Can measurement error explain the productivity paradox?

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1. Introduction

> "... official data show enormous productivity gains in the manufacture of computers but apparently little productivity improvement in their use ... A key issue for this paper, therefore, is to explore why official data seem not to be showing the payoff from investments in computer power. What has all that computer power been doing, and where is the 'black hole' into which all those computers are disappearing?"
>
> Martin Neil Baily and Robert J. Gordon (1988, 350-351)

The above quotation by Baily and Gordon nicely expresses the essence of the productivity paradox. Their paper considers whether errors in economic measurements could explain the productivity paradox. Nordhaus (1988, 425) succinctly summarized the Baily-Gordon findings as follows: "At the end of the day, I would have to conclude that there's not much gold in the hills of mismeasurement". Another discussant of the Baily and Gordon paper explained why the growth of computers could not make much difference to explanations of productivity change:

> "It is a basic rule of growth accounting that large changes in investment cause only small changes in output. The reasons for this are that investment is a small fraction of GNP and that the marginal product of capital is small. Since computers are a quite small part of total investment, a vast increase in investment in computers would yield only a small increase in measured output even if all the computers were being used productively and were generating measured output ... These calculations imply that if computers are being used productively (in the U.S.), they have raised the average annual growth rate of output over the past two decades by roughly a twenty-fifth of a percentage point."
>
> David Romer (1988, 427)

Thus Romer explained the productivity paradox by showing that there is no paradox due to the spread of computers per se: computers are simply too small a part of the economy to make much difference.

However, a paradox remains if we follow Skinner (1986) and interpret the productivity paradox more broadly:

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> "American manufacturers' near-heroic efforts to regain a competitive edge through productivity improvements have been disappointing ... Unfortunately, *XYZ*'s frustration with a full-out effort that achieves only insignificant competitive results is typical of what has been going on in much of American industry. Why so little competitive return--even a negative return--on so much effort? ... Why this apparent paradox?"
>
> Wickharn Skinner (1986, 55)

From the results of the next section, the average growth in total factor productivity (labour productivity) for 18 OECD countries fell from 3.25% (4.41%) per year over the years 1961-1973 to 1.09% (1.81%) per year over the years 1974-1992. Thus, along with everyone else, we find that measured productivity growth fell off sharply in the post-1973 period. This downturn can be placed in more of a historical perspective with the long time series on labour productivity in the non-farm business sector of the U.S. for the years 1909-1979 that Nordhaus (1982) has compiled. He found that while there was a more or less constant rate of productivity growth averaging around 2 to 2½ percent per year from World War I to the mid-1960s, after that the rate of growth dropped to around one percent by 1979.

Standard measures show that there has been no substantial recovery in productivity growth in the past 25 years, in contrast to the steady growth over the previous 50 years. Rather, the productivity slowdown has persisted despite of large absolute increases in research and development, scientific knowledge and technological innovations. This seems to be the essence of the productivity paradox.

In this paper, we argue that economic mismeasurement can help explain the productivity paradox in two ways. First, we outline reasons for why there has been a systematic understatement of real productivity growth. However, these reasons cannot explain the abruptness of the measured slowdown. We argue that much of the initial post-1973 productivity growth decline in OECD countries was real, stemming from decision making errors attributable to measurement problems that are associated with higher levels of inflation and also with the proliferation of new goods and the difficulties of pricing these in inflationary circumstances. With the return in more recent years to lower levels of inflation, we believe that a partial recovery of productivity growth rates in most OECD countries has been masked somewhat by problems in measuring productivity.

Before turning to an examination of the possible reasons for the productivity mismeasurement and slowdown, we present some evidence of the slowdown in section 2. In section 3, we indicate how an increasing proliferation of new products and new processes combined with existing statistical agency measurement procedures can lead to a systematic understatement of productivity growth. This section draws heavily on the work of Paul Romer (1994) and R.J. Hicks (1940), and considers the costs and benefits of developing new products. The costs are typically measured well by statistical agencies. However, there exist problems in measuring the benefits. This asymmetry in the accuracy of measurement of costs and benefits of new products gives one possible source of productivity mismeasurement. In section 4, we attempt to make the case that an increasing proportion of business expenditures are actually consumption expenditures and these classification errors have the effect of reducing measured productivity growth. Section 5 follows up on the earlier analysis of Baily and Gordon (1988) and examines mismeasurement of service sector outputs. Sections 6 and 7 consider the role of historical cost accounting and the increases in inflation that occurred in the years 1974-1990. Historical cost accounting, high inflation and high rates of business income taxation interact to produce chaos in the intertemporal allocation of resources which in turn can lead to productivity growth declines. Section 8 concludes with some observations on what can be done to remedy some of the economic mismeasurement problems discussed in early sections.

2. The productivity slowdown

We present our own evidence of the productivity slowdown. In particular, we calculate total factor productivities and labour productivities for 18 OECD countries for the years 1960-1992. We find, along with everyone else, that measured productivity growth did drop off sharply in the post-1973 period.

The data set consists of prices and quantities for three outputs (exports, investment, and combined private and government consumption), and three inputs (labour, imports and reproducible capital) for 18 OECD countries, 1960-1992. The construction of this data set is described in detail in Fox (1997).

The productivity growth rates were calculated using a Fisher index approach; see Diewert (1992) for reasons for this choice of index number formula. The Fisher (1922) quantity index can be written as follows:

$$g^{t} \equiv \left[\frac{\sum_{j=1}^{N} p_j^{t} y_j^{t}}{\sum_{j=1}^{N} p_j^{t} y_j^{t-1}} \cdot \frac{\sum_{j=1}^{N} p_j^{t-1} y_j^{t}}{\sum_{j=1}^{N} p_j^{t-1} y_j^{t-1}} \right]^{1/2} \qquad (1)$$

where N is the number of goods being aggregated, and p_j^{t} and y_j^{t} denote the price and quantity, respectively, of good j at time t.

Let g^t be an index of inputs. With more than one output, a similar index for the output variables, G^t, is constructed. Productivity growth (P) for period t is defined as:

$$P^t \equiv (G^t/g^t) - 1. \qquad (2)$$

Multiplying P^t by 100 gives the percentage productivity growth between periods t - 1 and t.

For aggregate (total factor) productivity growth (table 1), the output quantity index was created from private and government consumption, investment, and exports less imports (i.e. the quantity for imports was set to be negative in the calculation of the index). The input quantity index was created from labour and capital. Examining table 1, we see that every country in the sample had lower productivity growth in the period 1974-1992 compared with the period 1961-1973. This demonstrates that the productivity slowdown is found in the data across a broad range of industrialized countries. Moreover, the slowdown is far from trivial. The average productivity growth across all 18 countries for the earlier period was 3.25%, while it fell to 1.09% in the latter period.

As labour productivity growth is often of independent interest, we present estimates calculated in a similar fashion to total factor productivity growth. Dividing the output quantity index by an index of the growth in labour input (i.e., growth in total hours worked) gave the estimates of labour productivity growth in table 2. Again we see the productivity slowdown in each of the countries, and a substantial decline in the averages across countries: 4.41% for 1961-1973 compared with 1.81% for 1974-1992.

While the timing is not identical for each country, a close examination of the numbers in tables 1 and 2 indicates a sharp fall in productivity growth in all the countries around 1974-1975.

To get a clearer picture of this, figure 1 presents averages for each year across the 18 OECD countries. The ‘unweighted’ series are the simple arithmetic means for each year. In this case each country gets an equal weight in the average. This is informative, but if one wishes to consider the aggregate performance of the 18 OECD countries, then the fact that the economies differ in size should be taken into consideration. This leads to the ‘weighted’ series. These series were constructed by first putting all prices into U.S. dollars using exchange rates, constructing the indices for each country as above, multiplying these indices by each country’s share in the OECD (18 countries) total output, and then summing the resulting share weighted indices.

The sudden decline in productivity growth in these industrialized countries after 1973 is clearly seen in figure 1, as is the subsequent lack of a recovery. This empirical observation, combined with our knowledge of the great advances in technology during this period, is what leads us to examine possible reasons for this ‘productivity paradox’.

3. The costs and benefits of new products

Standard accounting practices recognize the costs of introducing new products. However, the benefits of the new products are not as accurately measured. We first examine the costs, and then explain how the mismeasurement of the benefits can lead to a downward bias in productivity estimates.

Each new commodity that is offered on the market place involves certain fixed

TABLE 1
Total factor productivity growth rates (%)

	AUS	AUT	BEL	CAN	CHE	DEU	DNK	ESP	FIN	FRA	GBR	GRC	JPN	NLD	NOR	NZL	SWE	USA	Mean	Std. Dev.
1961	1.94	4.83	3.46	0.83	3.72	2.69	2.98	11.09	3.19	3.43	1.75	7.27	5.94	-2.37	5.67	1.94	4.27	1.82	3.74	3.07
1962	3.45	2.08	3.46	3.69	1.12	2.83	2.00	6.06	3.79	4.80	-0.38	3.40	5.53	4.85	1.18	-0.10	2.43	2.49	2.93	1.79
1963	4.06	2.20	2.42	2.92	2.32	1.54	-0.47	6.58	-0.89	2.04	3.25	4.11	4.36	1.25	3.07	3.79	3.93	1.98	2.72	1.80
1964	0.95	3.70	5.04	2.74	3.19	6.38	4.85	4.52	-0.48	3.50	3.03	10.44	8.70	6.69	2.13	1.08	6.79	2.79	4.25	2.78
1965	-1.25	0.52	1.86	2.63	3.25	2.65	2.36	3.20	5.73	4.04	1.66	4.90	3.03	3.86	3.78	2.82	1.56	2.18	2.71	1.59
1966	3.65	4.65	1.96	2.68	1.97	2.34	0.83	4.60	3.37	2.43	2.05	4.51	5.35	1.25	1.76	0.88	-0.17	2.28	2.61	1.57
1967	0.92	2.52	4.64	0.12	2.37	3.87	0.64	2.85	5.63	3.54	3.64	4.53	6.31	5.91	2.93	-5.55	1.49	1.32	2.65	2.74
1968	5.15	3.49	3.07	2.70	2.58	3.38	4.71	4.46	5.81	2.55	3.35	3.87	8.19	4.85	3.02	0.60	6.38	1.38	3.87	1.81
1969	1.21	6.43	5.48	1.20	1.88	3.25	4.76	7.09	6.85	3.59	1.48	8.08	8.52	4.82	5.67	5.89	4.55	0.15	4.50	2.52
1970	2.35	7.10	6.35	2.58	4.30	0.54	1.65	1.11	5.03	4.08	4.50	7.07	5.41	4.93	0.96	-2.53	3.35	-0.04	3.28	2.63
1971	2.08	3.43	2.17	3.17	2.07	2.71	1.86	3.28	-0.73	3.03	4.40	3.92	0.41	3.24	2.18	4.06	0.79	1.70	2.43	1.33
1972	1.82	5.54	5.71	0.43	1.52	3.25	4.08	3.92	5.89	3.17	1.74	4.77	4.51	3.50	-0.07	2.28	4.19	0.52	3.15	1.86
1973	-0.53	1.82	5.81	3.22	1.32	2.49	5.50	5.08	2.10	3.07	3.64	7.62	2.58	4.64	3.88	2.39	4.28	1.51	3.36	1.93
1974	-0.34	2.22	3.69	0.33	0.28	1.98	-2.56	3.95	0.52	1.91	0.48	1.25	0.48	5.59	3.80	0.97	2.36	-1.66	1.10	2.43
1975	5.92	6.17	2.22	0.84	-3.60	1.96	1.45	1.30	-3.64	0.78	-0.07	3.83	2.37	0.18	-0.14	-3.68	0.23	0.45	0.92	2.79
1976	1.78	1.16	2.74	2.97	0.60	3.19	5.55	1.83	-3.05	2.76	3.89	4.60	-0.52	4.13	3.01	2.40	0.93	0.72	2.14	2.02
1977	0.02	2.55	1.27	2.26	1.51	1.71	1.14	3.39	5.88	2.35	-0.16	0.71	1.62	1.13	3.33	-6.47	-2.11	0.78	1.16	2.54
1978	5.93	-0.49	1.61	0.37	0.04	1.84	0.65	3.02	2.72	2.50	2.37	4.89	1.77	1.07	3.02	-4.01	1.72	0.72	1.67	2.15
1979	-0.42	1.98	0.10	-0.61	1.48	1.58	-0.50	1.13	2.94	2.12	0.21	2.49	1.57	0.66	4.09	-0.78	2.37	0.16	1.14	1.38
1980	0.11	0.96	8.39	-1.14	3.01	-0.51	-1.20	2.08	2.65	0.84	-1.70	0.77	1.23	-1.52	2.50	0.48	0.09	-0.34	0.93	2.35
1981	0.55	-0.37	-1.02	0.43	-0.51	0.83	2.11	2.98	1.91	1.50	2.75	-5.54	1.71	-2.10	-0.78	3.59	0.13	0.94	0.51	2.13
1982	-0.84	-3.00	2.55	0.24	-1.39	0.23	1.53	1.20	1.84	3.14	0.45	-2.50	1.15	-0.97	-1.19	0.00	0.25	-0.76	0.10	1.55
1983	7.53	1.83	1.11	1.40	0.95	2.88	0.74	3.20	0.74	1.34	4.34	-1.16	-0.25	2.05	3.59	4.88	1.41	-0.14	2.02	2.10
1984	0.31	-2.08	1.24	2.87	1.04	1.45	1.62	5.37	1.98	1.83	-0.96	3.12	1.43	2.97	3.10	1.61	2.09	2.10	1.73	1.62
1985	0.61	1.37	1.47	0.99	1.98	1.52	3.14	2.39	-0.88	1.63	2.26	-1.53	3.66	0.97	1.50	-4.79	0.09	0.97	0.97	1.91
1986	-0.55	1.04	0.48	0.65	1.93	1.10	-1.61	-0.57	-1.53	1.39	3.81	-1.20	1.19	1.92	0.21	4.07	1.92	0.08	0.80	1.61
1987	1.47	1.47	1.46	0.49	0.94	0.86	0.25	3.72	5.73	1.08	2.25	-3.71	1.74	0.67	2.52	-3.11	2.25	0.38	1.14	2.12
1988	-1.91	1.76	2.46	0.48	2.48	2.68	0.60	0.63	3.13	3.32	0.80	2.21	2.58	0.44	-1.82	3.37	0.38	1.35	1.40	1.59
1989	-1.12	2.52	1.63	-0.10	3.01	2.32	0.57	-1.50	3.11	2.43	-0.50	0.76	2.43	2.56	2.39	-0.22	0.82	0.85	1.24	1.47
1990	-2.55	1.48	1.80	-0.78	1.20	3.58	1.37	0.26	-1.88	-0.85	-0.87	-3.30	2.51	1.10	3.19	-2.17	0.58	-0.05	0.26	1.97
1991	3.25	0.48	2.22	-0.51	-0.57	3.17	0.84	0.61	-4.58	-0.58	0.72	2.21	1.57	-0.36	2.05	-0.42	0.21	-0.03	0.59	1.82
1992	1.81	-0.66	1.31	-0.07	1.07	1.06	0.53	1.49	1.20	0.54	0.44	-3.17	1.12	-0.32	3.93	-0.30	0.79	1.15	0.83	1.05
1961-1973	1.98	3.70	3.96	2.22	2.44	2.92	2.75	4.91	3.48	3.37	2.62	5.74	5.81	3.65	2.78	1.35	3.37	1.54	3.25	0.56
1974-1992	1.13	1.07	1.93	0.58	0.81	1.76	0.88	1.92	0.99	1.61	1.07	0.12	1.57	1.06	2.02	-0.24	0.87	0.40	1.09	0.43
1961-1992	1.48	2.14	2.75	1.25	1.47	2.23	1.64	3.13	2.00	2.32	1.70	2.40	3.21	2.11	2.33	0.41	1.89	0.87	1.96	0.49

NOTE: AUS=Austrafia, AUT=Austria, BEL=Belgium, CAN=Canada, CHE= Switzerland, DEU=West Germany, DNK=Denmark, ESP=Spain, FIN=Finland, FRA=France, GBR=Great Britain GRC= Greece, JPN=Japan, NLD=Netherlands, NOR=Norway, NZL=New Zealand, SWE=Sweden

TABLE 2
Labour productivity growth rates (%)

	AUS	AUT	BEL	CAN	CHE	DEU	DNK	ESP	FIN	FRA	GBR	GRC	JPN	NLD	NOR	NZL	SWE	USA	Mean	Std. Dev.
1961	2.52	6.39	3.98	0.86	3.05	3.86	3.98	12.13	5.00	4.23	2.05	7.81	13.01	-2.13	7.30	2.49	5.36	2.23	4.67	3.70
1962	3.57	4.18	4.17	3.34	0.57	4.41	3.07	6.11	6.95	5.61	-0.02	5.91	9.39	4.81	2.15	0.32	3.21	2.15	3.88	2.42
1963	4.06	3.73	2.81	2.84	2.19	2.77	0.63	7.70	-0.05	2.54	3.89	7.49	8.28	1.42	4.32	3.83	4.94	2.07	3.64	2.31
1964	0.30	5.15	5.91	2.17	3.36	7.84	5.65	6.25	0.66	4.82	3.34	12.43	12.11	6.89	2.79	1.12	8.31	2.61	5.10	3.52
1965	-1.17	1.98	2.90	2.38	4.36	3.37	3.74	4.33	7.56	5.49	2.61	7.72	6.14	4.44	5.24	3.18	2.59	1.76	3.81	2.16
1966	3.65	6.60	3.32	2.61	2.72	3.89	2.22	5.95	6.35	3.37	3.17	7.53	8.20	1.91	3.04	1.15	0.54	2.02	3.79	2.21
1967	1.04	4.62	6.64	0.46	3.01	7.19	1.41	4.49	9.11	5.34	5.23	6.55	9.62	7.66	4.19	-5.07	2.20	2.03	4.21	3.57
1968	5.60	5.12	4.24	2.93	3.20	3.50	6.60	5.71	8.24	4.11	4.30	6.06	12.51	5.51	4.64	2.19	8.52	1.32	5.24	2.63
1969	0.91	8.85	6.97	1.26	0.98	3.22	6.25	9.00	8.67	4.58	2.73	10.34	14.04	5.48	7.09	5.75	5.75	0.14	5.67	3.73
1970	2.36	10.03	8.61	3.30	4.60	1.25	3.70	2.28	7.13	5.55	6.62	8.39	10.68	6.28	2.04	-2.46	4.08	0.85	4.74	3.48
1971	2.38	5.21	3.37	3.41	2.42	4.29	3.11	4.70	1.05	4.52	6.19	6.80	4.60	4.31	3.41	5.28	2.11	2.15	3.85	1.52
1972	2.38	8.49	7.67	0.05	1.75	4.31	5.32	4.52	7.64	4.74	2.57	6.35	8.30	4.87	-0.74	3.06	5.84	-0.34	4.27	2.91
1973	-0.45	3.27	7.62	3.04	1.66	2.95	8.30	6.59	3.12	4.45	3.27	11.62	5.50	5.68	5.37	2.41	5.56	1.14	4.51	2.88
1974	-0.02	3.28	5.26	0.97	0.91	3.64	-1.71	6.02	1.34	3.57	1.88	-2.33	5.00	7.31	5.49	1.50	3.32	-1.14	2.46	2.77
1975	7.53	10.98	5.09	1.80	-1.54	4.29	3.31	4.16	-1.56	2.82	0.75	7.39	5.38	1.39	0.65	-4.00	0.73	1.58	2.82	3.66
1976	2.53	2.03	3.02	3.47	1.91	3.18	6.63	3.37	-2.34	3.53	4.59	7.06	0.12	4.54	3.83	4.31	2.13	-0.24	2.98	2.28
1977	0.63	3.88	2.73	2.90	1.60	2.09	2.20	5.19	7.84	3.27	0.09	2.96	2.95	1.53	4.86	-6.07	-1.55	0.19	2.07	2.95
1978	7.35	0.68	2.34	0.33	0.25	2.24	1.47	5.12	3.33	3.83	2.81	6.15	3.12	1.41	3.50	-4.11	2.05	0.06	2.33	2.57
1979	-0.88	2.61	0.46	-0.63	1.77	1.67	-0.86	2.90	2.98	3.05	0.44	3.87	2.78	0.83	4.81	-0.16	2.54	0.13	1.57	1.72
1980	0.29	1.94	10.92	-0.71	3.20	-0.23	-0.87	3.79	3.18	1.66	-1.09	2.28	2.56	-1.80	3.22	1.07	0.34	0.34	1.67	2.87
1981	0.77	0.67	-0.30	0.92	-0.63	1.69	3.49	5.21	2.96	2.64	4.52	-5.36	3.15	-2.21	0.08	4.49	0.64	1.08	1.32	2.60
1982	0.70	-3.20	3.58	2.90	-0.94	1.21	1.62	2.12	2.88	4.37	0.47	-0.10	2.39	-0.24	-0.23	0.57	0.48	0.49	1.06	1.80
1983	9.44	2.95	1.86	1.60	1.53	3.92	0.58	4.63	1.70	2.15	5.06	-0.68	0.33	2.93	4.55	6.04	1.59	-1.01	2.73	2.57
1984	-0.61	-2.15	1.58	2.93	1.38	1.45	1.27	7.90	2.71	2.64	-1.48	4.12	2.12	3.40	3.75	1.54	1.94	1.05	1.98	2.23
1985	-0.27	2.31	2.20	0.91	2.00	1.89	3.88	3.47	-0.37	2.24	2.15	-2.29	4.99	0.89	1.53	-5.31	0.12	1.01	1.19	2.33
1986	-1.19	2.12	0.78	0.91	2.39	1.27	-2.57	-1.14	-1.70	1.83	4.33	-0.61	2.49	2.16	0.26	6.10	2.50	-0.19	1.09	2.19
1987	1.15	2.65	1.83	0.45	1.35	1.31	1.39	4.44	8.01	1.54	2.04	-3.17	2.70	1.40	3.85	-3.06	2.47	-0.03	1.69	2.51
1988	-2.75	2.48	2.26	0.61	3.11	2.93	1.25	0.17	4.09	3.80	0.39	0.07	3.41	0.13	-1.24	5.55	0.45	1.03	1.54	2.07
1989	-1.68	3.49	1.73	0.85	3.47	2.53	2.16	-2.60	4.23	2.86	-0.51	1.50	3.80	2.43	4.13	1.45	1.11	0.80	1.76	1.92
1990	-2.79	2.06	2.44	0.49	1.58	3.62	1.96	0.87	-0.86	-1.16	-0.49	-3.06	4.61	0.44	4.74	-1.50	1.20	0.30	0.76	2.22
1991	4.77	1.21	3.70	1.26	0.10	3.49	1.60	2.09	-2.81	0.05	2.34	4.23	3.62	-0.78	2.92	0.92	1.01	0.75	1.69	1.92
1992	2.08	-0.28	2.60	0.59	2.18	1.87	0.94	4.04	3.27	1.27	1.32	0.05	3.18	-0.41	4.28	-0.86	2.09	0.97	1.62	1.50
1961-1973	2.09	5.66	5.25	2.20	2.61	4.07	4.15	6.13	5.50	4.57	3.54	8.08	9.43	4.39	3.91	1.79	4.54	1.55	4.41	0.71
1974-1992	1.42	2.09	2.85	1.19	1.35	2.32	1.45	3.25	2.04	2.42	1.56	1.16	3.06	1.33	2.90	0.43	1.32	0.38	1.81	0.51
1961-1992	1.69	3.54	3.82	1.60	1.86	3.03	2.55	4.42	3.45	3.29	2.36	3.97	5.65	2.58	3.31	0.98	2.53	0.85	2.87	0.64

NOTE: AUS=Australia, AUT=Austria, BEL=Belgium, CAN=Canada, CHE= Switzerland,
DEU=West Germany, DNK=Denmark, ESP=Spain, FIN=Finland, FRA=France, GBR=Great Britain
GRC= Greece, JPN=Japan, NLD=Netherlands, NOR=Norway, NZL=New Zealand, SWE=Sweden

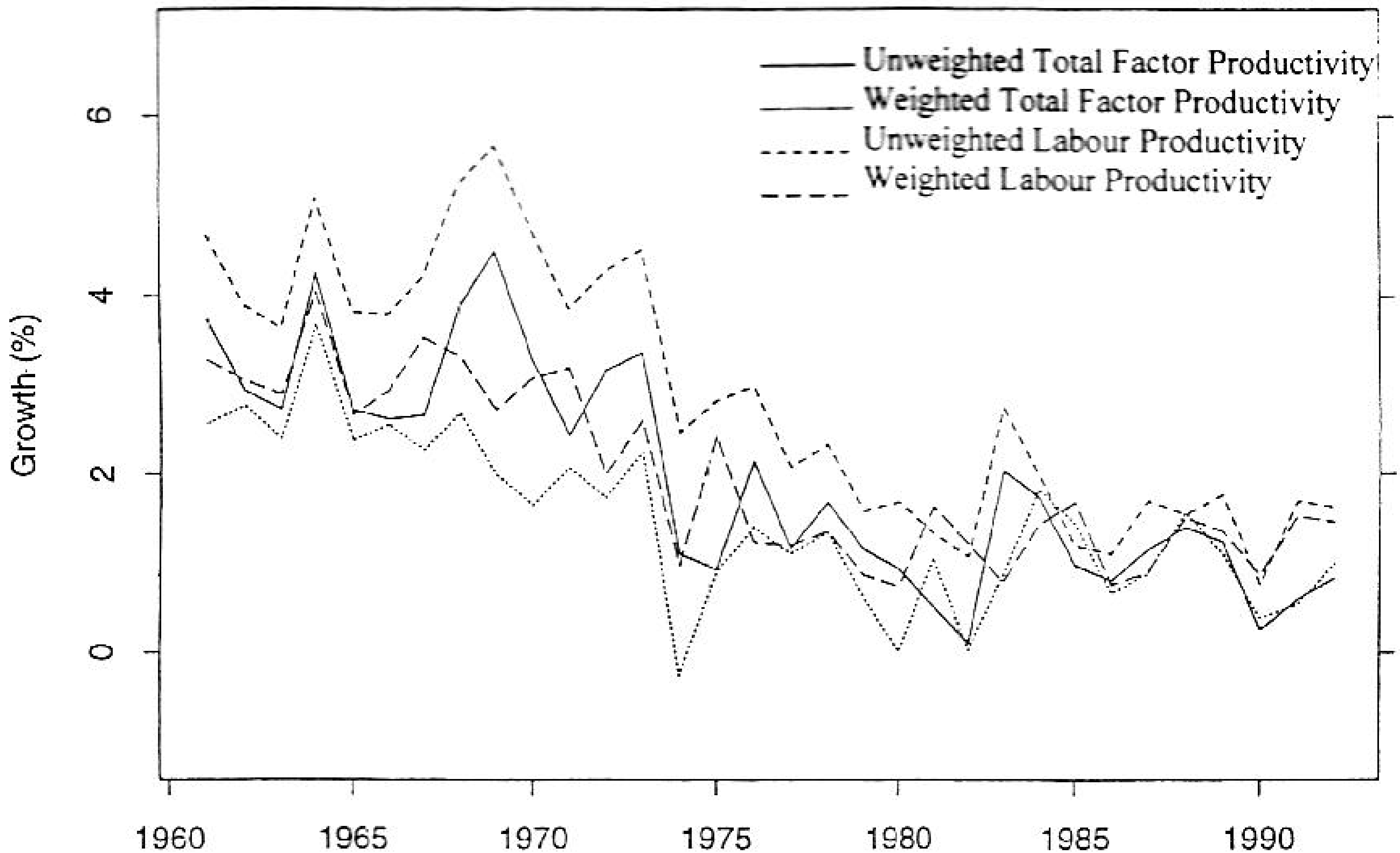

FIGURE 1 Average productivity growth rates

costs of development and marketing. If the number of new commodities grows faster than sales of output, then these fixed costs will also grow faster than output and measured productivity (output divided by input) will be negatively impacted. In this section, the nature of these fixed costs is discussed in more detail under six categorical headings:

(1) *The cost of basic invention*. This includes the basic research and development costs involved in creating a new product or in creating a process for its production.

(2) *Designing new capital equipment*. These costs will generally not vary with the number of units of the new commodity produced and sold. These capital expenses will show up in business accounts as either intermediate expenditures (if the costs are immediately written off) or as capital expenditures to be gradually written off as depreciation expenses.[1]

(3) *Retraining workers*. A new commodity usually requires a new production process, and new workers to be hired or existing workers to be reallocated to the new process. Training will be required for these workers, which has the nature of a fixed cost.

(4) *Inventory costs*. The production of each new commodity will usually generate fixed costs of buying, storing and shipping new inputs. Similar fixed costs are also associated with selling, storing and shipping units of the new commodity. The fixed costs associated with the replacement of depleted inventory stocks can be approximated using the square root inventory replenishment rule discovered by the engineer Green (1915, 887), the management scientist Whitin (1952), the economists Baumol (1952) and Tobin (1956), and many others. This rule indicates that the costs of maintaining inventories will be proportional to the square root of sales or purchases.[2] A related increasing returns to scale effect which relies on a probabilities argument was proposed by Edgeworth.[3] The point is that as a producer offers a greater variety of commodities for sale, inventory costs can be expected to increase in a greater proportion than the increase in sales.

(5) *Selling costs*. Each new product that a company sells must be advertised, selling prices must be determined, price lists and catalogues must be printed, and so on. It is not a trivial matter to determine the cost of a new product. With the exception of plants that produce only one product, the problem of the allocation of overhead costs is especially difficult.[4] We return to this problem in section 7.

(6) *The cost of product failure*. Another factor which tends to make the production of new commodities more costly relative to expanding the production of existing ones is risk. Both the demand for and cost of a new commodity are more uncertain than for an existing, well established commodity. Hence producers will inevitably make mistakes in trying to produce and market new commodities, leading to resource waste and business failures.[5]

The fixed costs which are typically associated with the introduction of a new commodity will generally lead to a shrinkage in the quantity of 'old' goods that the economy can supply in the short run. We can illustrate this in figure 2, adapting a diagram due to Romer (1994, 13).

Prior to the introduction of the new good, the economy could produce the amount *OC* of old goods. The fixed costs of introducing the new good can be represented by the line segment *AC*. Once these fixed costs have been incurred, the production possibilities set for the economy over old and new goods is represented by the traditionally shaped production frontier *EA*. Turning now to the consumer side of the model, we follow the example of Hicks (1940, 114) and assume that the consumer has well defined preferences over combinations of old and new goods; two representative indifference curves are indexed by U_1 and U_2 in figure 2. In the period prior to the introduction of the new good, the amount *OC* of old goods is consumed and the utility level U_1 is achieved. In the subsequent period when the new good is introduced, the consumer ends up at the point *F* and attains the higher utility level U_2. The equivalent amount of old goods that attains the utility level U_2 is *OD*, so the consumer ends up with the net gain (in terms of old goods) of *CD* due to the introduction of the new commodity. However, note that if the fixed costs were large enough, then it can easily happen that the point *D* lies to the left of *C*, indicating that from the welfare point of view, it was a mistake to introduce the new commodity. This is basically the analysis presented in Romer (1994, 12-14).[6]

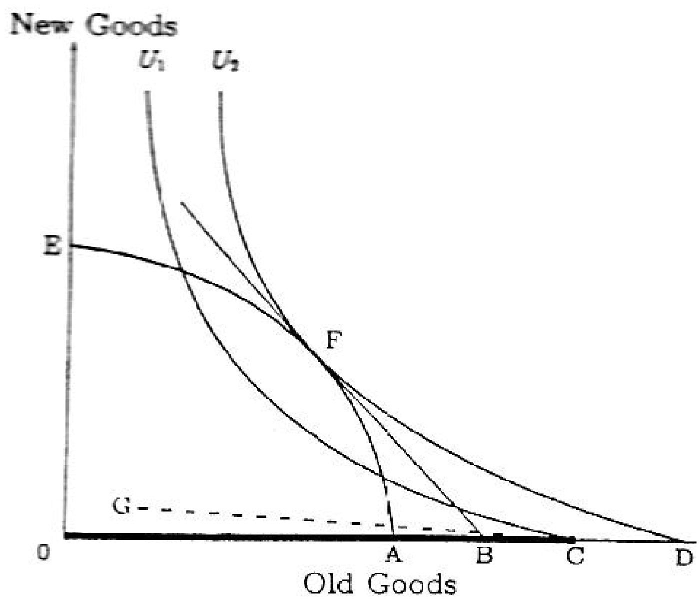

FIGURE 2 Fixed costs and the introduction of new goods

A measurement error occurs because of the way statistical agencies deal with new commodities. Consider the introduction of a new model of an existing good, which is an improvement over the older version. Eventually the statistical agency will place a price ratio for the new good into the relevant elementary price index. However, the decline in 'absolute price' going from the old to new variety (i.e., the fall in the price of quality) is never captured by this price index. This 'quality adjustment' or 'linking' bias has been commented on by Griliches (1979), Gordon (1981, 1990, 1993), Diewert (1996) and many others.

In terms of figure 2, linking bias will lead the statistical agency to estimate the amount of old goods that is equivalent to the utility level associated with the point *F* to be *OB* instead of the true amount *OD*. The only way the bias *BD* will be reduced to zero is if the consumer's indifference curve through *F* is the straight line *FB* instead of the curved line *FD*.

As already noted, standard accounting practices will recognize the costs of introducing new products. Now we see that *existing statistical agency practices ensure that the benefits of new products are biased downwards* by the amount of curvature in consumers' indifference curves. This leads to the underestimation of productivity gains.

Hicks (1940, 114) proposed a theoretical solution to the problem of measuring the benefits of new products: if we could estimate the slope of the (dashed) line that is just tangent to the indifference curve that passes through the consumer's initial consumption point *C*, then a shadow or reservation price for the new good could be constructed for the new commodity in the period prior to its introduction and then normal index number theory could be applied.[7] Of course, the problem facing a statistical agency is how can it produce estimated reservation prices on a large scale and on a timely basis.[8]

In order for the introduction of new goods to help explain the productivity paradox, we need new products to be introduced into the market at a faster rate after 1973 than in the prior period. Comprehensive information on new consumer products does not exist to our knowledge; all we can do is cite a few scattered statistics to support our belief that the pace of new product introductions has indeed increased in OECD countries. From Baily and Gordon (1988, 413) and Leonard Nakamura (1997b, 22), the number of items stocked in the average U.S. grocery supermarket has grown from 2,200 in 1948 to 9,000 in 1972 and to 19,612 in 1994. According to Nakamura (1997b, 22), the number of new product introductions to supermarkets in the U.S. has grown from 1,281 in 1964, to 1,831 in 1975, and to 16,790 in 1992. Diewert and Smith (1994, 346) reported that the number of standard chemical products that were carried by a leading U.S. chemical supply company that were available for immediate delivery rose from 16,000 products in 1984 and 27,000 products in 1990.

The increase in the number of commodities available to the consumer is not limited to traditional goods such as foods: airline deregulation has increased the number of direct connecting flights in Canada; the number of financial products (such as options and mutual funds) has increased substantially in recent years; gambling products have grown from virtually nothing 25 years ago in Canada to an 18.7 billion dollar industry today; specialty bookstores with tens of thousands of titles have made their appearance; microbreweries and the reduction of trade barriers have increased the beer choice set; etc. The single most important recent development that has dramatically increased choice sets is internet access. For example, one quarter of Canadian and American adults can now globally search for the lowest price on the internet for a vast array of goods including computers, autos and homes. At present, only 15% of internet users have actually purchased anything on the internet but this percentage will surely increase over time. The internet is certain to revolutionize the selling of goods and services; retail margins will drop and effective consumer choice sets will increase dramatically.

Finally, Mr. William Hawkes of the A.C. Nielsen Company has stated that the number of universal product codes that his company distinguishes in the U.S. has grown from 950,000 in 1990 to 1,650,000 in 1995. Part of this growth is due to market penetration (i.e., more manufacturers are choosing to have their existing products coded) but a large part of it is due to the growth in new products.

It seems likely that the number of new products available to the average consumer has expanded more rapidly in the last 25 years than in previous years.[9] As we noted above, the fixed costs of developing, making, storing and selling each new commodity will tend to drag down measured productivity growth[10] because the costs of new product development are generally measured by the statistical system but the benefits of an increased choice set are not. It appears that instead of demanding more from a fixed menu of available commodities, consumers are demanding smaller portions from an expanding menu of consumption possibilities. This necessarily leads to lower measured productivity growth due to the above mentioned fixed costs.[11]

Some economists such as Diewert (1996), Leonard Nakamura (1997a,b) and Boskin et al. (1996) think that the new goods problem is very significant. Others such as Klumpner (1996), Triplett (1997), and Nordhaus (1988) are more skeptical.[12] The proliferation of commodities may help to explain a gradual measured productivity slowdown over the past 25 years, corresponding to a gradual increase in the number of commodities available to consumers, but the post-1973 productivity growth decline that was documented in section 2 was too abrupt for this explanation to work. Thus we agree with Triplett (1997, 39) that the "slowdown (in the U.S.) is too abrupt, and too large, to have been a statistical illusion created by changes in the way quality change is handled in the CPI."

4. Business expenses or consumption expenditures?

> "Between 1978 and 1988, for example, CPI-adjusted expenditure data show per capita consumption of fresh vegetables falling by 15.2 percent and by 2.4 percent for fresh fruits. Those indicators conflict sharply with retailer perceptions as well as with USDA disappearance data, which show a 25-percent increase in that period.

> ... Clearly, something is wrong if the alternative methods give such sharply different conclusions."
>
> James M. MacDonald (1995, 28)

The above quotation indicates that U.S. CPI deflated per capita food expenditures declined between 1978 and 1988 while U.S. Department of Agriculture production based estimates of per capita food consumption increased. These conflicting statistics could be reconciled by the following hypothesis:[13] due to the growth in self employment, business services and general white collar employment, increasing expenditures that were earlier regarded as consumption are being classified as business intermediate expenditures and hence, as Triplett (1997, 9) observed, these former consumption expenditures would not show up as part of GDP. This has the effect of lowering measured productivity growth. 'Business' travel and entertainment expenses, along with company gyms, daycare centers, cars and home loans are examples of former consumption expenditures which would not show up in final aggregate GDP. Additional examples of final demand expenditures that are misclassified as business intermediate expenditures include pollution control and environmental preservation expenditures[14] and improvements in workplace safety and amenities.[15]

However, the magnitude and extent as well as the abruptness of the productivity growth collapse after 1973 cannot be accounted for by the increasing misclassification of final demand as intermediate business expenditures.

5. The mismeasurement of outputs in service industries

Baily and Gordon (1988, 392-417) discussed the problems involved in measuring the outputs of various U.S. service industries. For the most part, these problems remain with us. Our brief overview of these is organized under four headings:

(1) *The treatment of margins*. As noted by Baily and Gordon (1988, 360), to find the real output of a firm or industry requires deflating the values of both the outputs and the intermediate inputs (i.e., those purchased from other producers). For an industry that sells a commodity (e.g., wholesale trade, retail trade or the banking industry which basically sells depositors' dollars at a higher price), the nominal contribution to output is sales less purchases, which is equal to a margin (a difference between the selling and purchasing prices) times the quantity sold. The real output of such a trading industry is the quantity sold and the corresponding price is the average margin. However, statistical agencies do not usually collect enough data to determine margins or quantities sold except in sporadic census years; usually, only sales information is collected.[16] Thus estimates of both nominal and real output for trading industries will be biased downwards in a period when technological improvements (like the internet) are reducing margins and selling prices.

(2) *The treatment of interest*. National income accounting follows financial accounting in treating interest as a distribution from profits or operating surplus rather than as a cost of production.[17] This leads to intuitively unappealing measures of output in industries where interest earnings are important, such as banking and insurance. See Bernstein (1997), Fixler and Hancock (1997), Fixler and Zieschang (1997) and Sciadas (1997).

(3) *The treatment of risk*. The existing literature is virtually silent on the complex issues involved in measuring outputs in industries where the products are uncertain such as in insurance (Denny 1980, Hornstein and Prescott 1991, Diewert 1995), gambling (Diewert 1995) and options trading.

(4) *The measurement of complex multiproduct industries*. There are many service industries where the vast number and complexity of outputs hampers accurate measurement. Examples include the medical, business, recreational and sports, educational and telecommunications service industries. For instance, statistical agencies have not taken into account many of the new services and discount plans that telcos are now offering, so the real output of the telecommunications industry is probably larger than what is being measured. Unfortunately, statistical agencies have not had the resources to deal more adequately with the problems involved in measuring service outputs.[18]

The measurement problems mentioned in this section, like those considered in previous sections, could certainly account for a gradual slowdown in measured productivity growth but cannot account for the sudden and simultaneous downturn of productivity growth in virtually all OECD countries after 1973. Thus, in the next two sections we consider further explanations which might explain the observed collapse.

6. High inflation, historical cost accounting and taxes

Figure 3 plots the output price series for each country that correspond to the output quantity series used to calculate the productivity growth estimates of section 2. When looking at figure 3, it is striking how inflation increased in OECD economies after 1973. The bolder lines for Canada and Japan are illustrative of the experience of most countries. (Greece is the country whose inflation remains relatively high.) By referring to table 1 in section 2, we see that this sudden rise in output prices corresponded with the sharp fall in productivity growth for these countries. Early accountants such as Bauer (1919, 413) and Paton (1920, 3) were aware that historical cost income accounting was biased upwards during inflationary conditions and hence was unsuitable as a basis for the taxation of business income. Unfortunately, the defects in the historical cost income concept have never been corrected in OECD economies. Thus in this section, we shall indicate how high inflation interacts with the current system of business income taxation in a way that reduces the productivity of an economy.

Consider an equity financed firm that purchases a durable input at the beginning of period 1 at the price *P*. If this asset has been produced by another firm, then the relevant tax authority will generally not allow the purchasing firm

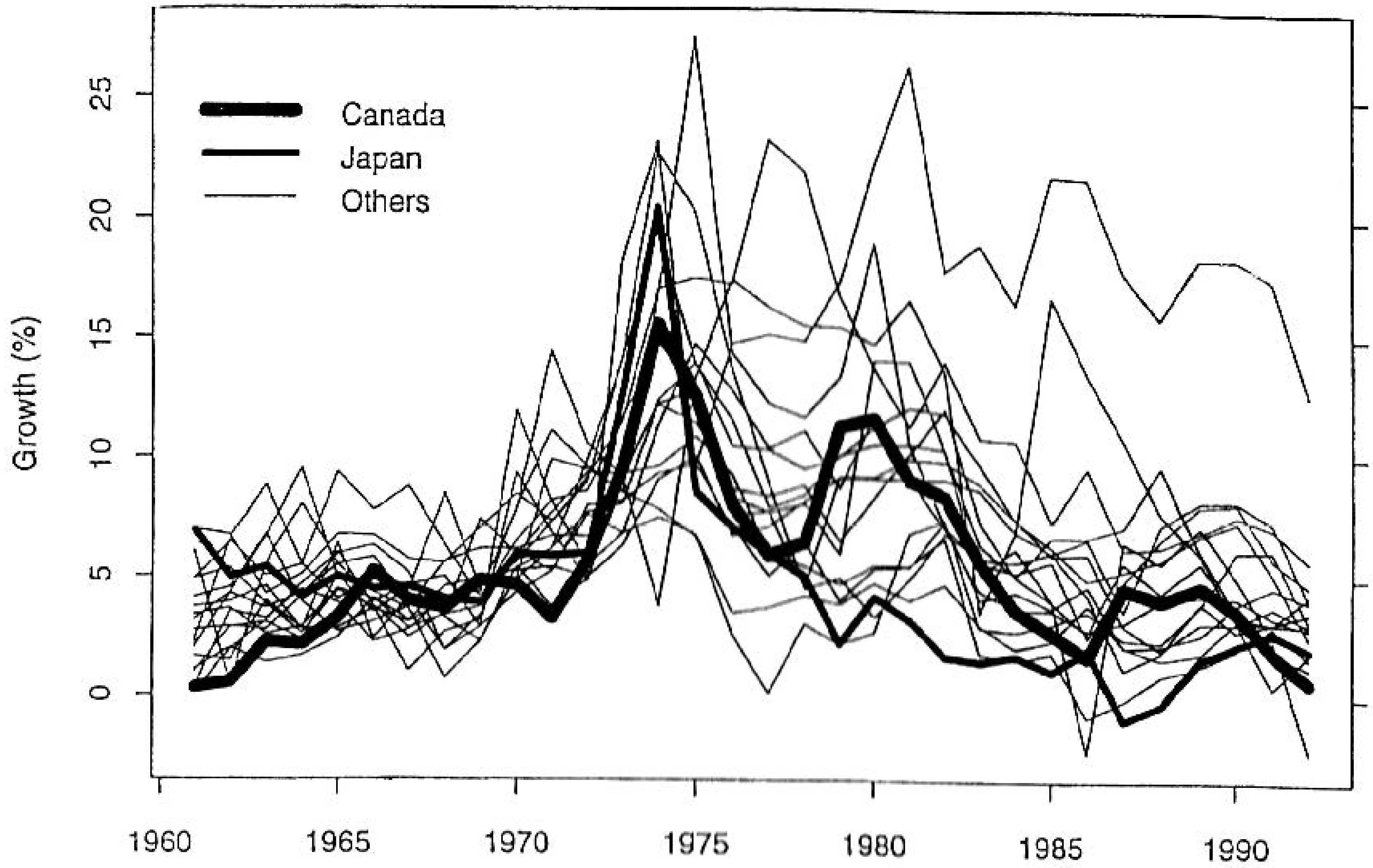

FIGURE 3 Output price growth rates

to immediately deduct P from its period 1 taxable income. Instead, the tax authority gives the firm a sequence of depreciation allowances, say D_t in period t, which sum up to the initial purchase price of the asset; i.e., we have

$$P = D_1 + D_2 + ... + D_T. \tag{3}$$

Thus the purchasing firm will be allowed to deduct only D_1 from its taxable income in period 1, D_2 in period 2, etc. The problem with this procedure is that a deduction from income that is received in the future is not as valuable as a deduction that is received immediately. Hence the beginning of period 1 value V of the sequence of depreciation deductions will be:

$$V \equiv (1 + r_1)^{-1} D_1 + (1 + r_1)^{-1}(l + r_2)^{-1}D_2 + ... + (1 + r_1)^{-1}...(1 + r_T)^{-1}D_T < P \tag{4}$$

where the inequality follows from (3) and the assumption that the firm's period t opportunity cost of capital (or interest rate) r_t is positive for periods $t = 1, 2, ..., T$. The fact that the purchase price P is greater than the present value of the depreciation deductions V means that the firm's discounted sequence of taxable incomes will be overstated by the amount $P - V$.[19] If the rate of business income taxation is the fraction ô, then this overstatement of taxable income will lead to an immediate tax liability of ô$(P - V)$ and in order to stay in business, the firm will have to charge higher prices for its outputs to recover these excess tax payments. However, in raising its output prices, the firm will further increase taxable income, leading to further tax payments. Thus when the firm purchases the durable input, in order to balance out the additional tax liabilities that will be associated with this purchase, the firm will have to charge itself an internal price P_I that will cover the purchase cost P and the final tax liability ô$[P_I - V]$. Thus P_I is determined as the solution to the following equation:

$$P_I = P + \hat{o}[P_I - V]. \tag{5}$$

Solving (5) for P_I yields:

$$P_I \equiv P + (1 - \hat{o})^{-1} \hat{o}[P - V] > P \tag{6}$$

where the inequality in (6) follows from $0 < \hat{o} < 1$ and (4).

In order to analyze the factors that make the gap between the internal price P_1 and the purchase price P larger, we assume straight line depreciation so that each depreciation deduction is the same; i.e.,

$$D_1 = D_2 = ..., D_T. \tag{7}$$

We further assume that the nominal interest rates r_t are all equal to a common r. Under these assumptions, we have

$$P = TD_1; \tag{8}$$

$$P_I/P = 1 + (1 - \hat{o})^{-1} \hat{o}[1 - \{1 - (1 + r)^{-T}\}]/rT^1. \tag{9}$$

Assuming that the rate of business income taxation is ô = .5, values of P_1/P may be found in table 3 for various asset lives T ranging from 1 year to 40 years and for various interest rates.

From table 3, it can be seen that the gap between the tax distorted internal asset cost P_I and the selling price P of the asset increases as the asset life T increases and as the nominal interest rate r increases. This is where inflation plays a role: as inflation increases, nominal interest rates also increase (in an approximately additive manner). As inflation increased after 1973, the gap between the price received by the producer of the durable input, P, and the effective cost P_I of using the asset for the purchaser increased dramatically. This difference in prices for producers and users of durable inputs caused by the tax system leads to a loss of productive efficiency for the economy as a whole.

TABLE 3
Tax distorted asset values relative to purchase prices

		P_1/P		
T	r=.03	r=.06	r=.09	r=.20
1	1.029	1.057	1.083	1.167
2	1.043	1.083	1.120	1.236
3	1.057	1.109	1.156	1.298
5	1.084	1.158	1.222	1.402
10	1.147	1.264	1.358	1.581
15	1.204	1.353	1.463	1.688
20	1.256	1.427	1.544	1.757
30	1.347	1.541	1.658	1.834
40	1.422	1.624	1.731	1.875

To see why this loss of efficiency occurs, consider a simple two sector model of the economy where the first sector produces goods for final demand and the second produces an intermediate investment good used by the first sector.

Suppose the first industry uses variable resources L, ('labour', say) and an intermediate input I that is produced by the second industry. The technology for the first sector is summarized by the production function F where

$$Y = F(L_1, I) \tag{10}$$

denotes the maximum amount of output Y that industry 1 can produce given that it is using L_1 units of variable resources and I units of the intermediate input.

The second sector produces units of the intermediate good using L_2 units of the variable resource. We choose units of measurement for I so that output is measured in terms of units of input used. Thus the production function for the second sector is

$$I = L_2. \tag{11}$$

There is an aggregate resource constraint on the use of the variable input across the two sectors. If L denotes the aggregate resource availability, we have the following constraint:

$$L_1 + L_2 = L. \tag{12}$$

In order to determine the optimal allocation of resources in this highly simplified economy, we substitute equations (11) and (12) into the sector 1 production function F and maximize with respect to L_1; i.e., we then need only solve the following unconstrained maximization problem:

$$\max_{L_1} F(L_1, L - L_1). \tag{13}$$

Let L_1^* denote the solution to (11), define the optimal intermediate good production by $I^* = L - L_1^* = L_2^*$ and define the optimal final output as $Y^* = F(L_1^*, I^*)$. This optimal solution is illustrated in figure 4. The straight line in figure 4 corresponds to the variable resource allocation line (12) and the curved line which is tangent to this straight line corresponds to the highest level of output Y^* that can be produced by available resources.

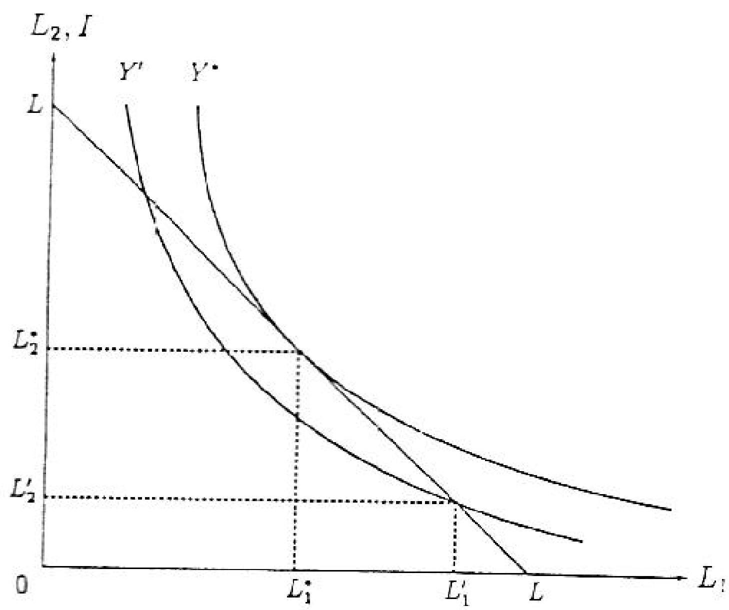

FIGURE 4

Now suppose the government taxes the output of the intermediate good sector at the tax rate t. This will cause sector 1 to economize on its utilization of the intermediate good; its demand for I will drop from L_2^* to L_2' and the output of sector 1 will drop from Y^* to Y'. This new lower level of output is determined as follows: we start at (L_1^*, L_2^*) and travel down the line LL until we hit the isoquant that has slope equal to $-1/(1 + t)$.

Figure 4 illustrates what happens when the government taxes the output of one sector that is used as an input by another sector: the imposition of this tax wedge causes an overall loss of productive efficiency. This means that this tax policy is effectively destroying output.

An analytic approximation to the loss of output $Y^* - Y'$ can be obtained if we use duality theory. Assume that the sector 1 production function F exhibits constant returns to scale and define the unit cost function c that is dual to F by $c(w, p) \equiv \min_{L_1, I}\{wL_1 + pI: F(L_1, I) = 1\}$ where w is the wage rate and p is the price of the intermediate input. In our present model, $p = (1 + t)w$. Letting c_1 and c_2 denote the partial derivatives of $c(w, p)$ with respect to w and p, respectively, the equilibrium level of output $Y(t)$ which can be represented as a function of the tax distortion t can be regarded as the solution to the following equation, where we have set $w = 1$:

$$[c_1(1, 1 + t) + c_2(1, 1 + t)]Y(t) = L. \quad (14)$$

Differentiating (14) with respect to t and making use of the identities $c_{12}(1, 1 + t) = c_{21}(1, 1 + t)$ and $c_{21}(1, 1 + t) + c_{22}(1, 1 + t)(1 + t) = 0$ leads to the formulae:

$$Y'(0) = 0 \quad (15)$$

$$Y''(0) = c_{22}(1, 1)Y^2/L = -\varepsilon I(0)Y(0)/L \quad (16)$$

where $\varepsilon \geq 0$ is the negative of the own price elasticity of demand for intermediate inputs by sector 1 evaluated at the undistorted equilibrium. A second order approximation to the loss of output generated by an intermediate good tax of size t expressed as a fraction of the optimal output $Y(0) = Y^*$ is given by:

$$[Y(0) - Y(t)]/Y(0) = (½)t^2 \varepsilon s_I/s_L \quad (17)$$

where $s_I \equiv I(0)/Y(0)$ is the (optimal) intermediate goods share of output and $s_L \equiv L/Y(0)$ is the (optimal) variable inputs share of output.

The numbers $[P_I/P] - 1$ in table 3 can be regarded as distortion wedges t that could be substituted into formula (17) to obtain approximate measures of the loss of output due to the lack of indexation of depreciation allowances. Assuming that the average asset life T is 20 years, that the elasticity of demand for investment goods ε is unity, that the share of variable resources S_L in national output is unity and that the investment share of output s_I is 10%, leads to the approximate deadweight losses as a function of the nominal interest rate r in table 4.

Table 4 shows that when the nominal interest rate is low ($r = .03$), the tax induced loss of output is only a third of a percent per year in our highly simplified model. However, if inflation increases and nominal interest rates are driven up to 20% (r = .20), then the approximate tax induced loss of output becomes a whopping 2.87%. Thus the range of losses in table 4 is of an order of magnitude that can help explain the sudden world wide drop in productivity growth in the post-1973 era when interest rates shot up. However, as inflation and interest rates have fallen in recent years, the above model predicts a productivity growth recovery, which does not seem to have occurred. This is where the other more gradual mismeasurement effects discussed in sections 3 to 5 play a role in explaining continuing poor productivity performance.

TABLE 4
Loss of output for equity financed investment

r	0	.03	.06	.09	.20
Loss	0	.33%	.91%	1.48%	2.87%

The above model assumes that all investments are financed by equity capital and that equity returns to capital are discriminated against relative to interest, which is deductible as an expense in typical definitions of taxable income. However, even if firms purchasing durable inputs finance their purchases by debt, similar losses of efficiency occur due to the taxation of interest income.

Suppose initially that interest is not taxed. Then it can be shown that the depreciation allowances system of taxation is equivalent to immediate expensing. To see this, suppose that the firm financed the initial asset purchases by issuing debt and that it retired D_t of this debt at the end of period t for t = 1, 2, ..., T: i.e., the firm retired its debt for financing the asset according to the officially sanctioned sequence of depreciation allowances D_t. The present value of its sequence of debt retirement payments and the associated interest costs is:

$$\begin{aligned}
&(1 + r)^{-1} [D_1 + r(D_1 + D_2 + ... + D_T)] + \\
&(1 + r)^{-2} [D_2 + r(D_2 + D_3 + ... + D_T)] + ... + (1 + {}_r)^{-T}[D_T + rD_T] \\
&\qquad = (1 + r)^{-1}(1 + r)D_1 + (1 + r)^{-1}rD_2 + (1 + r)^{-2}(1 + {}_r)D_2 + ... \quad (18)\\
&\qquad = D_1 + (1 + r)^{-1}rD_2 + (1 + r)^{-1}D_2 + ... \\
&\qquad = D_1 + D_2 + ... + D_T \\
&\qquad = P.
\end{aligned}$$

Thus, by financing the asset cost by issuing debt and then retiring the debt in accordance with the tax schedule of depreciation allowances for the asset, the firm can achieve the same result as would be achieved by immediate expensing of the asset.

The above equivalence does not carry over when interest is taxed. To see why this is so, consider the case of a small open economy where the opportunity cost of capital is determined by foreign lenders and they demand the real rate of return ñ. If the home country's domestic inflation rate is i, then foreign lenders will demand a yearly rate of return r which is defined by:

$$1 + r = (1 + \text{ñ})(1 + i). \tag{19}$$

If nominal interest is taxed at the rate ô, then the before tax nominal interest rate R is defined by $(1 + \text{ô})R = r$; i.e.,

$$R \equiv (1 + \text{ô})^{-1}r. \tag{20}$$

We assume that the purchaser of the asset finances the purchase by issuing bonds and retires the debt according to the official sequence of depreciation deductions. Using the nominal after tax return that foreign investors demand to do the discounting, the present value of the firm's debt retirement charges and interest payments under the current system of business income taxation will be:

$$\begin{aligned} \text{V} \equiv\ & (1 + r)^{-1}[D_1 + R(D_1 + D_2 + \ldots + D_T)] + \\ & (\text{l} + r)^{-2}[D_2 + R(D_2 + D_3 + \ldots + D_r)] + \ldots + (\text{l} + r)^{-\text{T}}[D_T + RD_T] \\ & > P \end{aligned} \tag{21}$$

where the above inequality follows by comparing the first line of (18) with the first line of (21) and using the inequality $R > r$. Thus, when interest is taxed, the purchasing firm will again have to charge itself a higher effective price V for the use of a durable input than its actual purchase price P.

Note that we have used the after tax interest rate to do the discounting in (21). A small open economy can trade freely with the rest of the world using foreign prices for imports and exports. The imposition of tariffs on imports leads to a loss of productive efficiency for a small open economy. In a similar manner, the taxation of interest leads to a loss of intertemporal productive efficiency for a small open capital importing or exporting economy.[20]

In order to calculate V/P under various assumptions about ñ and i, we make the simplifying assumption of straight line depreciation; i.e., we assume (7) again. Using (7) and (21) and defining $\text{á} \equiv 1/(1 + r)$, V/D_1 becomes:

$$\begin{aligned} V/D_1 &= \text{á} + \text{á}^2 + \ldots + \text{á}^T + R[\text{á}^T + \text{á}^2(T - 1) + \ldots + \text{á}^T(1)] \\ &= \text{á}(1 - \text{á}^T)(1 - \text{á})^{-1} + \text{á}R(1 - \text{á})^{-1}[(1 - \text{á}^T) + (1 - \text{á}^{T-1}) + \ldots + (1 - \text{á})] \\ &= (\text{á}(\text{l} - \text{á}^T)(\text{l} - \text{á})^{-1} + \text{á}R(1 - \text{á})^{-1}[\text{T} - \text{á}(1 - \text{á})^{-1}(1 - \text{á}^T)] \\ &= (R/r)T + r^{-1}[1 - (1 + r)^{-T}][\text{l} - (R/r)]. \end{aligned} \tag{22}$$

Using (22) and (8), we obtain the following formula for V/P:

$$V/P = (R/r) - T^{-1}r^{-1}[\text{l} - (1 + r)^{-T}][(R/r) - 1]. \tag{23}$$

We now assume that the domestic tax rate is 36% ($r = 0.36$), the foreign real rate of return is 5% (ñ = 0.05) and the domestic inflation rate i is alternatively, 0%, 3% and 9%. The corresponding values of V/P (the tax distorted cost of a depreciable asset relative to its undistorted cost) for various asset lives ranging from 1 year to 40 years may be found in table 5.

For very long lived assets, the distortion due to the taxation of nominal interest is severe no matter what the rate of inflation. However, for short-lived assets, the degree of distortion increases dramatically as domestic inflation increases. The $i = 0$ column will be approximately equal to the degree of distortion that would be obtained if the tax system were indexed for inflation.

The results in table 5 may help to explain why heavy industry has migrated away from industrial countries that have high rates of business income taxation.

TABLE 5
Tax distorted asset values relative to expenditures tax values

		V/P	
T	i = 0	i =0.03	i=0.09
1	1.027	1.042	1.071
2	1.040	1.062	1.102
3	1.052	1.081	1.130
5	1.075	1.115	1.180
10	1.128	1.188	1.272
15	1.173	1.244	1.337
20	1.212	1.289	1.381
30	1.274	1.354	1.435
40	1.321	1.397	1.466

The methodology for computing the loss of productive efficiency that was explained earlier can be applied in the present context. If inflation is three per cent and the average depreciable asset is depreciated over 20 years, then from table 5, $V/P = 1.289 \equiv 1 + t$ and the economy-wide loss of productive efficiency is approximately $(½)(0.289)^2\varepsilon s_I/s_L = .4\%$ if $\varepsilon = 1$, $s_I = .1$ and $s_L = 1$. If inflation increases to 9%, then under the same other assumptions, the approximate deadweight loss is $(½)(.381)^2(1)(.1)/1 = .7\%$.

Comparing the debt financed model with the equity financed model, we see that the double taxation of equity capital under conditions of high inflation leads to a large productivity growth drop in our highly simplified model whereas the taxation of (deductible) nominal interest does not lead to such a disastrous drop.

Of course, the models presented in this section are too simplified to provide accurate estimates of the effects of inflation and an imperfectly indexed tax system on productivity: we simply want to make a case that these effects could be very significant.[21]

We turn now to another mechanism by which inflation can generate significant losses in productive efficiency.

7. High inflation and cost accounting

> "Only ten per cent of our manufacturers and merchants know the actual cost to manufacture and sell their products; 40 per cent estimate what their costs are, and 50 per cent have no method, but price their goods arbitrarily. Most of the

manufacturers and merchants who do not know what their goods cost are basing their selling price on what their competitors sell for, and with only this knowledge for a basis they are frequently cutting prices and demoralizing the industry in which they are engaged."

Edward N. Hurley, quoted in Porter (1916, 325)

The above quotation indicates that historically, it was not an easy matter for a multiproduct firm to figure out its costs by commodity produced. The cost allocation problem is still with us today and is made worse by high inflation.

The cost allocation problem is important because if firms sell their products at prices that differ substantially from long run costs, then substantial resource misallocation in the economy as a whole will occur. The distortions t_i in this case are now the differences between long run costs and selling prices. As in the previous section, it is likely that inflation substantially increases errors in costing. To see why this is, we briefly consider the history of cost accounting.

The current method of cost accounting has its roots in the first book on factory accounting by Garcke and Fells (1893, 70-71). They explained how the cost of an article is equal to its primary labour and materials cost plus an allocation of factory indirect expenses (such as the wages of supervisors and clerks, rent, fuel, lighting, heating, cleaning, office supplies and depreciation). Garcke and Fells (1893, 71) suggested that these indirect expenses could then be distributed over products in a proportional manner using either (i) direct labour or (ii) direct labour plus materials as the allocator. This primitive method of cost allocation has persisted down to the present day.[22]

There are a number of problems with the above methods of cost allocation: (i) indirect expenses are not accurately allocated to products (Whitmore 1906, 252); (ii) interest charges on the use of capital equipment are specifically excluded from costs and (iii) depreciation charges are not indexed for inflation.

We have noted earlier the reluctance of national income accountants to include interest as a cost; this also seems to date back to the pioneering work of Garcke and Fells (1893, 73), who felt that the interest on capital should not form part of the cost of production as it does not vary proportionately with the volume of business.

Although a few accountants (e.g. Whitmore 1906 and Scovell 1914) followed engineering practice and advocated the inclusion of interest in cost, the majority (see e.g. Dickinson 1913) followed the example of Garcke and Fells and omitted interest.[23] During periods of rapid inflation, nominal interest rates increase and the neglect of interest as a cost will lead to increasing errors in pricing.

Almost 100 years ago, the engineer A. Hamilton Church (1901, 1902) laid out a comprehensive theory of cost allocation that would be useful even today. The essence of Church's method was to regard each machine and the area around it as a profit center or 'little shop':

"No sophistry is needed to assume that these charges are in the nature of such rents,

> for it might easily happen that in a certain building a number of separate little shops were established, each containing one machine, all making some particular part or working on some particular operation of the same class of goods, but each shop occupied, not by a wage earner, but by an independent mechanic, who rented his space, power, and machinery, and sold the finished product to the lessor. Now, in such a case, what would be the shop charges of these mechanics? Clearly they would comprise as their chief if not their only item, just the rent paid. And this rent would be made up of: (1) interest, (2) depreciation, (3) insurance, (4) profit on the capital involved in the building, machine, and power-transmitting and generating plant. There would also most probably be a separate charge for power according to the quantity consumed.
>
> Exclude the item of profit, which is not included in the case of shop charge, and we find that we have approached most closely to the new plan of reducing any shop into its constituent production centres. No one would pretend that there was any insuperable difficulty involved in fixing a just rent for little shops let out on this plan."
>
> A. Hamilton Church (1901, 907-908)

Church's method was too data intensive to be successfully implemented when it was proposed[24] and, although a few accountants like Whitmore (1906) endorsed it, the method was soon forgotten. Of course, Church's method is based on a user cost treatment of capital and so it is constantly being rediscovered in the management literature; see Craig and Harris (1973, 19).

It should be noted that historical cost accounting also contributes to the misallocation of resources on capital markets during periods of high inflation in the sense that historical cost rates of return become meaningless. Edwards, Kay and Meyer (1987, 94) table average rates of return for 160 UK companies during the years 1966-1981 using various income concepts. The average historical cost rate of return was an overstated 14.8% compared to their preferred alternative real terms average rate of return of 5.3%. For the high inflation years 1974-1981, the average historical cost rate of return was 17.3% compared to the average real terms rate of return of 3.3%. Real terms accounting is equivalent to Sweeney's (1935, 1964) stabilized accounting.

Sweeney (1964, xxxvii) states that the "accounting profession itself is doubtless principally to blame for the failure of stabilized accounting to be generally adopted ...." He goes on to also attribute blame to business managers who are more interested in "letting stockholders see profits that merely look large and then benefitting themselves from the resulting higher salaries, better stock options, and profitable stock sales." Government is accused of allowing currency to lose purchasing power, while meanwhile hauling in "the excessive income taxes that thereby unevenly and unjustly fall upon taxpayers with large depreciable assets and with high net money-value assets."

We summarize the thrust of our argument in this section as follows: management cost accounting has failed to adapt a system of cost allocation that was well suited to a time when the capital-labour ratio was much smaller. As a result, in periods of rapid inflation, accounting costs are not accurate (due to an inadequate treatment of interest and depreciation) and this leads to mistakes in pricing products (Miller 1984, 153; Port, King and Hampton 1988, 105-108) and a resulting loss of efficiency in the economy as a whole.

8. Conclusion

Can measurement error explain the productivity paradox? Our answer is yes, although the measurement errors are of three different types.

The first type of measurement error is due to the lack of adjustment for the effects of inflation that is inherent in the financial accountant's definition of business income. The effects of this measurement error were discussed in section 7. This error could be eliminated by action on the part of the government (tax reform) or by action on the part of the accounting profession (a movement to real terms or stabilized accounting). Unfortunately, the chances of reform seem slim.

The second type of measurement error is due to the failure of traditional cost accounting to deal adequately with the cost allocation problem; the pricing of the services of durable inputs is particularly inadequate during periods of high inflation. This type of measurement error was discussed in section 6. As management accountants rediscover the cost allocation techniques pioneered by Church (1901, 1902), the loss of productive efficiency due to inappropriate cost allocation and pricing decisions should diminish.

The third type of measurement error discussed in this paper is simple mismeasurement of inputs and outputs by statistical agencies. These kinds of error were discussed in sections 3 to 5. They can be cured if measurement issues assume a higher public profile and statistical agencies are given more resources.

Our overall hypothesis is that the first two types of measurement error contributed to the productivity growth collapse after inflation increased dramatically in the 1970s and that a productivity growth recovery dating back to the mid 1980s has been obscured by the type three measurement errors.

Notes

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1 Early industrial engineers realized that the choice of how to deal with development expenses between the two accounting categories was somewhat arbitrary due to the uncertainty about how many units of the new commodity would actually be sold (and at what price) in future periods; see Arnold (1900, 367) and Miller (1909, 827).

2 Suppose the sales of a single product firm expanded fourfold going from period 0 to *t*. Then the associated inventory fixed costs would double. Now consider a second scenario where the firm introduced three new products at the end of period 0 and by period *t* the sales of each new product equaled the (constant) sales of the old product. In each situation, total sales increased fourfold but the fixed costs in the second case

are double the fixed costs of the first case at the end of period *t*.

3 Edgeworth (1898, 124) considered the inventory stocking problem faced by a restaurant or club and noted that optimal inventory stocks are proportional to the square root of anticipated demands: "Suppose now the number of members in the club to be doubled or trebled, while their habits are unaltered. At first sight it might appear that the reserve of provisions which the manager requires should increase proportionately. But the corrected theory is that the ratio of the new reserve to the old should not be two or three but the *square root* of two or three."
4 Most economists are unaware of the difficulties involved in allocating costs. For a readable introduction to these problems, see Church (1901, 1902) and Emerson (1908, 1909). These two industrial engineers were pioneers in the development of cost accounting. However, the first person to realize the importance of the cost allocation problem was the mathematician and inventor Charles Babbage (1835, 203).
5 The early industrial engineering literature recognized these uncertainty costs. See for example Lewis (1901, 712) and Miller (1909, 825).
6 Many other economists have presented the main idea in Romer's analysis but without the nice diagrams, e.g., Nordhaus (1988, 423).
7 See Diewert (1980, 498-501) (1987, 779) for an adaptation of Hicks' basic idea to superlative index numbers.
8 Diewert (1980, 501-503) suggested an econometric approach to the estimation of these shadow prices and Hausman (1996) actually implemented one for breakfast cereals using scanner data. Hausman maintains that it would be simple for statistical agencies to implement an effective estimation of shadow prices procedure but we are not convinced of this argument.
9 The reduction in trade barriers and the resulting expansion of international trade has also contributed to the expansion in consumer choice sets.
10 Early industrial engineers were well aware of the cost advantages of a small specialized product line, e.g., Browne (1899, 35, 37) and Roland (1899, 48-50). Lewis (1899, 365) attributed the relative decline of British engineering manufacturing to the tendency of American and German competitors to specialize their production.
11 However, as Diewert and Smith (1994, 346) observed, computers have helped to limit the adverse productivity effects of a rapidly increasing choice set, since in the U.S. at least the ratio of real inventories to real sales has remained approximately constant during the past 40 years according to Blinder and Maccini (1991, 75). Without computerized inventory control, the inventory to sales ratio would have risen.
12 "To assess the expanding choice, I went to the local grocery store. I found that about 5 percent of the shelves were devoted to cereals, including dozens of brands such as Freakies, Mueslix, Twinkies, Kix, Kasli, Total, Life and Just Right. You might ask yourself how much your net economic welfare would decrease if the number of cereals were reduced by half" (Nordhaus 1988, 423). Hausman's (1996) research indicates that increases in varieties of cereals is quite significant from the welfare point of view. We also note that Nordhaus' own study of linking biases in the measurement of consumer light services showed that they were enormous; see Nordhaus (1996).
13 It is more likely that the conflicting statistics can be explained by the post-1978 bias in BLS CPI components that was discovered by Reinsdorf (1993).
14 This factor has been advanced as a partial explanation of the productivity slowdown

(contributing 0.2% to 0.5% per year to the slowdown) by many researchers including McConnell (1979, 44), Malkiel (1979, 83-84), Nordhaus (1982, 138), Mairesse (1982, 161) and Baily and Gordon (1988, 362).

15 This factor has also been advanced as a partial explanation of the productivity slowdown by Summers (1982, 167) and Baily and Gordon (1988, 409).

16 "Data on both Wholesale and Retail trade are not fully complete for Input-Output needs. Sales, cost of sales, revenue from subsidiary activity and some input data by kind-of-business are available for the Census year, the last one being in 1971 ... The Wholesale Trade survey is an establishment based survey covering only Wholesale Merchants and collects data on sales and stocks. The Retail Trade survey is a location based survey and collects data on sales by store type; however, stock figures are derived from separate surveys" (Statistics Canada 1987, 54).

17 "It was noted in Chapter 1 that surplus is a measure before payment of interest and dividends; in other words, interest and dividends are a distribution of earnings rather than a payment for a commodity. This convention gives rise to difficulties when measuring the production of financial intermediaries, particularly banks, where, from the point of view of those institutions, interest income is analogous to operating revenue" (Statistics Canada 1987, 34).

18 For documentation on how Statistics Canada's budget has shrunk in recent years, see Nakamura and Diewert (1996). It should be mentioned that statistical agencies have attempted to overcome their lack of national resources by pooling their efforts in international efforts like the Voorburg Group on Services (initiated by Jacob Ryten of Statistics Canada).

19 We believe that this point was first made by Brown (1948, 305).

20 Put another way, the purchasing firm has to add the increased interest costs due to the taxation of interest to the purchase cost of the asset, since the increased interest costs are associated with the use of the asset. Many OECD countries (e.g., Australia, Canada and New Zealand) have eliminated the double taxation of dividends that was implied by our earlier equity financed model. Thus dividend payments in these countries are now roughly equivalent to interest payments in terms of their tax treatment.

21 Thus we fall into the Jorgenson and Yun (1990) camp, who found significant deadweight losses from the taxation of capital in the U.S. On the other hand, Nordhaus (1982, 145) doubts that inflation could be an important part of the productivity puzzle.

22 Emerson (1908, 1909) introduced standard costs to the cost accounting literature and Harrison (1919) introduced variance analysis. Variance analysis decomposes differences in planned values with actual values into price and quantity components. However, variance analysis is typically applied only to labour and materials costs and not to overhead costs. Whitmore (1931) provides an overview of the early literature.

23 The engineering literature realized long ago the importance of including interest as a cost in determining whether to make or buy a product; see for example Popcke (1912, 863). The reluctance of accountants to regard interest as a cost is somewhat surprising since interest was regarded as a cost in much of the nineteenth century accounting literature; see Solomans (1968, 9-17).

24 Renold (1950, 113) described the failure of the Church system when implemented in his father's factory around the turn of the century.

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