CAPITAL OBSOLESCENCE, GROWTH ACCOUNTING AND TOTAL FACTOR PRODUCTIVITY

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The stability of capital lifespan over time is a key assumption of growth accounting studies. However, many empirical works refute this hypothesis and suggest that the average service-life of capital goods has shown a decrease in the advanced economies since the 1970s. I show in this paper that this acceleration in capital obsolescence could strongly impact on traditional measures of Total Factor Productivity. For instance, a moderate increase in the capital retirement rate since the early 1970s could explain almost all the productivity slowdown observed in the US economy in the period 1974-2000.

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1. Introduction

The growth accounting framework has been used extensively in the economic literature to shed some light on ultimate sources of growth and to estimate trends in productivity. This research programme has contributed greatly to the understanding of the sources of economic development and, more recently, has helped to characterise the nature of the so-called "New Economy". Nevertheless, this stream of research has also raised some productivity paradoxes. For instance, how can the marked and persistent productivity slowdown observed in most industrialised economies since the 1970s be explained? Economist have frequently put forward a mismeasurement hypothesis rooted in the fact that the rapid shift in economic activity toward the service sector since the 1970s made estimates of real output less reliable in advanced economies[1]. Unfortunately, as pointed out by Sichel (1997) and Triplett (2002), this hypothesis has been of limited use in explaining the productivity paradox, at least in the US economy.

This paper suggests a complementary mismeasurement explanation. Unlike previous studies, the focus here is on mismeasurement of inputs rather than outputs. The idea is to examine the results of empirical and theoretical studies that claim that the lifespan of capital goods is not exogenously determined by technological parameters. The retirement of capital goods is an economic decision impacted on by economic variables and market conditions. In this framework, capital retirement varies over time. As Hulten (1990) pointed out, the assumption that retirements are independent of market conditions is one of the most serious problems in capital measurement. However, traditional growth accounting studies estimate Total Factor Productivity (*TFP*) by assuming a constant capital lifetime. The resulting estimates of capital stocks and hence *TFP* growth, are thus biased. The issue here is whether this bias can explain, at least partially, the puzzling *TFP* dynamics. Because reliable estimates of changes in average capital lifetime are not generally available at the macroeconomic level, the research strategy adopted in this paper consists of investigating the potential quantitative impact of different scenarios of evolution of capital lifespan on estimates of aggregate capital stock and *TFP*. Numerical experiments are carried out using US data for the period 1948-2000.

The paper is organised as follow. Section 2 proposes a standard growth accounting exercise that highlights the so-called US productivity slowdown. Section 3 presents the mismeasurement hypothesis and evidence that suggests that the average service life of capital goods has been decreasing since the 1970s. Section 4 describes the numerical experiments to quantify the potential impact of this phenomenon on estimates of aggregate capital stock and *TFP* measures. Section 5 concludes.

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1. See Triplett (2002) for a recent survey.

2. Growth Accounting and the US Productivity Slowdown

Like most empirical studies devoted to the so-called US Productivity Slowdown, this paper adopts a traditional growth accounting framework based on the seminal work of Solow (1957) extended by Jorgenson and Griliches (1967)[2]. This framework relies heavily on the existence of a production possibility frontier, which describes efficient combinations of outputs and inputs for the economy as a whole.

Aggregate output (Y_t) consists of consumption goods (C_t) and investment goods (I_t). These outputs are produced from capital (K_t) and labour (L_t) services. Productivity is usually represented as a Hicks-neutral augmentation (A_t) of aggregate inputs:

$$Y(C_t, I_t) = A_t\, F(K_t, L_t) \tag{1}$$

Under the assumption of competitive markets and constant returns to scale, producer equilibrium implies that the share-weighted growth of outputs equals the sum of the share-weighted growth of inputs and growth in *TFP*:

$$\bar{s}_{C,t}\Delta\ln C_t + \bar{s}_{I,t}\Delta\ln I_t = \bar{s}_{K,t}\Delta\ln K_t + \bar{s}_{L,t}\Delta\ln L_t + \Delta\ln A_t \tag{2}$$

where $\bar{s}_{C,t}$ is consumption's average share of nominal output, $\bar{s}_{I,t}$ is investment's average share of nominal output, $\bar{s}_{K,t}$ is capital's average share of nominal income and $\bar{s}_{L,t}$ is labour's average share of income $(\bar{s}_{C,t} + \bar{s}_{I,t} = \bar{s}_{K,t} + \bar{s}_{L,t} = 1)$.

Inputs and outputs are aggregates of many subcomponents. The concept of output adopted here is similar to Jorgenson and Stiroh's (2000). Like them, I exclude the government sector and include the service flow from consumer durables and owner-occupied housing[3]. Labour services data are taken directly from an updated version of Ho and Jorgenson (1999).

For the purposes of this paper, the focus is on measurement of capital services. The estimate of capital services relies heavily on data from the Bureau of Economic Analysis (*BEA*) and the Bureau of Labor Statistics (*BLS*). The starting point is the dataset assembled by the *BLS* for its estimate of multifactor productivity (*MFP*). These annual data cover the 61 industries that comprise the *Private Business Sector* and provide measures of real investment, price, and tax parameters for 76 classes of assets (38 for equipment goods, 23 for non-residential structures, 11 for residential structures and 4 for land and inventories). These data are completed by series provided by the *BEA* for 13 types of consumer durable assets.

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2. A comprehensive description of this methodology can be found in BLS (1983) and Jorgenson and Stiroh (2000).
3. See Jorgenson and Landefeld (2004) for more details.

From these data, the productive capital stock ($K_{i,t}$) for each of the 85 depreciable assets[4] can be estimated using the perpetual inventory method:

$$K_{i,t} = (1 - \delta_{i,t})K_{i,t-1} + \frac{I_{i,t} + I_{i,t-1}}{2} \tag{3}$$

where $\delta_{i,t}$ and $I_{i,t}$ respectively denote average physical depreciation rate and amount of real investment. The values of the $\delta_{i,t}$ parameters are crucial for this study. For the base case estimate, I accept the common assumption that the $\delta_{i,t}$ are stable over time ($\delta_{i,t} = \delta_i \ \forall t$) and use the widely accepted values reported by Jorgenson and Stiroh (2000).

The next step in estimating capital services consists of aggregating together the stocks of assets obtained by applying equation (3). An important result of production theory is that it is desirable to aggregate capital goods in terms of their marginal products in current production as opposed to the marginal costs of producing the capital goods. In this framework, the aggregated stock is obtained by using implicit rental prices as weights. This approach, originated by Jorgenson and Griliches (1967), is based on the identification of implicit rental prices with marginal products of different types of capital. Estimates of these prices usually incorporate differences in asset prices, service lives, depreciation rates and the tax treatment of capital incomes. The computation of the rental prices ($c_{i,t}$) is provided in the Appendix.

The resulting aggregated capital stock is often referred to as *Capital Services* by Jorgenson and his associates, and as *Capital Input* by the *BLS*[5]. Its growth rate is usually obtained by applying a Tornqvist aggregator of the form:

$$\Delta \ln K_t = \frac{1}{2} \sum_i (s_{i,t-1} + s_{i,t}) \Delta \ln K_{i,t} \tag{4}$$

where $s_{i,t} = \dfrac{K_{i,t} c_{i,t}}{\sum\limits_i K_{i,t} c_{i,t}}$ is the income share of asset i for period t.

Table 1 presents the resulting growth rates of capital services provided by the whole capital stock and by each of its components. Table 2 reports the weight of each component in the global aggregate.

Once global output and capital and labour services have been estimated, equation (2) allows us to compute *TFP* growth as a residual, *i.e.* as the growth of output that is not explained by the growth of inputs:

$$\begin{aligned}
\Delta \ln TFP_t = \Delta \ln A_t &= (\overline{s}_{C,t} \Delta \ln C_t + \overline{s}_{I,t} \Delta \ln I_t) \\
&\quad - (\overline{s}_{K,t} \Delta \ln K_t + \overline{s}_{L,t} \Delta \ln L_t)
\end{aligned} \tag{5}$$

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4. Land and inventories are considered non-depreciable assets.
5. See Dean and Harper (2001) for more details on the *BLS* productivity measurement programme and methodology.

1. Growth in Capital Services

Periods	Total	Consumer Durables	Equipment & Software	Non-residential Structures	Residential Structures		Inventories	Land
					Owner-Occupier	Tenant-Occupied		
1948 - 1973	4.13	6.20	5.08	2.60	2.73	3.95	4.05	1.93
1973 - 1979	4.33	5.13	6.63	2.75	2.40	3.47	3.53	2.31
1979 - 1990	3.88	4.95	5.51	3.13	1.75	2.72	2.29	2.60
1990 - 1995	2.90	3.48	4.96	1.27	0.55	2.53	2.55	0.99
1995 - 2000	5.11	6.23	9.49	1.89	1.45	2.92	4.24	1.92
1948 - 1973	4.13	6.20	5.08	2.60	2.73	3.95	4.05	1.93
1973 - 2000	4.02	4.95	6.39	2.47	1.61	2.89	2.97	2.11
1948 - 2000	4.07	5.55	5.76	2.53	2.15	3.40	3.49	2.02

Note: Average annual percentage rates of growth.

2. Average Income Shares

Periods	Total	Consumer Durables	Equipment & Software	Non-residential Structures	Residential Structures		Inventories	Land
					Owner-Occupier	Tenant-Occupied		
1948 - 1973	100.00	23.72	18.76	15.40	7.41	13.05	9.14	12.52
1973 - 1979	100.00	24.41	23.62	15.55	6.98	13.47	5.39	10.58
1979 - 1990	100.00	22.53	24.66	16.24	6.44	16.30	4.58	9.26
1990 - 1995	100.00	22.26	24.55	15.67	6.70	19.73	3.55	7.54
1995 - 2000	100.00	21.19	26.40	13.95	5.86	21.96	3.94	6.70
1948 - 1973	100.00	23.72	18.76	15.40	7.41	13.05	9.14	12.52
1973 - 2000	100.00	22.65	24.73	15.56	6.50	17.35	4.45	8.76
1948 - 2000	100.00	23.18	21.80	15.48	6.94	15.24	6.75	10.60

Note: Average annual percentages.

Table 3 summarises the results. They are consistent with standard growth accounting studies that focus on the post-war period (*e.g.* Jorgenson 2001). After strong output and *TFP* growth up to the early 1970s, the US economy slowed markedly through 1995, with output growth falling from 4.13 per cent to 2.74 per cent and *TFP* declining from 1.36 per cent to 0.55 per cent. During the 1980s, *TFP* growth dipped to 0.34 per cent, that is to say to barely one fourth of its pre-1973 level. But since the late 1990s things have changed. Growth in output in the 1995-2000 period is stronger than it was in the 1948-1973 period, and *TFP* growth has shown a clear recovery. Nevertheless, this persistent productivity slowdown is puzzling and neither growth accounting studies nor growth theories have offered a satisfactory explanation. Rejecting the idea that technological progress was dormant during this period, many observers have argued that the so-called productivity slowdown was, in reality, a statistical fiction[6]. This mismeasurement hypothesis is examined in the next section.

3. Growth rates of Output, Inputs and TFP				
Periods	Output	TFP	Capital	Labor
1948 - 1973	4.13	1.36	4.13	1.83
1973 - 1979	3.48	0.53	4.33	1.93
1979 - 1990	3.14	0.34	3.88	2.00
1990 - 1995	2.74	0.55	2.90	1.63
1995 - 2000	4.69	1.04	5.11	2.35
1948 - 1973	4.13	1.36	4.13	1.83
1973 - 2000	3.43	0.55	4.02	1.98
1948 - 2000	3.77	0.94	4.07	1.91

Note: Average annual percentage rates of growth.

3. The Mismeasurement Hypothesis

The mismeasurement hypothesis suggests that some or all of the productivity slowdown is accounted for by increased mismeasurement of real output since the 1970s. More precisely, many economists have focused on problems related to price indexes used to translate nominal output to real output, especially in the service industries where output growth is likely to be underestimated (Griliches, 1992). Given the rapid shift in economic activity toward the service sector since the 1970s, it is appealing to believe that this measurement problem has worsened,

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6. *Cf.* Darby (1984), Baily and Gordon (1988) and Griliches (1994).

providing at least a partial explanation for productivity slowdown (Griliches 1994). Unfortunately, on further examination, this argument appears to have little quantitative significance. Sichel (1997) showed that even under assumptions most favourable to finding a big effect, the growth in the poorly measured sector of the economy only boots the measurement gap by 0.1 or 0.2 percentage points. This result is consistent with the work of Baily and Gordon (1988) who showed that an increase in the undermeasurement of specific components of *GDP* is unlikely to contribute much to the measured productivity slowdown. Using recently revised *BEA* data, Triplett (2002) confirmed that this mismeasurement hypothesis was of limited use in trying to solve the productivity puzzle. Underestimate of real output exists, but plays a relatively minor role in the productivity slowdown, pointing to the need for complementary explanations.

One point emphasised by Triplett (2002) is that the hypothesis of mismeasurement is actually a hypothesis of differential mismeasurement. This means that to explain the productivity slowdown, errors in economic measurement would have to be larger after than before the 1960s . This is why the rapid shift toward service industries was *a priori*, a good candidate. Another candidate is the very sharp acceleration of investment in *Equipment and Software* in the US economy since the late 1960s.

Table 4 presents annual average growth rates of investments in these assets computed from the data used in the previous section. Following the *BEA* methodology, growth rates of real investment (*i.e.* investment in productive capital) presented in the Column 1 of Table 4 are computed using the Fisher chain-type quantity index. The second and third columns report results obtained by using rental prices to weight quantities in the Fisher formula. These numbers express investment growth rates measured in terms of capital services. They are thus directly comparable to the capital services growth rates presented in Table 1. To give an idea of the impact of information technologies (*IT*) on total investment in Equipment and Software, the Column 3 excludes *IT* related assets.

4. Growth rates of Investment in Equipment & Software (Productive Capital and Capital Services)			
Periods	Productive Capital	Capital Services	
		Total	Non-IT
1948 – 1960	0.76	1.09	1.08
1960 – 1970	6.99	8.02	6.64
1970 – 1980	5.90	8.30	4.67
1980 – 1990	3.26	7.75	0.78
1990 – 1995	6.66	10.71	4.94
1995 – 2000	12.14	18.70	7.55
1948 – 2000	5.55	8.19	4.27

Note: Average annual percentage rates of growth.

The acceleration of investment in the 1960s is remarkable. The average compounded annual growth rate has increased almost eightfold when compared to the 1948-1960 period. Note that because *IT* was still in its infancy, its diffusion has played a very minor role in this take off. A second acceleration in investment in Equipment and Software took place in the 1990s. Unlike the first, this acceleration has been well documented in the recent *New Economy* literature and is rooted in the diffusion of *IT* (*cf* Stiroh 1998 and Jorgenson 2001 among others).

The surge in investment in Equipment and Software in the US economy coincides with a sudden break in the evolution of the prices of these assets relative to consumption goods. One plausible explanation for this is that technological advance has made equipment less expensive, triggering an increase in the pace of investment. Average annual growth rates of relative equipment prices are presented in Table 5.

5. Growth rates of the Relative Price of Investment in Equipment & Software (Productive Capital and Capital Services)

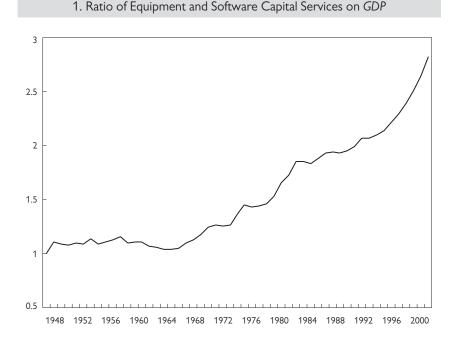| Periods	Productive Capital	Capital Services	
		Total	Non-IT
1948 – 1960	1.55	1.22	1.20
1960 – 1970	-0.89	-1.83	-1.14
1970 – 1980	-0.87	-3.06	-0.30
1980 – 1990	-2.32	-6.40	-1.23
1990 – 1995	-2.55	-6.17	-1.55
1995 – 2000	-3.98	-9.13	-1.75
1948 – 2000	-1.10	-3.50	-0.62

Note: Average annual percentage rates of growth.

Relative prices of *productive capital* and *capital services* increase at nearly the same rate until the 1960s and then begin to decline. It is interesting that this sudden break in the evolution of these relative prices coincides with the beginning of the productivity deceleration.

Looking now at the ratio of *Equipment and Software* services on real *GDP*, it is clear that this pivotal period coincides with a radical rupture in the evolution of the capital-output ratio (*cf.* Figure 1). The ratio of Equipment and Software on *GDP* is more or less stable until the mid-1960s, and then increases threefold in the next 30 years.

Taken together, these results are puzzling. The 1970s marked the beginning of a long-lasting period of slowing economic growth (*cf.* Table 3) so how can such a boom in investment be explained? One explanation is that a sizeable part of the investments was aimed at restoring firms'

1. Ratio of Equipment and Software Capital Services on *GDP*

productivity and profitability by replacing old and thus less efficient capital goods. The swift decline in relative prices of equipment can be seen as a symptom of an accelerated arrival of better new capital goods which speeded up the obsolescence of installed equipment (Greenwood and Jovanovic, 2001).

This suggests a focus on the retirement of capital goods as an endogenous decision. As argued by Feldstein and Rothschild (1974), it seems unrealistic to assume that retirements are determined exogenously when asset owners have the option of scrapping or otherwise disposing of assets in response to changes in relative prices or other market conditions (Cockburn and Murray, 1992). However, as Hulten (1990) and Berndt (1991) and others emphasise, given the importance of the capital depreciation process, there is surprisingly little evidence concerning its actual character.

There are some few exceptions that should be mentioned. In an early attempt to provide more reliable estimates of the rate of economic depreciation of computers, Oliner (1993) showed that the service lives of IBM mainframes and peripheral equipment appeared to have become shorter since the early 1970s. It is well known that computers are particularly vulnerable to obsolescence induced by technical advances. But this phenomenon is not restricted to *IT* related assets. Using data collected from a survey of machinery dealers, Oliner (1996) estimated the retirement pattern for a broad set of conventional machine tools. His

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study shows that the average service life of these machines has also become shorter since the mid-1970s because of the diffusion of new technologies. These results are important because these two classes of assets account for a sizeable share of total investment in *Equipment and Software*.

The evidence from these studies are however too sparse to provide reliable insights concerning the quantitative impact of this phenomenon on estimates of whole capital stock. Several pieces of research on the UK economy have attempted to fill this gap (see Mayes and Young, 1994, for a survey). Minford, Wall and Wren-Lewis (1991) used information from the *CBI* survey to construct estimates of manufacturing capacity. Comparing this series with the capital stock generated on the basis of constant service lives, they concluded that official data seriously overestimate true capital stock. While their series begins in 1966, they suggested that the overestimation reaches a peak of 44 per cent in 1986. Completing their study by examining the relationship between employment, capital stock and output, the authors conclude that the evidence suggests substantial capital scrapping in the 1980s recession.

Evidence from company accounts seems to reinforce this mismeasurement hypothesis. Using firm-level data from UK manufacturing companies for the 1972-1982 period, Wadhwani and Wall (1986) suggested that the overestimation of capital stock could vary from 10 per cent to 35 per cent over 10 years. Using the same data source, Smith (1987) concentrated on measuring the level of capital stock in 1983. He found substantial disparities between the official and company account based estimates of capital stock, the first exceeding the second by 36 per cent in manufacturing and 16 per cent in non-manufacturing.

Note that similar studies carried out on French firm-level data are also compatible with an underlying shortening of the service lives of capital goods (Atkinson and Mairesse 1978, Cette and Szpiro 1988, Sylvain 2003).

All this evidence suggests that the rapid pace of technological change combined with the severe economic recessions that followed the oil crises induced a substantial acceleration in capital obsolescence in most industrialised economies since the 1970s. Is this overestimation of capital stock growth responsible for all the well known productivity puzzles? A definitive answer to this question is very difficult to provide and is far beyond the scope of this paper. However, the next section contributes to the debate by testing the potential impact of a shortened average lifespan of capital goods on the *TFP* slowdown observed in the US economy.

4. Lessons from Few Numerical Exercises

The strategy adopted in this section consists of simulating the impact of various scenarios of accelerated capital obsolescence on the *TFP* estimates presented in Section 2. The first step is to define the characteristics of

each scenario. Because the aim is not to provide alternative reliable measures of *TFP,* but rather to check the significance of the mismeasurement story, I have always opted for fairly conservative hypotheses. Thus, without well-documented evidence on the evolution of obsolescence rates for consumer durable goods, I considered them to be stable over time. Because land and inventories are supposed to be non-depreciable assets, equipment and structures are finally the only capital goods that can potentially be impacted by an increase in the rate of obsolescence. Then, to keep things as simple as possible, it is assumed that since period t_0, the geometric depreciation rate of each asset i of these two classes of assets varies as follows:

$$\delta_{e,t}^i = (1 + \Delta\delta_e)\delta_{e,t-1}^i \qquad (6)$$

for equipment and software, and:

$$\delta_{s,t}^i = (1 + \Delta\delta_s)\delta_{s,t-1}^i \qquad (7)$$

for structures.

Note that the global effect of such variation in individual depreciation rates on the rate of growth of the aggregate capital stock (and thus on *TFP*) is not easy to determine because it impacts both on the rate of growth of concerned stocks of assets (see equation (3)) and their relative weight in the aggregate by modifying their rental price (see equation (9) in the Appendix).

The main issue now is to determine reasonable values for $\Delta\delta_e$ and $\Delta\delta_s$. What is the magnitude of the acceleration of obsolescence? Again, no clear answer emerges from the empirical studies. However, it is possible to use previous empirical evidence on plausible overestimate of the aggregate capital stock to appreciate the likelihood of the global impact of various scenarios of increase in depreciation rates on the simulated aggregated capital stock.

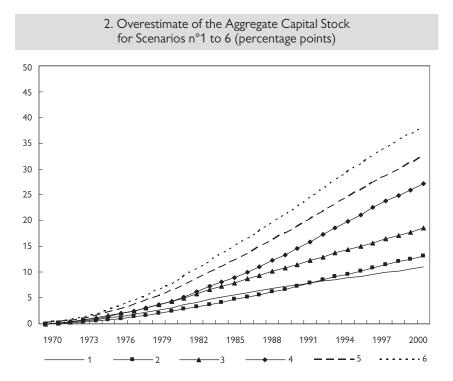Consider for instance the scenarios in Table 6.

6. Scenarios of Rise in Depreciation Rates

	Equipment and Software	Structures
Scenario n°1	5 %	0 %
Scenario n°2	2 %	2 %
Scenario n°3	5 %	2 %
Scenario n°4	2 %	5 %
Scenario n°5	5 %	5 %
Scenario n°6	6 %	6 %

Scenario n°1 assumes that, from period t_0 onwards, the depreciation rate for equipment increases by 5 per cent per year ($\Delta\delta_e = 0.05$ in equation (6)) whereas the depreciation rate for structures remains constant over

time ($\Delta \delta_s = 0$ in equation (7)). Is this plausible? One way to answer this question is to compute the outcome of this assumption on the evolution of the aggregate capital stock and to compare this series to the base case estimate. This allows us to determine if the mismeasurement that would be generated by such an increase in depreciation rates is compatible with empirical evidence reported by the literature.

Assuming for simplicity that the acceleration in capital obsolescence began in 1970 (*i.e.* t_0 = 1970), Figure 2 depicts the overestimates of aggregate capital stock associated with each scenario.

2. Overestimate of the Aggregate Capital Stock
for Scenarios n°1 to 6 (percentage points)

It is interesting that Scenario n°1 would lead to an overestimate of aggregate capital of little more than 10 per cent in 30 years, that is to say much less than the numbers reported by the macro-level studies cited in Section 3. More generally, all six scenarios presented in Table 6 seem quantitatively compatible with the reported empirical evidence.

Another way to appreciate the impact of each scenario on the evolution of aggregate capital stock is to look at the resulting aggregate rate of depreciation. Following Whelan (2002), this global depreciation rate (δ_t) can be obtained directly by weighting each individual depreciation rate (δ_t^i) by its share (s_t^i) in the aggregate capital stock:

$$\delta_t = \sum_i s_t^i \delta_t^i \qquad (8)$$

Table 7 presents the results of this computation.

Periods	Base Case	Scenario n°1	Scenario n°2	Scenario n°3	Scenario n°4	Scenario n°5	Scenario n°6
1948 - 1973	4.43	4.45	4.45	4.46	4.46	4.48	4.48
1973 - 1979	4.68	5.13	5.05	5.32	5.37	5.65	5.86
1979 - 1990	5.00	5.81	5.86	6.33	6.84	7.39	7.95
1990 - 1995	5.40	6.39	6.77	7.32	8.64	9.37	10.39
1995 - 2000	5.48	6.79	7.32	8.05	9.92	10.97	12.39
1948 - 1973	4.43	4.45	4.45	4.46	4.46	4.48	4.48
1973 - 2000	5.09	5.95	6.12	6.61	7.42	8.03	8.76
1948 - 2000	4.77	5.21	5.30	5.56	5.97	6.29	6.66

7. Average Aggregate Depreciation Rates for each Scenario

Note: Average annual percentage.

The first column of Table 7 summarises the results for the base case estimate. In this case, and according to the traditional growth accounting framework, the depreciation rates are assumed to be constant over time. Note however that the aggregate depreciation rate rises over time because of composition effects in favour of fast depreciating assets. When the various scenarios are compared with the base case estimate, the impact of the acceleration of capital obsolescence on the overall depreciation rate appears to be fairly moderate. Sizeable differences only emerge in the last decade for the most extreme scenarios.

How do these differences in capital stock estimates translate into differences in *TFP* growth estimate? The answer to this question is given in Table 8.

Periods	Base Case	Scenario n°1	Scenario n°2	Scenario n°3	Scenario n°4	Scenario n°5	Scenario n°6
1948 - 1973	1.36	1.38	1.37	1.38	1.37	1.38	1.39
1973 - 1979	0.53	0.83	0.67	0.87	0.74	0.93	1.04
1979 - 1990	0.34	0.91	0.60	0.97	0.78	1.14	1.32
1990 - 1995	0.55	0.88	0.84	1.00	1.16	1.32	1.52
1995 - 2000	1.04	1.25	1.28	1.37	1.59	1.68	1.77
1948 - 1973	1.36	1.38	1.37	1.38	1.37	1.38	1.39
1973 - 2000	0.55	0.95	0.79	1.03	0.99	1.23	1.38
1948 - 2000	0.94	1.16	1.06	1.20	1.17	1.30	1.38

8. Comparison of Measured TFP Growth Rates

Note: Average annual percentage rates of growth.

Several important results arise out of this table.

First, the impact of an increase in the rate of depreciation on *TFP* growth measures is very significant. Note that even when this increase only affects equipment (Scenario n°1), the magnitude of the measured productivity slowdown is greatly reduced. Actually, when the rapid shift towards services sector (*cf*. Section 3) and the procyclical nature of traditional *TFP* measures are taken into account, the productivity puzzle almost vanishes. It is also notable that this scenario requires a very moderate increase in the overall rate of capital depreciation (from 5.09 to 5.95 per cent, *cf*. Table 7) and thus a very limited mismeasurement of total capital stock (barely more than 10 per cent in 30 years, *cf*. Figure 3).

Second, the relationship between aggregate depreciation rates and *TFP* measures is not monotonic. While the average aggregate depreciation rate in Scenarios n°1 and n°2 increases from 5.95 to 6.12 per cent for the 1973-2000 period, the average measured *TFP* growth rate actually decreases (from 0.95 to 0.79 per cent) over the same period. This is due to composition effects. The aggregate depreciation rate is computed on the real capital stock (productive capital) whereas the *TFP* measures involve capital services.

Third, if one accepts that structures might also be affected by an increase in obsolescence due to the shortened service life of certain kinds of factories and to the existence of a certain degree of complementarity between structures and equipment, the mismeasurement implied by accelerated obsolescence increases significantly. Scenario n°6 even suggests that once the negative effects of the oil crises have been absorbed, the accelerated diffusion of new technologies observed since the 1960s (*cf*. Tables 4 & 5 and Figure 2) could have induced a sizeable rise in aggregate *TFP* growth.

5. Conclusion

There is much evidence to suggest that the average service life of capital goods has decreased since the 1970s. This paper aimed to quantify the potential impact of this phenomenon on estimates of aggregate capital stock and *TFP* measures. Estimates carried out using a standard growth accounting framework show that this impact could be very significant. When the effects of the oil crises, the procyclical nature of *TFP* measures, and the rapid shift in economic activity toward the service sector since the 1970s are taken into account, the so-called US productivity slowdown would not survive a moderate shortening of the average capital lifespan. These results strongly suggest that future efforts should be devoted to characterising the evolution of capital lifespan in order to improve the accuracy of *TFP* measures.

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APPENDIX

Estimating the rental price of capital

The rental price $c_{i,t}$ of asset i in period t can be estimated by[7]:

$$c_{i,t} = (r_t + \delta_i - \pi_{i,t})\theta_{i,t}p_{i,t} + \varphi_{i,t}p_{i,t} \qquad (9)$$

where r_t, $\delta_{i,t}$, $\pi_{i,t}$ and p_t denote respectively the nominal rate of return on capital, the average rate of economic depreciation, the asset-specific capital gains term and the deflator for new capital goods. The variables $\theta_{i,t}$ and $\varphi_{I,t}$ synthesize the impact of tax parameters. They are broken down as follows:

$$\theta_{i,t} = \frac{1 - u_t z_t - e_{i,t}}{1 - u_t} \qquad (10)$$

with: u_t : the corporate income tax rate

   z_t : the present value of \$1 of tax depreciation allowances

   $e_{i,t}$: the effective rate of the investment tax credit.

The nominal rate of return on capital r_t is not observable. Thanks to the hypothesis of competitive markets, it is possible to define r_t as a solution to the following equation:

$$R_t = \sum_i k_{i,t}c_{i,t} = \sum_i (r_t + \delta_i - \pi_{i,t})k_{i,t}\theta_{i,t}p_{i,t} + k_{i,t}\varphi_{i,t}p_{i,t} \qquad (11)$$

The variable R_t is the capital income estimated by the *BLS* as the difference between the nominal value added and the cost of labour. In a competitive economy, capital income is equal to its rental cost defined by $\sum_i K_{i,t}c_{i,t}$.

From equation (11), the nominal rate of return on capital can thus be written as:

$$r_t = \frac{R_t - \sum_i (\delta_i - \pi_{i,t})K_{i,t}\theta_{i,t}p_{i,t} + K_{i,t}\varphi_{i,t}p_{i,t}}{\sum_i K_{i,t}\theta_{i,t}p_{i,t}} \qquad (12)$$

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7. See BLS (1983).