IT use in manufacturing. Our estimates suggest that the thresholds represented by the presence of computers and the use of a computer network are unlikely to be significant factors in explaining differences in productivity growth in manufacturing subsectors. Our estimates also indicate that the NAICS Transportation equipment subsector is one of the most intense users of fully integrated enterprise software, second only to the NAICS Electrical Equipment subsector. Yet existing studies have not found high productivity growth in the SIC Transportation equipment industry group.

These estimates also provide a starting point for additional research on computer use and economic performance, and for developing new measures of capital or enriching existing ones. The CNUS contains considerable additional information about manufacturing plant's electronic business processes and the uses of them beyond what is presented here. For example, there is information on the kind of network (EDI, Internet, both), on about 25 business processes, and whether those networked processes are used to interact internally, or with the plant's customers or suppliers

The estimates presented here may mask effects of using computer networks software that might be captured in more refined plant-level analyses. While the estimates are based on plant-level responses, they are presented at the subsector level, and do not include estimates of the joint effect of other electronic business processes, or other inputs to the production process. Future analyses will parallel and expand on the existing micro data literature, including formal modeling of industry-level production functions based on exact and statistical linkages with data on other inputs (such as capital investments) and outputs, and that follow plants over time.

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