Table 5. Substitutability and complementarity. Allen-Uzawa's elasticity of substitution for baseline case (four types of labor inputs)

Manufacturing							
Food				**Textile**			
	1980–89	**1990–98**			**1980–92**	**1993–98**	
IT & YL	10.445	4.5166		IT & YL	8.7841	3.9614	
IT & YH	−20.843	−5.4259		IT & YH	−22.269	−3.7831	
YL & YH	1.4537	1.4478		YL & YH	1.5802	1.451	
Paper & pulp				**Chemicals**			
	1980–88	**1989–92**	**1993–98**		**1980–89**	**1990–98**	
IT & YL	1.6988	1.3986	1.3209	IT & YL	3.3424	2.2828	
Stone & clay				**Pri. metal**			
	1980–91	**1992–98**			**1980–87**	**1988–94**	**1995–98**
IT & YL	3.5543	1.9676		IT & YL	3.2555	1.6979	1.9228
Fab. metal				**Gen. machinery**			
	1980–87	**1988–93**	**1994–98**		**1980–89**	**1990–98**	
IT & YL	5.8058	4.1781	4.7314	IT & YL	3.5528	6.7831	
IT & YH	−10.695	−6.9642	−6.3244	IT & YH		−8.6414	
YL & YH	1. 3718	1.3874	1.3412	YL & YH		2.3471	
Elec. machinery				**Trans. equipment**			
	1980–92	**1993–98**			**1980–88**	**1989–92**	**1993–98**
IT & YL	5.0917	3.7034		IT & YL	2.6372	1.5929	1.4647
IT & YH	−3.1283	−0.73924					
YL & YH	2.1956	2.1819					
Instruments							
	1980–93	**1994–98**					
IT & YL	5.8419	4.1783					
IT & OH	−11.169	−2.3892					
YL & OH	4.0883	3.3868					
Nonmanufacturing							
Construc.				**Trade**			
	1980–89	**1990–98**			**1980–98**		
IT & YL	3.7776	1.9186		IT & YL	3.4879		
Finance				**Trans. & commu.**			
	1980–95				**1980–85**	**1986–89**	**1990–98**
IT & YL	2.9116			IT & YL	5.0983	3.269	2.301
Services							
	1980–89	**1990–98**					
IT & YL	3.5142	2.188					
IT & OH	−1.8956	0.05846					
YL & OH	1.7061	1.1704					

Note: *IT = IT capital. YL = young worker with low education level. YH = young worker with high education level. OH = old worker with high education level. See Table 1 for industry abbreviations.*

creased. This is one cause of the poor performance of Japanese firms in the 1990s, when demand was very weak.

5. ICT stocks, human capital, and technological progress: 1980–98

In this section, we first examine sectoral value-added growth and the contribution of each input to economic growth between 1981 and 1998. Then we derive the rate of technological progress in the framework developed in section 3. We confirm a sharp decline in the rate of technological progress from the 1980s to the 1990s. We investigate possible causes of the decline of technological progress by examining factors that determine the rate of technological growth and analyzing the ways in which

Table 6. Substitutability and complementarity. Allen-Uzawa elasticity of substitution for the extended case (six types of labor inputs)

Paper & pulp			
	1980–88	**1989–92**	**1993–98**
IT & PL	1.3256	1.3347	1.3407
Stone & clay			
	1980–84	**1985–91**	**1992–98**
IT & PL	2.5316	1.7619	1.5
Elec. machinery			
	1980–85	**1986–88**	**1989–98**
IT & PL	2.1819	1.6653	1.5938
IT & NPYH	−3.4026	−1.2292	−0.1413
PL & NPYH	3.1913	3.4077	3.3558
Trans. equipment			
	1980–87	**1988–89**	**1990–98**
IT & PL	4.4181	2.5665	2.2881
IT & NPOH	−12.561	−11.242	−6.4093
PL & NPOH	3.526	3.043	2.6718

Note: *IT = IT capital. PL = production worker with low education level. NPYH = nonproduction, young worker with high education level. NPOH = nonproduction, old worker with high education level. See Table 1 for industry abbreviations.*

Table 7. Cost share of variable inputs (percentage points)

	Food	**Textile**	**Paper & pulp**	**Chemicals**	**Stone & clay**	
1981–89	0.383	0.360	0.215	0.207	0.247	
1990–98	0.329	0.265	0.180	0.162	0.193	
	Pri. metal	**Fab. metal**	**Gen. machinery**	**Elec. machinery**	**Trans. equipment**	**Instruments**
1981–89	0.190	0.397	0.284	0.515	0.307	0.432
1990–98	0.143	0.334	0.322	0.430	0.229	0.348
	Construc.	**Trade**	**Finance**	**Trans. & commu.**	**Services**	
1981–89	0.284	0.331	0.499	0.274	0.344	
1990–98	0.210	0.228	n.a.	0.228	0.330	

Note: *Averages in this table are arithmetic averages. Finance data in the 1990s are excluded because of data problems. See section 3. See Table 1 for industry abbreviations. n.a. = not available.*

they have changed over the study period. We consider 11 manufacturing industries and 4 nonmanufacturing industries (excluding the finance and insurance sector).[32]

As explained in section 3, we approximate the production function parameter k by the long-run ratio of the variable cost to the total cost. In doing so, the value of k in the 1980s may be different from that in the 1990s. This is obvious for the general machinery industry, in which the number of variable inputs has changed over time. We approximate k_{1980} by the 1980s average variable cost/total cost ratio, and k_{1990} by the 1990s variable cost/total cost ratio. We then further divide the two decades into four subperiods (1981–84, 1985–89, 1990–94, and 1995–98).

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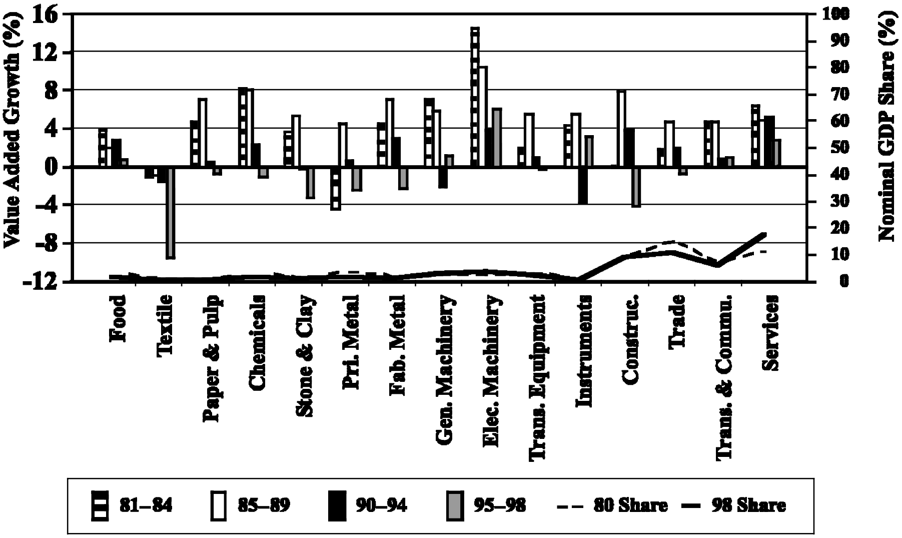
[32] We exclude the finance and insurance industry because data for this industry after 1995 are problematic.

Figure 1. Value-added growth and GDP share



5.1 Value-added growth and contribution of inputs to growth

The results on sectoral value-added growth (see table 8 and figure 1) reveal a remarkable contrast between the 1980s and the 1990s. Most industries show a very high rate of value-added growth in the 1980s. After the crash of the stock and real estate markets around 1990, the growth rate declines substantially and, in some industries, falls into the negative region, particularly during 1995–98. Of 11 manufacturing industries, 6 have negative rates of value-added growth during 1995–98: textile (−9.50 percent), paper and pulp (−0.64 percent), chemicals (−0.99 percent), stone and clay (−3.26 percent), primary metal (−2.43 percent), and fabricated metal (−2.30 percent). Among the four machinery industries, transportation equipment also has a negative growth rate (−0.28 percent) in that period. Three other machinery industries, however, experience a higher rate of value-added growth in the latter half of the 1990s than in the first half: general machinery (1.11 percent), electrical machinery (5.99 percent), and instruments (3.13 percent). In four nonmanufacturing industries under investigation, construction and trade have a negative rate of value-added growth during 1995–98 (−4.04 percent and −0.64 percent, respectively). The two lines in figure 1 below the bar charts show the nominal GDP share of each industry.[33] The thick solid line is the nominal GDP share in 1998, and the dotted line is

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[33] It should be noted here that we include software output in GDP, whereas the published GDP figure, which is based on the 1968 SNA convention, does not. In the published figure, software is considered to be an intermediate input rather than a final-goods output.

Table 8. Sources of value-added growth: 1981–98 (percentage points)

	Food	Textile	Paper & pulp	Chemicals	Stone & clay	Pri. metal	Fab. metal	Gen. machinery
Total sample period: 1981–98								
Value-added	2.288	−3.112	2.993	4.447	1.488	−0.149	3.285	2.803
Variable inputs	0.163	−1.733	−0.070	−0.070	−0.676	−0.209	−0.549	−0.283
Quasi-fixed inputs	1.933	−0.171	2.033	1.847	0.299	1.056	0.848	2.101
Technological progress	0.088	−1.317	1.033	2.614	1.768	−0.967	3.002	1.132
1980s: 1981–89								
Value-added	2.782	−0.956	6.066	8.172	4.613	0.448	5.978	6.437
Variable inputs	0.114	−1.152	0.022	−0.435	−1.017	−0.216	−0.607	−0.233
Quasi-fixed inputs	2.770	1.519	2.535	2.059	1.057	1.699	1.529	3.603
Technological progress	−0.243	−1.387	3.515	6.498	4.391	−1.033	4.975	3.107
1990s: 1990–98								
Value-added	1.796	−5.221	0.008	0.851	−1.544	−0.742	0.660	−0.706
Variable inputs	0.211	−2.312	−0.161	0.296	−0.334	−0.201	−0.491	−0.333
Quasi-fixed inputs	1.103	−1.833	1.534	1.636	−0.452	0.417	0.172	0.620
Technological progress	0.419	−1.248	−1.390	−1.128	−0.788	−0.902	1.066	−0.805
Subperiod: 1981–84								
Value-added	3.810	−0.991	4.728	8.246	3.644	−4.403	4.606	7.133
Variable inputs	−0.018	−0.831	−0.312	−0.455	−1.290	−0.034	−1.724	−0.559
Quasi-fixed inputs	2.679	1.526	2.354	1.972	0.597	2.383	0.477	4.029
Technological progress	1.052	−1.672	2.695	6.711	3.949	−6.620	5.760	3.589
Subperiod: 1985–89								
Value-added	1.967	−0.928	7.149	8.113	5.395	4.506	7.087	5.884
Variable inputs	0.220	−1.407	0.289	−0.418	−0.798	−0.362	0.295	0.028
Quasi-fixed inputs	2.843	1.513	2.680	2.128	1.427	1.154	2.379	3.264
Technological progress	−1.266	−1.158	4.175	6.328	4.745	3.676	4.351	2.723
Subperiod: 1990–94								
Value-added	2.838	−1.651	0.527	2.343	−0.148	0.625	3.090	−2.133
Variable inputs	0.170	−3.174	−0.205	0.300	−0.479	−0.481	−0.382	−0.677
Quasi-fixed inputs	2.770	−2.643	2.763	3.087	0.774	1.206	0.472	0.732
Technological progress	−0.134	3.978	−2.054	−1.077	−0.472	−0.114	3.068	−1.954
Subperiod: 1995–98								
Value-added	0.508	−9.502	−0.636	−0.985	−3.261	−2.426	−2.298	1.106
Variable inputs	0.263	−1.223	−0.105	0.291	−0.151	0.149	−0.627	0.100
Quasi-fixed inputs	−0.943	−0.811	0.019	−0.149	−1.965	−0.559	−0.202	0.481
Technological progress	1.115	−7.412	−0.554	−1.192	−1.182	−1.877	−1.382	0.649

Note: *Averages in this table are geometric averages. The sum of input contributions and technological progress growth may not add up to value-added growth. Finance data in the 1990s are excluded because of data problems. See section 3. See Table 1 for industry abbreviations. n.a. = not available.*

that in 1980. The shares of GDP of the primary metal and trade sectors declined sharply from 1980 to 1998, whereas the GDP share of services rose sharply.

The following simple regression of value-added growth on the 1990s dummy confirms a sharp decline of value-added growth from the 1980s to the 1990s. We regress the average value-added growth in four subperiods on a constant and the 1990s dummy and obtain the following result (the t-values are shown in parentheses, and N is the number of observations):

$$\textit{Value-added growth} = \underset{(7.711)}{4.773} - \underset{(-5.116)}{4.479} \times \textit{90sDummy},$$

$R^2 = 0.311$, $N = 60$. The 1990s dummy is very significant. A similar simple regression (not reported here) with a manufacturing dummy, however, reveals that there is no

Table 8. (Continued)

	Elec. machinery	Trans. equipment	Instru-ments	Construc.	Trade	Finance	Trans. & commu.	Services
Total sample period: 1981–98								
Value-added	8.396	2.179	2.105	2.246	2.132	n.a.	2.794	4.768
Variable inputs	1.267	−0.369	−0.486	−0.387	−0.880	n.a.	−0.042	1.726
Quasi-fixed inputs	2.973	2.282	1.238	1.400	2.030	n.a.	2.368	3.372
Technological progress	4.242	0.277	1.443	1.241	0.972	n.a.	0.469	20.348
1980s: 1981–89								
Value-added	12.152	3.969	5.018	4.300	3.463	7.917	4.682	5.462
Variable inputs	2.741	−0.427	−0.666	−0.667	−0.926	1.012	−0.240	1.719
Quasi-fixed inputs	4.464	3.092	2.407	1.573	2.754	1.944	3.441	3.959
Technological progress	4.969	1.329	3.338	3.421	1.606	4.919	1.469	−0.241
1990s: 1990–98								
Value-added	4.765	0.420	−0.729	0.233	0.819	n.a.	0.940	4.078
Variable inputs	−0.186	−0.311	−0.306	−0.105	−0.835	n.a.	0.156	1.733
Quasi-fixed inputs	1.503	1.479	0.082	1.228	1.311	n.a.	1.306	2.788
Technological progress	3.520	−0.765	−0.418	−0.894	0.343	n.a.	−0.521	−0.454
Subperiod: 1981–84								
Value-added	14.435	2.024	4.340	0.041	1.907	5.409	4.632	6.300
Variable inputs	4.293	−0.704	−0.888	−1.121	−0.655	1.472	−0.547	1.699
Quasi-fixed inputs	5.329	3.206	2.482	0.518	3.496	2.497	3.866	4.316
Technological progress	4.822	−0.475	2.758	0.640	−0.936	1.418	1.292	0.284
Subperiod: 1985–89								
Value-added	10.359	5.551	5.565	7.837	4.725	9.966	4.722	4.796
Variable inputs	1.516	−0.205	−0.489	−0.303	−1.142	0.646	0.006	1.734
Quasi-fixed inputs	3.777	3.000	2.347	2.425	2.164	1.504	3.103	3.675
Technological progress	5.086	2.795	3.805	5.702	3.687	7.806	1.610	−0.660
Subperiod: 1990–94								
Value-added	3.798	0.988	−3.714	3.787	2.003	n.a.	0.878	5.119
Variable inputs	−0.374	−0.506	−1.023	−0.035	−0.730	n.a.	−0.047	1.703
Quasi-fixed inputs	1.910	2.064	0.395	2.146	0.846	n.a.	1.357	3.330
Technological progress	2.334	−0.592	−2.942	1.632	1.900	n.a.	−0.436	0.078
Subperiod: 1995–98								
Value-added	5.986	−0.284	3.134	−4.038	−0.643	n.a.	1.017	2.792
Variable inputs	0.051	−0.066	0.596	−0.193	−0.967	n.a.	0.412	1.770
Quasi-fixed inputs	0.996	0.753	−0.307	0.092	1.896	n.a.	1.243	2.114
Technological progress	5.022	−0.980	2.829	−3.963	−1.570	n.a.	−0.626	−1.116

statistically significant difference between manufacturing and nonmanufacturing with respect to the value-added growth pattern.

Tables 9 and 10 show each input's contribution to value-added growth. To save space, we group "structure" and "buildings" in the category of "structure capital stocks," and we combine "machines and tools" and "transportation machines" to make the category of "equipment capital stocks." For labor inputs, we report the four labor input cases (young with low levels of education, young with high levels of education, old with low levels of education, and old with high levels of education). Recall that the production and nonproduction classifications are not used for the nonmanufacturing industries.

Table 9 shows that the contribution of ICT stock to value-added growth is always positive throughout the period except in the fabricated metal industry in the latter

Table 9. Capital's contribution to value-added growth (percentage points): 1981–98

	Food	Textile	Paper & pulp	Chemicals	Stone & clay	Pri. metal	Fab. metal	Gen. machinery
Total sample period: 1981–98								
IT capital	0.186	0.148	0.148	0.119	0.479	0.075	0.207	0.122
Equipment	0.832	0.936	1.049	0.811	0.665	0.472	0.679	1.234
Structure	0.138	−0.032	0.471	0.203	0.076	0.354	0.092	0.102
1980s: 1981–89								
IT capital	0.146	0.106	0.127	0.355	0.054	0.188	0.145	0.141
Equipment	1.153	0.887	0.940	0.774	0.949	0.291	0.719	1.636
Structure	0.162	−0.041	0.451	0.112	0.105	0.261	0.083	0.122
1990s: 1990–98								
IT capital	0.226	0.190	0.110	0.604	0.095	0.225	0.098	0.109
Equipment	0.513	0.985	1.158	0.848	0.383	0.653	0.640	0.834
Structure	0.114	−0.022	0.491	0.294	0.047	0.834	0.081	0.448
Subperiod: 1981–84								
IT capital	0.102	0.074	0.098	0.249	0.027	0.070	0.089	0.097
Equipment	1.075	0.507	0.591	0.685	1.026	0.005	0.443	1.723
Structure	0.130	−0.209	0.164	−0.147	0.054	−0.051	0.020	0.087
Subperiod: 1985–89								
IT capital	0.182	0.132	0.150	0.440	0.076	0.284	0.190	0.175
Equipment	1.215	1.192	1.221	0.845	0.887	0.521	0.939	1.567
Structure	0.188	0.093	0.682	0.320	0.145	0.511	0.134	0.151
Subperiod: 1990–94								
IT capital	0.255	0.173	0.138	0.537	0.064	0.229	0.181	0.132
Equipment	0.781	1.075	1.446	0.803	0.347	0.662	0.798	0.988
Structure	0.119	0.060	0.714	0.507	0.121	0.852	0.104	0.117
Subperiod: 1995–98								
IT capital	0.190	0.211	0.076	0.688	0.133	0.221	−0.006	0.079
Equipment	0.179	0.873	0.800	0.904	0.427	0.642	0.442	0.642
Structure	0.107	−0.126	0.214	0.028	−0.045	−0.055	0.095	0.036

Note: *Averages in this table are geometric averages. Finance data in the 1990s are excluded because of data problems. See Section 3. See Table 1 for industry abbreviation. n.a. = not available.*

half of the 1990s, and the same is true for (non-ICT) equipment. In contrast, structure's contribution to value-added growth is small and becomes negative in the latter half of the 1990s in four industries (textile, stone and clay, primary metal, and instruments). This clearly shows that industrial growth gravitates from physical expansion to internal upgrading of equipment (both ICT-related and non-ICT-related equipment).

Table 10 reveals a remarkable contrast between workers with low education levels and those with high education levels in the 1990s. In the 1990s, the contribution of young workers with low education levels is negative in all industries under consideration, regardless of the level of value-added growth. In contrast, the contribution of young workers with high education levels to value-added growth is positive in all industries except for the textile and instruments sector in the 1990s. Many Japanese industries are currently experiencing the effect of population aging and are upgrading their workforce with respect to education levels. For old workers, this upgrading is far more sweeping. In the 1990s, all industries except for services have a

Table 9. (Continued)

	Trans. equipment	Instruments	Construc.	Trade	Finance	Trans. & commu.	Services
Total sample period: 1981–98							
IT capital	0.218	0.510	0.032	0.075	n.a.	0.381	0.814
Equipment	1.422	1.333	0.194	0.286	n.a.	0.967	1.371
Structure	0.300	0.045	0.093	0.268	n.a.	0.400	0.566
1980s: 1981–89							
IT capital	0.229	0.466	0.020	0.058	0.583	0.253	0.753
Equipment	1.841	1.802	0.302	0.450	0.278	1.589	1.560
Structure	0.347	0.121	0.093	0.250	0.105	0.370	0.616
1990s: 1990–98							
IT capital	0.207	0.555	0.045	0.092	n.a.	0.510	0.876
Equipment	1.005	0.866	0.086	0.122	n.a.	0.348	1.182
Structure	0.252	−0.032	0.092	0.285	n.a.	0.430	0.516
Subperiod: 1981–84							
IT capital	0.151	0.370	0.007	0.027	0.349	0.043	0.625
Equipment	1.777	1.665	0.446	0.584	0.209	2.197	1.435
Structure	0.234	0.321	0.132	0.292	0.144	0.491	0.720
Subperiod: 1985–89							
IT capital	0.293	0.543	0.030	0.083	0.771	0.421	0.856
Equipment	1.893	1.912	0.188	0.344	0.333	1.105	1.661
Structure	0.437	−0.038	0.063	0.217	0.074	0.273	0.533
Subperiod: 1990–94							
IT capital	0.243	0.385	0.050	0.080	n.a.	0.546	0.825
Equipment	1.138	1.148	0.089	0.126	n.a.	0.273	1.526
Structure	0.455	−0.022	0.119	0.355	n.a.	0.500	0.592
Subperiod: 1995–98							
IT capital	0.162	0.767	0.038	0.107	n.a.	0.467	0.939
Equipment	0.841	0.516	0.083	0.119	n.a.	0.443	0.755
Structure	0.000	−0.044	0.057	0.198	n.a.	0.342	0.420

negative contribution of old workers with low education, whereas the contribution of old workers with high education levels is positive in all industries in the same period. Thus, although old workers with low education levels are quasi-fixed (as shown in section 4), their inputs are adjusted in the long run by natural attrition or by employment adjustment. They are quasi-fixed but variable in the long run.

5.2 Technological progress, ICT externality, and ICT-induced skill obsolescence

As noted in section 5.1, the rate of value-added growth declined substantially in the 1990s. This decline was not simply a result of a slump in demand and the consequent decrease in factor inputs. The rate of technological progress also declined substantially in many industries. The prolonged slump of the 1990s was not merely a demand-driven phenomenon: the supply side played a substantial role.

In table 8, the rate of technological growth, which is the residual of the value-added growth that is not attributable to the inputs' contribution, is shown for the total sample period, for the 1980s and 1990s, and for four subperiods (1981–84, 1985–89, 1990–94, 1995–98). Figure 2 shows the changes from subperiod to subperiod, as well

Table 10. Labor's contribution to value-added growth (percentage points): 1981–98

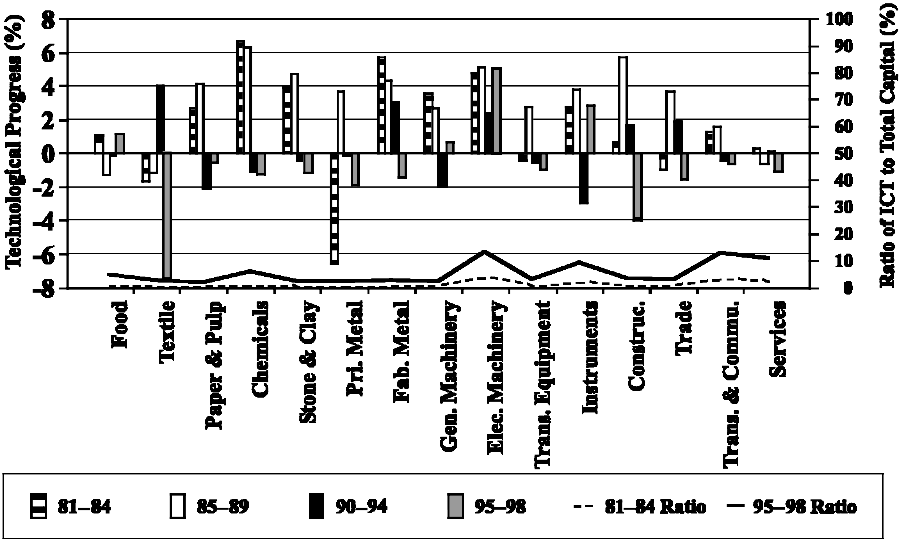
	Food	Textile	Paper & pulp	Chemicals	Stone & clay	Pri. metal	Fab. metal	Gen. machinery
Total sample period: 1981–98								
Low education, young (under 40)	−0.371	−1.777	−0.188	−0.549	−0.750	−0.416	−0.793	−0.517
Low education, old (40 and over)	0.488	−1.157	0.126	0.160	−0.732	−0.047	−0.209	0.133
High education, young (under 40)	0.350	−0.094	0.162	0.237	0.073	0.090	0.125	0.277
High education, old (40 and over)	0.481	0.108	0.228	0.444	0.224	0.189	0.290	0.485
1980s: 1981–89								
Low education, young (under 40)	−0.287	−1.223	−0.106	−0.790	−1.071	−0.405	−0.906	−0.374
Low education, old (40 and over)	1.091	0.502	0.724	0.350	−0.339	0.805	0.404	0.980
High education, young (under 40)	0.259	−0.033	0.189	0.202	0.077	0.076	0.157	0.331
High education, old (40 and over)	0.364	0.168	0.234	0.627	0.268	0.268	0.331	0.544
1990s: 1990–98								
Low education, young (under 40)	−0.456	−2.329	−0.271	−0.307	−0.428	−0.427	−0.680	−0.661
Low education, old (40 and over)	−0.111	−2.789	−0.468	−0.031	−1.123	−0.891	−0.817	−0.706
High education, young (under 40)	0.441	−0.155	0.135	0.273	0.070	0.105	0.094	0.223
High education, old (40 and over)	0.599	0.048	0.222	0.261	0.180	0.110	0.248	0.426
Subperiod: 1981–84								
Low education, young (under 40)	−0.547	−1.081	−0.410	−0.704	−1.317	−0.103	−1.783	−0.656
Low education, old (40 and over)	1.193	1.157	1.212	0.501	−0.849	1.871	−0.144	1.417
High education, young (under 40)	0.427	0.178	0.174	0.225	0.043	0.192	−0.028	0.352
High education, old (40 and over)	0.278	0.068	0.215	0.714	0.335	0.368	0.164	0.459
Subperiod: 1985–89								
Low education, young (under 40)	−0.078	−1.336	0.139	−0.858	−0.874	−0.646	−0.198	−0.147
Low education, old (40 and over)	1.009	−0.019	0.335	0.230	0.072	−0.040	0.844	0.631
High education, young (under 40)	0.125	−0.203	0.202	0.184	0.103	−0.017	0.305	0.314
High education, old (40 and over)	0.433	0.249	0.250	0.557	0.215	0.188	0.466	0.613
Subperiod: 1990–94								
Low education, young (under 40)	−0.496	−2.968	−0.343	−0.236	−0.543	−0.709	−0.661	−0.980
Low education, old (40 and over)	1.002	−3.419	0.059	0.392	−0.054	−0.639	−0.636	−0.768
High education, young (under 40)	0.412	−0.350	0.110	0.688	0.080	0.142	0.101	0.178
High education, old (40 and over)	0.867	−0.265	0.435	0.686	0.287	0.196	0.205	0.415
Subperiod: 1995–98								
Low education, young (under 40)	−0.405	−1.523	−0.182	−0.395	−0.284	−0.073	−0.704	−0.261
Low education, old (40 and over)	−1.485	−1.996	−1.122	−0.557	−2.444	−1.206	−1.044	−0.627
High education, young (under 40)	0.478	0.089	0.167	−0.244	0.057	0.059	0.085	0.280
High education, old (40 and over)	0.265	0.440	−0.043	−0.269	0.046	0.002	0.301	0.440

Note: *The averages in this table are geometric averages. Finance data in the 1990s are excluded because of data problems. See section 3. See Table 1 for industry abbreviations. n.a. = not available.*

Table 10. (Continued)

	Elec. machinery	Trans. equipment	Instruments	Construc.	Trade	Finance	Trans. & commu.	Services
Total sample period: 1981–98								
Low education, young (under 40)	−0.117	−0.587	−1.416	−0.419	−0.955	n.a.	−0.423	−0.008
Low education, old (40 and over)	0.578	0.032	−0.185	0.089	0.228	n.a.	0.546	0.393
High education, young (under 40)	0.496	0.193	0.055	0.308	0.525	n.a.	0.221	1.043
High education, old (40 and over)	0.540	0.342	0.422	0.719	0.720	n.a.	0.236	0.919
1980s: 1981–89								
Low education, young (under 40)	0.882	−0.656	−1.523	−0.687	−0.984	−0.888	−0.493	0.098
Low education, old (40 and over)	1.442	0.446	0.127	0.309	0.524	0.563	1.152	0.658
High education, young (under 40)	0.903	0.188	0.355	0.250	0.771	1.318	0.126	1.124
High education, old (40 and over)	0.656	0.274	0.392	0.615	0.752	0.999	0.202	0.866
1990s: 1990–98								
Low education, young (under 40)	−1.105	−0.518	−1.308	−0.150	−0.927	n.a.	−0.354	−0.114
Low education, old (40 and over)	−0.279	−0.381	−0.496	−0.131	−0.066	n.a.	−0.057	0.128
High education, young (under 40)	0.092	0.199	−0.244	0.366	0.279	n.a.	0.315	0.963
High education, old (40 and over)	0.424	0.411	0.452	0.822	0.688	n.a.	0.269	0.971
Subperiod: 1981–84								
Low education, young (under 40)	2.233	−0.854	−1.456	−1.128	−0.682	−0.457	−0.590	0.280
Low education, old (40 and over)	2.159	0.486	0.294	−0.487	0.851	1.190	0.762	0.695
High education, young (under 40)	1.369	0.312	0.203	0.184	1.024	1.580	0.253	1.465
High education, old (40 and over)	0.871	0.400	0.202	0.231	0.742	0.957	0.160	0.794
Subperiod: 1985–89								
Low education, young (under 40)	−0.186	−0.497	−1.578	−0.333	−1.225	−1.230	−0.415	−0.047
Low education, old (40 and over)	0.873	0.414	−0.007	0.951	0.263	0.064	1.465	0.629
High education, young (under 40)	0.531	0.089	0.476	0.304	0.569	1.109	0.025	0.852
High education, old (40 and over)	0.485	0.172	0.544	0.923	0.759	1.032	0.236	0.925
Subperiod: 1990–94								
Low education, young (under 40)	−1.466	−0.750	−1.667	−0.085	−0.810	n.a.	20.592	−0.101
Low education, old (40 and over)	−0.257	−0.185	−0.793	0.786	0.072	n.a.	−0.003	0.250
High education, young (under 40)	0.265	0.173	0.079	0.211	−0.033	n.a.	0.323	0.964
High education, old (40 and over)	0.532	0.495	0.266	0.941	0.322	n.a.	0.264	0.979
Subperiod: 1995–98								
Low education, young (under 40)	−0.652	−0.228	−0.856	−0.231	−1.073	n.a.	−0.055	−0.131
Low education, old (40 and over)	20.306	−0.625	−0.124	−1.267	−0.239	n.a.	−0.125	−0.025
High education, young (under 40)	−0.124	0.231	−0.647	0.559	0.670	n.a.	0.304	0.962
High education, old (40 and over)	0.288	0.305	0.684	0.674	1.147	n.a.	0.276	0.961

Figure 2. Technological progress and ICT ratio



as the ICT stocks' share in the total capital stock of each industry in the 1981–84 period and the 1995–98 period. Table 8 and figure 2 indicate there is a downward shift in technological progress from the 1980s to the 1990s. To see this, we regress the subperiod average rates of technological progress on a constant and the 1990s dummy:

$$Technological\,progress = \underset{(4.672)}{2.315} - \underset{(-3.733)}{2.616} \times 90sDummy, \qquad (9)$$

$R^2 = 0.194$, $N = 60$. The coefficient for the 1990s dummy is negative and statistically significant, suggesting a downward shift. When a dummy representing manufacturing industries is included, the coefficient of this dummy is statistically insignificant. Thus, the shift occurs in manufacturing and nonmanufacturing industries in the same way.

There are, however, a few exceptions to the general pattern of a declining rate of technological progress. The 1995–98 rate of technological progress in the electrical machinery and instruments sector is almost the same as in the 1980s. These two industries are among those industries having a high rate of ICT capital formation in both the 1980s and 1990s (table 9 and figure 2). This does not necessarily suggest a linkage between ICT capital formation and the rate of technological progress, however, because the services sector has a higher rate of ICT capital formation, and its rate of technological progress is negative even in the latter half of 1990s (figure 2). The relationship between technological progress and ICT capital stocks is more subtle, and we need to examine the issue using a more formal analysis. First, however, we review several possible factors that may influence the rate of technological progress.

First, there is a strong argument that ICT capital stocks have positive externality. Computers are interconnected via local area networks and/or the Internet. Their productivity increases more than proportionally as the number of computers increases. The value of software also increases more than proportionally as the number of users increases. Some observers argue that the U.S. productivity increase found in Jorgenson and Stiroh (2000), Oliner and Sichel (2000), and others[34] stems partly from this externality. This so-called New Economy argument is based on the notion of externality in ICT capital stocks.[35] If there is such externality in ICT capital stocks, then the growth residual (that is, the rate of technological progress) must be correlated with ICT capital stocks in some way.

Second, casual observation shows that there is a "digital divide" between the young and the old. Older workers may be skeptical about "new and improved" technological gadgets and perhaps slower to adopt new technology. If such inflexibility is present in the workplace, then technological progress resulting from ICT may be lower in industries that employ more old workers than young workers.

Third, let us temporarily ignore the effect of information technology development and consider the more conventional factors that influence productivity. Skills obtained by learning by doing and on-the-job training are often considered to be the most important determinant of productivity. The so-called Toyota Production System, which combines *kanban* (just-in-time) and TQC (total quality circle), clearly recognizes the importance of such skills acquired on site. Long-term knowledge about jobs and coworkers greatly enhances a worker's productivity in team production. This is externality in the workplace, and one worker's productivity is positively related to his coworkers' productivity. If this is important in production, industries that employ numerous old workers with many years of experience would be expected to show a higher growth residual (technological progress). This productivity advantage might be eroded by advances in information technology, however, if such

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[34] Many microeconomic studies find a large economic impact from ICT use in firms. See the surveys of Brynjolfsson and Yang (1996) and Brynjolfsson and Hitt (2000). In addition, recent studies on this subject based on aggregate data find evidence of ICT externality of this kind (see footnote 6 and references therein).

[35] Stiroh (1999a) reviews the New Economy literature.

innovations render this tacit knowledge obsolete. Thus, if this mechanism is important, one would expect a positive correlation between the ratio of old workers and the growth residual before the rapid increase of information capital stocks and a negative correlation after it.

Fourth, a classical Schumpeterian argument states that technological development is often carried out by monopolistic firms. If this is the case, one would expect a positive correlation between pure profits and the growth residual. An alternative argument is that monopolistic firms generally do not experience any market pressure to innovate, so one would expect a negative correlation between pure profits and the growth residual. Finally, there is a strong argument that the impact of capital stocks on structure is different from their impact on equipment.[36] We will also consider this possibility.

To examine the validity of the above arguments, we employ the panel data of the 15 industries and four subperiods used in our previous analysis. We then estimate an equation explaining the growth residual, or equivalently, the rate of technological progress, by (1) the ratio of old workers with low levels of education to the total labor inputs (*OL)*, (2) the ratio of old workers with high levels of education to the total labor inputs (*OH*), (3) the ratio of a net profit to the total cost (*PROFIT*), (4) the ratio of ICT stocks to the total capital stocks (*ITK*), and (5) the ratio of the non-ICT equipment capital stocks to total capital stocks (*EQ*), as follows:[37]

$$\textit{Technological progress} = \textit{constant} + (\beta_{\mathrm{OL}} + \delta_{\mathrm{OL}} \times \textit{90sDummy}) \times OL + (\beta_{\mathrm{OH}} + \delta_{\mathrm{OH}} \times \textit{90sDummy}) \times OH + (\beta_{\mathrm{PROFIT}} \times \textit{PROFIT}) + (\beta_{\mathrm{ITK}} \times \textit{ITK}) + (\beta_{\mathrm{EQ}} \times EQ) + \varepsilon_{it}.$$

Here we allow the possibility of structural change resulting from ICT development around 1990 by including a coefficient dummy variable for the 1990s (*90sDummy*). Since we are not sure about stochastic properties of industry-specific effects, we estimate both the fixed-effects and the random-effects. In addition, since explanatory variables may be endogenously determined so that they may be correlated with error terms, we also employ the generalized method of moments (GMM).[38]

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[36] See Gordon (1990) and De Long and Summers (1992).

[37] We tried other specifications, including one allowing a lag structure using annual data, but the result was not promising. In particular, we tried a specification that Jong-Wha Lee suggested, allowing a technology spillover effect of ICT through high-skilled workers (a cross term of ICT and high-education labor). Unfortunately, a severe multicolinearity problem was found, ruining the regression results.

[38] Instruments we use are (1) constant; (2) *90sDummy;* (3) the ratio of the old (40 years and over) in the total population; (4) the ratio of college and junior college graduates in the total

Our results are shown in tables 11–14. In all cases the random-effects model is chosen by the Hausman test, so we report only the random-effects model here. The use of GMM reveals that the coefficient of $90sDummy \times OL$ (δ_{OL}) is not statistically significant, and to include this variable makes other estimates deteriorate, so we exclude it from the GMM part of tables 11–14. Similar problems occur for *PROFIT,* so it is also excluded from the GMM part of tables 11–14.

Table 11 reports the results for the case in which we use only manufacturing industries. The number of observations (N) is 44. Table 11 shows that $\beta_{OH} > 0$, $\delta_{OH} < 0$, and $\beta_{ITK} > 0$ are statistically significant at the 10 percent, 1 percent, and 5 percent levels, respectively. Thus, the result supports the existence of positive ICT externality (New Economy effect), a positive effect on productivity growth of old workers with many years of experience in the high-education segment in the 1980s (long-term employment effect), and a negative effect of ICT in the 1990s on the productivity growth of manufacturing firms with old workers with many years of experience (ICT-induced obsolescence effect). In contrast, we find no effect on manufacturing firms' productivity growth that can be attributed to the inflexibility of older workers, no pure-profit effect, and no evidence of externality in (non-ICT) equipment. Qualitatively, the same result is obtained for all industries, reported in table 14. It should be noted, however, that when the sample industries are four nonmanufacturing industries, no variable has explanatory power with respect to the rate of technological progress (table 13).

However, the positive ICT externality (New Economy) effect is not robust. Let us exclude electrical machinery from these 11 manufacturing industries and restrict sample industries to 10 manufacturing industries ($N = 40$). The result is reported in table 12. The coefficient β_{ITK} is now statistically insignificant. In contrast, the obsolescence effect of ICT (δ_{OH}) is still statistically significant. Thus, ICT's effects are mostly concentrated in the electrical machinery industry, which is an ICT-producing industry, and there is no compelling evidence for *general* ICT externality. It should be kept in mind, however, that the ICT externality we examined is a within-the-industry externality: for example, a network effect in the same industry. A cross-industry spillover of ICT effects may occur: for example, one industry's ICT invest-

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20- to 24-year-old population of 1951–55, 1956–60, 1961–65, and 1966–70; (5) population growth; (6) one-period-lagged value-added growth; (7) one-period-lagged capital/labor ratio; (8) one-period-lagged ITK estimated using Miyagawa's ICT capital; and (9) one-period-lagged EQ. Hansen's overidentifying restrictions test (Hansen 1982) shows that our choice is reasonable. We also tried other macroeconomic variables, but the results were not satisfactory because of apparent multicolinearity.

Table 11. Technological growth, old workers, and IT in manufacturing industries

Parameter	Estimate	Standard error	t-statistic	p-value
Constant				
Random effects	0.349	4.957	0.070	0.944
GMM	0.860	4.141	0.208	0.836
β_{OL}				
Random effects	0.011	0.081	0.137	0.891
GMM	0.018	0.051	0.356	0.722
δ_{OL}				
Random effects	0.015	0.036	0.426	0.670
GMM	n.a.	n.a.	n.a.	n.a.
β_{OH}				
Random effects	0.644	0.370	1.740	0.082
GMM	0.660	0.430	1.535	0.125
δ_{OH}				
Random effects	−0.861	0.287	−2.995	0.003
GMM	−0.782	0.250	−3.125	0.002
β_{PROFIT}				
Random effects	1.541	2.918	0.528	0.597
GMM	n.a.	n.a.	n.a.	n.a.
β_{ITK}				
Random effects	0.515	0.226	2.282	0.022
GMM	0.392	0.153	2.568	0.010
β_{EQ}				
Random effects	−0.045	0.056	−0.808	0.419
GMM	−0.046	0.036	−1.281	0.200
Specification test	**Value**		**p-value**	
Hausman (FE vs. RE)	10.353		0.169	
Hansen	1.493		0.684	

Note: *Number of industries = 11. Number of observations = 44. Dependent variable = rate of technological progress. FE = fixed effects. RE = random effects. Hansen = Hansen's overidentifying restrictions test (Hansen 1982). n.a. = not applicable.*

ment may represent a positive externality for other industries. We do not have a clear model of technology externality over industry borders and must leave such investigation to future research.

This result is consistent with the conclusion of Stiroh (2001), who uses data for U.S. manufacturing industries from 1973 to 1999 to estimate the correlation between ICT capital intensity and the rate of technological progress. His results suggest that the primary impact of ICT is through traditional capital-deepening and provide little evidence that ICT capital formation is responsible for accelerating the rate of technological progress in the United States.

Let us summarize the results obtained in this section. For the effect of labor force composition on the rate of technological progress, the results do not support the claim that inflexible old workers played a role in Japan's productivity slowdown. There is no correlation between the rate of technological progress and the ratio of old workers with low levels of education in the total labor inputs. The results suggest, however, that information technology development in the 1990s had a negative impact on the past strength of the Japanese economy. This past strength may be at-

Table 12. Technological growth, old workers, and IT in manufacturing industries, excluding electrical machinery

Parameter	Estimate	Standard error	t-statistic	p-value
Constant				
Random effects	1.151	6.363	0.181	0.856
GMM	0.291	5.174	0.056	0.955
β_{OL}				
Random effects	0.002	0.098	0.023	0.982
GMM	0.020	0.060	0.328	0.743
δ_{OL}				
Random effects	0.022	0.041	0.526	0.599
GMM	n.a.	n.a.	n.a.	n.a.
β_{OH}				
Random effects	0.570	0.422	1.351	0.177
GMM	0.673	0.455	1.481	0.139
δ_{OH}				
Random effects	−0.898	0.313	−2.874	0.004
GMM	−0.745	0.279	−2.675	0.007
β_{PROFIT}				
Random effects	2.147	3.259	0.659	0.510
GMM	n.a.	n.a.	n.a.	n.a.
β_{ITK}				
Random effects	0.684	0.460	1.487	0.137
GMM	0.146	0.404	0.361	0.718
β_{EQ}				
Random effects	−0.053	0.066	−0.806	0.421
GMM	−0.030	0.041	−0.744	0.457
Specification test	**Value**		**p-value**	
Hausman (FE vs. RE)	9.279		0.233	
Hansen	1.815		0.612	

Note: *Number of industries = 10. Number of observations = 40. Dependent variable = rate of technological progress. FE = fixed effects. RE = random effects. Hansen = Hansen's overidentifying restrictions test (Hansen 1982). n.a. = not applicable.*

tributed to productivity increases gained from well-educated workers' learning by doing. In the manufacturing industries that have experienced strong growth in the past, the rate of technological progress in the 1980s has a positive (though weak) correlation with a "maturing" well-educated labor force. That is, the ratio of older well-educated workers in the total labor inputs has a positive (though weak) effect on technological progress. This suggests that the increased average skill among well-educated workers resulting from longer experience has a positive effect on productivity. The relationship changes significantly in the 1990s, however, and becomes negative. The nature of technological progress apparently changed adversely. We find no evidence to support ICT externality, except in the case of the ICT-producing industries.

6. Concluding remarks on policy implications

The improved data set we compiled reveals that ICT capital stocks are an important substitute for young workers with low education levels (section 4.3). These results strongly suggest that ICT investment is an effective way to counter the prospective

Table 13. Technological growth, old workers, and IT in nonmanufacturing industries

Parameter	Estimate	Standard error	t-statistic	p-value
Constant				
Random effects	−0.185	6.961	−0.027	0.979
GMM	−1.868	4.949	−0.377	0.706
β_{OL}				
Random effects	0.083	0.212	0.392	0.695
GMM	0.089	0.138	0.644	0.520
δ_{OL}				
Random effects	−0.073	0.084	−0.871	0.383
GMM	n.a.	n.a.	n.a.	n.a.
β_{OH}				
Random effects	−0.144	0.719	−0.201	0.841
GMM	0.184	0.624	0.295	0.768
δ_{OH}				
Random effects	0.043	0.368	0.116	0.908
GMM	−0.082	0.251	−0.326	0.744
β_{PROFIT}				
Random effects	7.279	8.078	0.901	0.368
GMM	n.a.	n.a.	n.a.	n.a.
β_{ITK}				
Random effects	0.144	0.359	0.401	0.689
GMM	−0.295	0.194	−1.522	0.128
β_{EQ}				
Random effects	−0.050	0.148	−0.339	0.735
GMM	−0.014	0.086	−0.166	0.868
Specification test	**Value**		**p-value**	
Hausman (FE vs. RE)	3.975		0.409	
Hansen	5.534		0.137	

Note: *Number of industries = 4. Number of observations. = 16. Dependent variable = rate of technological progress. FE = fixed effects. RE = random effects. Hansen = Hansen's overidentifying restrictions test (Hansen 1982). n.a. = not applicable.*

shortage of young workers in Japan. The results also imply that to strengthen this effect of ICT investment, it is necessary to improve the educational level of the labor force; otherwise, the impact of ICT investment may be seriously hindered by a shortage of complementary well-educated labor inputs. The need to improve education levels is all the more apparent if one considers the fact that ICT capital stocks and high-education-level labor are complements in all cases in which high-education-level labor is a variable input.

The results of section 5, however, show that the hope that many economists and politicians have with respect to the "ICT revolution," in which ICT externality greatly enhances productivity, is not supported by the data, at least with respect to within-industry effects. The productivity gain in ICT-producing industries is remarkable (e.g., the electrical machinery industry in our sample), but this is an industry-specific phenomenon rather than a revolution that affects all industries. On the contrary, our results suggest that information technology has a negative indirect effect on productivity. The advent of information technology may have drastically changed the comparative advantages of Japan's industries. The past technological and managerial strengths of Japanese manufacturing firms, which have been based

Table 14. Technological growth, old workers, and IT in all industries

Parameter	Estimate	Standard error	t-statistic	p-value
Constant				
Random effects	0.514	3.285	0.157	0.876
GMM	1.253	3.914	0.320	0.749
β_{OL}				
Random effects	−0.016	0.058	−0.275	0.783
GMM	−0.007	0.052	−0.143	0.886
δ_{OL}				
Random effects	−0.009	0.031	−0.277	0.781
GMM	n.a.	n.a.	n.a.	n.a.
β_{OH}				
Random effects	0.116	0.287	0.402	0.688
GMM	0.514	0.433	1.188	0.235
δ_{OH}				
Random effects	−0.399	0.218	−1.826	0.068
GMM	−0.556	0.229	−2.424	0.015
β_{PROFIT}				
Random effects	4.099	2.158	1.899	0.058
GMM	n.a.	n.a.	n.a.	n.a.
β_{ITK}				
Random effects	0.280	0.140	1.991	0.046
GMM	0.031	0.146	0.212	0.832
β_{EQ}				
Random effects	0.011	0.036	0.292	0.770
GMM	−0.018	0.030	−0.610	0.542
Specification test	**Value**		**p-value**	
Hausman (FE vs. RE)	6.536		0.479	
Hansen	2.653		0.448	

Note: *Number of industries = 15. Number of observations = 60. Dependent variable = rate of technological progress. FE = fixed effects. RE = random effects. Hansen = Hansen's overidentifying restrictions test (Hansen 1982). n.a. = not applicable.*

on workers' learning by doing in the workplace and other strategies (such as TQC and on-the-job/off-the-job training), may no longer be advantages as knowledge management systems improve and become easily transferred across international borders.

In this respect, Japan needs a thorough examination of its productivity slowdown in the 1990s, especially of the strengths and weaknesses in technology and management. As our data suggest, technology and management are not independent of one another. In section 5.2, we have shown that the long-term employment relationship that traditional Japanese management has cherished for the past 40 years increased productivity growth *until the advent of the ICT revolution of the 1990s.* This means that Japanese management was best suited for the technology available at that time, that is, pre-ICT production technology. After the ICT revolution, however, we observe the long-term employment relationship (and thus this part of Japanese management) becoming a stumbling block for productivity growth. This suggests that one form of management (including work organization and personnel management) may be efficient for one form of technology but not for others. Management styles are often stable in the long run, and mismatches may evolve between management and current technology.[39]

Moreover, technology itself is not exogenous. The past history of technological development shows the importance of the government in enhancing particular types of technological development. Obviously the government cannot choose appropriate technology for the economy, but it can provide a menu of possible technological choices from which the market chooses the winning one. The government can influence the course of technological development and properties of production technology, though it cannot determine them.

However, as the government delineates the choices and exerts its influence, *appetence* between technology and management should be properly taken into consideration. As we explained above and in section 5.2, a long-term relationship is a particularly effective management strategy for technology in which tacit knowledge acquired from long experience plays a crucial role in efficiently producing products of "integral architecture," such as passenger cars.[40] Simply assembling a large number of passenger car parts does not guarantee a good passenger car. We need tacit knowledge of design and production to make these parts work properly and smoothly long after production. A good Toyota car is thus an "integral product," far more than just assembled "modular parts." However, this is not the case for personal computers. (One can assemble a very good desktop computer from a central processing unit, random-access memory modules, hard disk drives, and so on.) We do not need tacit knowledge acquired from long experience to assemble computer parts: even with little experience one can assemble all components properly and produce a good personal computer if one has a good guidebook or guide video. In the ICT industries this modular architecture is often coupled with very rapid changes in product specification of modular parts. In such industries, a long-term relationship is likely to be a disadvantage rather than an advantage.

The advent of information and communication technology and competitive modular-architecture products marked the end of the happy coupling of traditional Japanese management with integral-architecture technology. The challenge that the Japanese economy faces is thus not only to adjust to modular-product technology, but

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[39] See Nishimura and Tamai (2001) for a model of long-run rigidity of management styles.

[40] See Nishimura and Morita (2002) for the importance of product architecture in understanding industrial structure. Japan is still highly competitive in the automobile industry, since the latter is an integral-architecture industry.

also to find new integral-architecture technology in which Japanese management has a competitive edge.

Appendix

We explain in detail in this appendix the heuristic procedure used to determine what inputs are variable and to estimate the translog variable cost function parameters allowing technological change (see section 4).

Step 1. Choice of variable inputs

Substep 1.1 (five factor inputs) (1) We take all four types of labor inputs, use machines and tools as variable inputs, and estimate equation (8) without period dummies. Some of the estimated γ_{ii} values are positive and statistically significant, implying that the concavity requirement is not likely to be satisfied. (2) Then, we take all four types of labor inputs, use transportation machines as variable inputs, and estimate equation (8) without period dummies. Some of the estimated γ_{ii} values are positive and statistically significant, implying that the concavity requirement is not likely to be satisfied. So we proceed to the next substep.

Substep 1.2 (four factor inputs) (1) We drop all capital stocks except for ICT stocks. We take all four types of labor inputs as variable inputs and estimate equation (8) without period dummies. Some of the estimated γ_{ii} values are positive and statistically significant, implying that the concavity requirement is not likely to be satisfied. (2) We keep machines and tools and drop one of the three labor inputs (young with high levels of education, old with low levels of education, and old with high levels of education). We estimate equation (8) without period dummies. Some of the estimated γ_{ii} values are positive and statistically significant, implying that the concavity requirement is not likely to be satisfied. (3) Then, we keep transportation machines and drop one of the three labor inputs. We estimate equation (8) without period dummies. Some of the estimated γ_{ii} values are positive and statistically significant, implying that the concavity requirement is not likely to be satisfied. So we proceed to the next substep.

Substep 1.3 (three factor inputs) We drop all capital stocks except for ICT stocks and keep young workers with low levels of education. Then we drop one of the remaining three labor inputs. We estimate equation (8) without period dummies. We next examine whether all estimated γ_{ii} values are negative with some statistical significance. In this step, 6 out of 16 industries show all negative γ_{ii} values with marginal statistical significance: food, textile, fabricated metal, electrical machinery, instruments, and services.[41] These six industries are likely to have sharper results if we consider period dummies explicitly based on technological change. Thus, we move to step 2 for these industries. For the remaining 10 industries, we proceed to the next substep.

Substep 1.4 (two factor inputs) We drop all capital stocks except for ICT stocks, keep young workers with low levels of education, drop two of the remaining three labor inputs, and estimate equation (8) without period dummies. We examine whether estimated γ_{ii} values are negative with some statistical significance. Out of the remaining 10 industries, 9 have estimated γ_{ii} values that are all negative with marginal statistical significance. We move to step 2 for these industries for the same reason given in substep 1.3. We proceed to the next substep for the general machinery category.

Substep 1.5 (period difference) The failure of substeps 1.1–1.4 for the general machinery industry suggests that there may be a break in the number of quasi-fixed factors for that industry between the 1980s and the 1990s. We divide the total sample period into two periods and reapply substeps 1.1–1.4 for each subperiod. The results suggest that the general machinery industry has two variable factors in the 1980s and three variable factors in the 1990s. We then proceed to step 2.

Step 2. Estimation of share equations with period dummies

Substep 2.1 (identifying the possible number of technological changes) For each industry, we identify the possible number of technological changes. As explained in the text, there may be a technological change between the 1980s and the 1990s because the usage of information technology is different in the two periods. (In the case of the general machinery industry, we found in step 1 that the number of quasi-fixed factors is different in the 1980s compared with that in 1990s, already implying a break in production technology.) In addition, there may be an additional technological change for specific industries. To identify technological changes for each industry, we look at table 9, which reports ICT stocks' contribution to value-added growth for the entire sample period and for each half-decade. For some manufacturing industries, the ICT capital stock contribution has a break in the late 1990s, which may indicate another technological change. In the case of the transportation and communication sector, we find a sharp increase in the ICT contribution in the 1980s. This suggests that there might be a technological change in the mid-1980s

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[41] Moreover, the combination of chosen labor inputs is unique to each industry in this category. That is, there is only one combination of labor inputs for each industry that has all negative γ_{ii} values with some statistical significance.

in this industry. Taking these observations into account, we consider additional intercept and slope dummies of the mid-1990s for manufacturing industries having a break in ICT contribution within the 1990s. In the case of the transportation and communication industry, we consider the mid-1980 dummies instead of the mid-1990 dummies.

Substep 2.2 (searching for the timing of technological change) For the technological change between the 1980s and 1990s, we first set 1990 as the year of change. For the industry-specific technological change (suggested in the previous substep), we set 1995 as the year for the change in the 1990s and 1985 as the year for the change in the 1980s. Upon deciding the number of period dummies (that is, technological changes), we estimate equation (8) with these period dummies, drop insignificant intercept and/or slope dummies, reestimate the equations, and examine whether estimated coefficients are consistent with the concavity requirement. We then move the point of change around the initial point to see whether this gives us a sharper estimation (in terms of the statistical significance of the γ_{ii} values), with the concavity requirement remaining satisfied. In the end, some period dummies are not statistically significant. The results are reported in tables 3a and 4a.

Step 3. Manufacturing industries

For manufacturing industries, we have one more dimension with respect to labor input types: production workers and nonproduction workers. This means we have eight types of labor inputs. Basically, we repeat steps 1 and 2 for these finer labor input data of manufacturing. There is a problem of apparent multicolinearity, however, and consequently some form of aggregation is necessary. We try all sensible aggregation possibilities and find that aggregating young and old production workers and using six types of labor inputs (production workers with low education levels, production workers with high education levels, nonproduction young workers with low education levels, nonproduction young workers with high education levels, nonproduction old workers with low education levels, and nonproduction old workers with low education levels) yielded satisfactory results. The results are reported in tables 3b and 4b.

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