CAPITAL QUALITY IMPROVEMENT AND THE SOURCES OF GROWTH IN THE EURO AREA

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Abstract

The euro area experienced a slowdown in output and Total Factor Productivity growth in the 1990s compared to the 1980s. We ask the following questions. Is the apparent slowdown in euro area output due to a lack of proper accounting for capital quality improvement? The answer is no. Did technological change really slow down in the euro area? The answer here is mixed. The part of the technological change that is embodied in capital goods and boosts output through investment in these goods in fact accelerated in the 1990s. In contrast, disembodied technological change, which boosts output through new consumer goods or new production processes, decelerated in the 1990s more sharply than the official figures portray.

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1. Introduction

The Lisbon agenda, adopted in 2000 by European heads of State and Government, is the main strategic plan for Europe's medium term growth. It has set the goal, among others, of thrusting Europe to the front of the race for the most competitive economy in the world by 2010. As we near the mid-term point in this effort, with a high-level review under way, it is rather clear that this grand goal of the agenda is nearly impossible to attain. The aim of the current debate is to see why progress on these goals has not been satisfactory and what can be done about it.

It has become clear by now that the Lisbon Agenda sets too many goals (over 100 according to a report by the IMF). However, even with a smaller number of goals success would not have been much better since a key (one might claim necessary) element is missing from the implementation process. There has not been a systematic quantitative analysis of the impact of individual reform proposals on potential growth. Such analysis would lead to a better prioritization of individual reforms as well as an assessment of whether these reforms need to be simultaneous or sequential.

A first step in such a quantitative effort is to clarify what have been the sources of growth in the European economy. This growth accounting exercise has been carried out by many researchers with a special focus on the comparison between the European and the US experiences (e.g. Schreyer 2001, Van Ark et al 2002, Vijselaar and Albers 2004).

Our aim in this paper is not to repeat this exercise but rather to give proper attention to the issue of accounting for capital quality improvement and its impact on the sources of growth. By accounting properly for capital quality improvement we are able to separate the contributions of the component of technological change that is embodied from that which is disembodied. We focus on the economy of the euro area. As it consists only of old Member States the euro area is considerably more homogeneous than the group of 25 countries comprising the European Union. More importantly, it is for these economies that the need to respond flexibly to asymmetric shocks is most urgent since they have given up the independent conduct of monetary policy.

1.1. Accounting for capital quality improvement

Ever since the computer became an integral part of our life it has been obvious that every year faster, more useful computers are introduced into the marketplace. Even before computers became an everyday item, cars were. Every few years we see a new generation of Honda Civic or VW Golf equipped with features that make it (usually) a far better driving experience than the previous generation. This phenomenon of capital quality improvement is general and widespread and has been going on for a long while. As it happens, it also makes the job of official statisticians and growth accountants much more difficult. The reason is that prices at which transactions of new capital take place are not meaningful (in some respects) and can lead to misleading statements about the sources of economic growth. Unless, that is, one adjusts these prices to reflect the improvement in quality embodied in new capital goods.

While many statistical agencies expend significant efforts to adjust prices there is growing evidence that substantial biases remain. The study by Gordon (1990) has been instrumental in documenting and quantifying the extent of these biases. Gordon's quality-adjusted indexes have been used by some researchers (starting with Hulten, 1992) as a way of quantifying the extent of improvement in equipment quality. Since quality improvement is *embodied* in capital goods and comes mostly as a result of technological improvements, it is often referred to as embodied technological change (ETC). In section 2, we make the connection between the two concepts more precise in the context of a model with two productive sectors.

While the methodology of Hulten (1992) that compares Gordon's quality-adjusted prices to some un-adjusted prices is not the only one aimed at estimating ETC, we argue in Section 2 that it can be safely thought to provide conservative estimates (perhaps a lower bound) to the rate of growth of ETC. An advantage is that it provides estimates of capital quality improvement by disaggregated assets. Cummins and Violante (2002) have undertaken the very useful task of extrapolating Gordon's quality-adjusted price indexes series to recent years. While this is done with time-series rather than hedonic techniques, it still provides a useful basis for a much needed correction to official statistics.

In Section 3, we expand on why this correction is essential in order to measure capital stock and output growth accurately. It is also essential for decomposing economic growth into its sources accurately. The lessons that we get from that discussion are that: 1) the output of investment-good producing sectors should be deflated by quality-adjusted prices. If not, its growth is likely to be underestimated. 2) Productive capital stocks (or more accurately, the service flows from capital that serve as input in production) should be constructed after deflating nominal investment flows by a quality-adjusted price index and depreciating old vintages with a rate that does not include quality change. Otherwise, the growth of capital stock is underestimated and its estimated contribution to growth is biased downward.

Our main purpose in this paper is to apply these issues to euro area statistics. While substantial attention has been paid to issues relating to Information and Communication Technologies (ICT) investment expenditures, its appropriate deflation and its contribution to growth, the empirical work to date has not recognized that the issue of quality improvement concerns a much wider array of capital assets than ICT. As a result, inferences about the role of capital accumulation and of different sources of technological change in euro area growth may be misleading. Our basic premise is that equipment price indexes in the euro area are insufficiently adjusted for quality improvement. Our way to fix them is by applying to them the estimated bias adjustments of Cummins and Violante (2002), which are based on the work of Gordon (1990). We do not, however, apply the aggregate US index but rather use series disaggregated by equipment assets. Our underlying assumption is that since these capital assets are freely traded across the Atlantic, their prices should be rather similar in the US and in the euro area. However, we do allow for different composition of investment by asset at the industry level between the US and the euro area.

In Section 4, we present the results of this exercise. We calculate that growth rates of official price indexes for equipment and software in the euro area are biased upward substantially. In particular, the average annual quality bias is 3.7 percent in the 1980s and 4.4 percent in the 1990s. The increased bias in the 1990s is due to an acceleration in the growth rate of embodied technological change during that period in most categories of equipment- not just ICT. When adjusted for quality, productive capital stocks of equipment and software grow on average 3 percentage points faster annually- a doubling of their growth rates. Quality-adjusted output grows 0.46 percentage points faster annually. In terms of growth accounting, quality adjustment subtracts 11 percentage points from the share of TFP in output growth and adds them to the contribution of equipment stock. The share of E&S in output growth in the euro area over the period 1982-2000 increases from 19 percentage points to 30 percentage points when adjusted for quality. The share of embodied technological change in quality-adjusted output growth amounted to 46 percentage points over the period 1982-2000.

It is important to note that the approach of substituting US deflators for European ones can best be seen as illustrative of the magnitude of the problems created by insufficient quality adjustment in the European data. It is, however, not a solution. US deflators might differ from European deflators for a host of reasons apart from quality adjustment, including compositional effects in aggregate deflators and country-specific inflationary developments. In other words, our set of alternative deflators cannot be seen as an alternative official dataset, but it can be seen as an important stepping stone in that direction.

2. A useful framework[1]

An example might be useful before we write down the model. Suppose that only two goods are produced in the economy: computer boxes whose processing speed is q_t Mhz and banking services. The number of computer boxes produced is denoted by i_t and the number of banking transactions by c_t. The production of computers and banking services requires both computers and labor as input. The households in this economy derive utility only from banking services and not from using computers. Thus, computer production is channeled completely to investment expenditure.

As a result of some exogenous technological change z_t the production of both computers and services becomes less costly over time in terms of resources. However, there is an additional force of exogenous technological change that increases the processing speed q_t of computers each year. As a result of the higher processing speed a computer box of vintage t is $\left(q_t/q_{t-1}\right)$ times more productive than a computer box of vintage $t-1$. In other words, a computer box of vintage t is equivalent to $\left(q_t/q_{t-1}\right)$ computer boxes of vintage $t-1$ and we can write in efficiency units $\tilde{i}_t = i_t q_t$. This increased productivity may also be thought of as higher quality of the vintage t computer and leads to obsolescence in the value of the vintage $t-1$ computer box by a factor of $\left(q_{t-1}/q_t\right)$, as we will see below.

2.1. The two production technologies

In order to formalize the concept of capital-embodied technological change we consider now a two-sector model of a closed economy without government where one sector produces investment goods ($\tilde{i}$) and the other sector produces consumption goods (c). Each good is produced using capital $(\tilde{k})$ and labor (l) as inputs according to the following production functions:

$$\tilde{i}_t = z_t q_t \tilde{k}_{\tilde{i},t}^{\alpha} l_{\tilde{i},t}^{1-\alpha} \tag{1}$$

$$c_t = z_t \tilde{k}_{c,t}^{\alpha} l_{c,t}^{1-\alpha} \tag{2}$$

where z is an index of technology representing Hicks-neutral technological change that is common to both sectors whereas q is an index of technology that is specific to the investment goods sector . A "~" denotes that the variable is defined in efficiency units. For simplicity, α , the elasticity of output with respect to capital is assumed to be the same in both sectors.[2]

The stock of capital (also in efficiency units) is defined as follows:

$$\tilde{k}_t = \left(1-\delta\right)\tilde{k}_{t-1} + i_t q_t \tag{3}$$

where δ is the (geometric) rate of physical decay. This captures the decay in productive ability due to wear in use and it has

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[1] The exposition in this section follows Solow (1960), Hornstein and Krusell (1996), Greenwood, Hercowitz, and Krussell (1997), Hercowitz (1998), and Sakellaris and Wilson (forthcoming). Ho and Stiroh (2001) also tackle some of the issues in this section. For clarity, we do not make a distinction here between structures and equipment investment, though Sakellaris and Wilson (forthcoming) argues that it is important empirically.

[2] Hornstein and Krusell (1996) show the implications of allowing α to vary across sectors.

also been labeled physical decay or deterioration. This rate is different than the rate of economic depreciation to be defined below.[3] Note that in order to construct the capital stock we need to adjust each vintage of investment expenditures for quality change that is due to capital-embodied technological change.

Essentially, what is being modeled here is the situation where the production of investment goods is subject to more rapid Hicks-neutral technological change than that of the rest of the goods. As a result, the marginal unit of investment goods uses an ever-decreasing amount of the economy's resources compared to what is needed to produce the marginal unit of a consumption good. This decrease in the relative marginal costs will show up in a corresponding decrease in relative prices under perfect competition.[4] Even though $\tilde{i}_t$ denotes the whole capital goods sector here the model may be used to study any situation where there is a stark difference in the rates of technological change between different sectors in the economy as for example between Information and Communication Technologies equipment and the rest of the economy.

Definition and discussion of embodied technological change

We define as capital-embodied technological change (ETC), or capital quality improvement, the phenomenon described in the above two equations where Total Factor Productivity (TFP) grows faster in the investment goods sector than in the consumption goods sector. This technological change is embodied in capital goods in the sense that was articulated in the above example. The index q measures computer processing speed or some other characteristic of the capital good that leads to higher efficiency of the capital good in the production of other goods. It is also embodied in the sense that the economy can only take advantage of this part of technological progress by producing and using new capital goods. The economy described by equations (1) and (2) enjoys a higher rate of growth of TFP the more that it invests in new capital. There is also a fundamental distinction between different vintages of capital goods.

However, an alternative interpretation may be given to the above two equations. The index q may not describe increases in the quality of capital goods but rather increased number of physical units produced with given resources. Instead of having the computer boxes produced embody higher processing speed indexed by q, we have the number of computer boxes produced using a given amount of resources grow with q while their processing speed remains the same. In the above simple model, these two interpretations are indistinguishable while clearly only the first one conforms to the concept of quality embodied in a new capital good.

It seems that the first interpretation is closer to what has been for most capital assets. For example, regarding ICT capital goods, Jorgenson (2001) has argued that rapid increases in the efficiency of semiconductors led to rapid increases in the quality of ICT capital goods without offsetting increases in their production costs. Since there are no intermediate inputs in the model provided here these quality changes show up directly in the final goods. Of course, a more satisfying model would include intermediate goods as well.

It is clear from the above discussion that the concept of embodied technological change is intimately linked with growth in capital goods quality. However, the setup here is too simple to characterize adequately all the important issues related to quality change. For example, increased quality is assumed here to arise costlessly to the economy whereas in a more

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[3] The quantity $1-\delta$ can be thought of as the ratio of the marginal product of a vintage of capital to that of the following year's vintage of capital.

[4] The assumption of perfect competition is a departure from reality. The existence of markups, of course, puts a wage between price and marginal costs that may influence any inference of the rate of ETC based on the decline in the relative prices of the two goods. However, as long as there is no trend in the ratio of the markups in the two sectors the measurement error generated would not be important.

realistic model it would have resource costs. If it is costly research that leads to higher quality then one would need to include that in the model as well. This research cost might be once-and-for-all or a recurring one.

2.2. Estimating Embodied Technological Change

Price-based Estimates

Assume that all factors of production are perfectly mobile across sectors and that perfect competition holds in all markets. Then, as a result of factor price equalization, the price of investment goods relative to consumption goods is:

$$P_t^{\tilde{i}}/P_t^c = 1/q_t. \tag{4}$$

Thus, one may compute the rate of growth of capital-embodied technological change from the rate of decline in the relative price of investment goods. This result forms the basis of the price-based approach to measuring embodied technological change. Note, however, that the price that appears in the numerator is that for efficiency-adjusted (or quality-adjusted) investment goods and not the transaction price of investment goods.

Gordon (1990) is a major study aimed at correcting mismeasurement in equipment price indexes due to quality change. He uses a combination of hedonic techniques and matched-model methods to provide quality-adjusted price indexes for 22 types of equipment and their components. Hulten (1992) is the first to use these series in order to identify embodied technological change. He constructs a single aggregate index from Gordon's indexes as well as one for the corresponding price indexes published by BLS. Taking the ratio of the two, he calculates the average annual growth rate of embodied technological change to be 3.44 percent for U.S. manufacturing during 1949-1983. Various papers have followed Hulten (1992) in using Gordon's data but differed in the methodology employed. Greenwood et al. (1997) argue that the baseline index for comparison should be the implicit price deflator for non-durable consumption goods. This has very little effect on their estimate of embodied technological change. A serious impediment for current work is that Gordon's series ends in 1983.

Cummins and Violante (2002) have undertaken the important task of updating these asset-specific price indexes to 2000. They do so by means of extrapolation using a time-series forecasting technique for the quality adjustment for each of the capital assets in the Gordon (1990) study. They estimate that the 1990's brought an acceleration in ETC as measured by the price-based approach. In particular, for US manufacturing their estimated rate of ETC jumped from about 4 percent in the 1970's and 1980's to about 5.6 percent in the 1990's (See their Table III, p. 261).

However, the comparison of the above two price indexes is not the only way to estimate the rate of growth of capital quality. An alternative approach relies on data on produced output and utilized inputs.

Production-based Estimates

Bahk and Gort (1993) provide estimates using Nelson's (1964) variant of Solow's (1960) embodiment model. They study a sample of young manufacturing plants and find that a 1-year drop in average age is associated with between a 2.5 and a 3.5 percent rise in the plant's gross output (See their Table 1 and p. 571). Assuming a one-sixth share weight for capital in the production function of gross output, these results correspond to a 15-21 percent annual rate of growth of embodied technological change. This is three to four times higher than the baseline price-based estimates discussed above.

Sakellaris and Wilson (forthcoming) implement a more direct approach based on equations (1) and (2). They:

1. Deflate output and investment by a price index that does not adjust for quality change.
2. Apply depreciation adjustments to capital that capture physical decay but not quality change.
3. Allow the marginal productivity of each vintage, q_t, to be freely estimated.

Their estimated series of q_t provides an estimate of ETC of about 12 percent annually for the years 1972-1996.

Structural Model-Based Estimates

Hobijn (2000) measures embodied technological change by fitting a simple stochastic vintage capital model to aggregate US data. After calibrating model parameters he filters out the implied path of embodied technological change and estimates the rate of growth of embodied technological change at about 4% for the period 1975-1999. This estimate, however, is biased downward because, as the author admits, the depreciation rate used in this calibration is too high.

A related approach is taken in Hobijn et al. (2002). They modify the neoclassical model of investment with convex adjustment costs to include embodied technological change. They then estimate the Euler equations for investment using data for 4-digit US manufacturing industries. Their estimates of the rate of embodied technological change for equipment range between 9.5% and 32.6%. The stark difference in estimates between the two papers may be due to the higher level of aggregation of the data in the former. Earlier papers using a production-side approach have already concluded that aggregation biases the rate of embodied technological change downward (see e.g. Wickens, 1970, You, 1976, and McHugh and Lane, 1987).

Comparison of Estimates

It should be clear from the above discussion that there is a high degree of uncertainty about the magnitude of capital quality growth. The price-based estimates set the average annual growth rate of ETC at about 3-6 percent depending on the time period. The production-based estimates set it at about 12 percent or even higher. Structural-model based estimates do not tip the scale either way as they range from 4 percent to over 30 percent.

Aggregate estimates based on prices may be downward biased because Gordon was only able to create new price indexes for durable goods for which sufficient data on model characteristics and prices existed. The Sears catalog was the primary source of this data. For a large number of goods there simply was no data. Production-based estimates, on the other hand, are likely to be upward-biased due to simultaneity. Since firms with higher TFP will invest more and, thus, have younger capital stock it will seem that newer vintages contribute more to productivity than older ones. Structural model-based estimates may have biases due to model misspecification but it is not clear whether the direction should be positive or negative.

3. Lessons for measurement

3.1. Productive capital stocks

From the simple model above it is clear that there are two consistent, though not equivalent, ways of constructing productive capital stocks.[5] The first is a quality-adjusted capital stock, $\tilde{k}_t$, as specified in equation (3). Here it is important to note that the investment flows are expressed in efficiency units and all past investment flows are adjusted by a rate of physical decay, δ, which is assumed to be geometric:

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[5] We abstract here from issues relating to aggregation of different capital assets into the flow of capital services (see Jorgenson and Griliches, 1967). In our empirical work, however, we deal with these issues.

$$\tilde{k}_t = i_t q_t + (1-\delta) i_{t-1} q_{t-1} + \ldots + (1-\delta)^t i_0 q_0. \tag{5}$$

An alternative, more conventional, way of constructing the capital stock is:

$$k_t = i_t + (1-\delta)\frac{q_{t-1}}{q_t} i_{t-1} + \ldots + (1-\delta)^t \frac{q_0}{q_t} i_0. \tag{6}$$

As a result, $\tilde{k}_t = q_t k_t$. We will call k_t the hybrid capital stock as it contains only partial adjustment for quality. It is clear that the difference in the growth rates of the two capital stocks is the rate of growth of embodied technological change (or of quality), i.e.

$$\frac{\dot{\tilde{k}}_t}{\tilde{k}_t} = \frac{\dot{k}_t}{k_t} + \frac{\dot{q}_t}{q_t} \tag{7}$$

Depreciation rates:

Hulten and Wykoff (1981) measure economic depreciation rates of capital assets by estimating the change in the value of that asset associated with aging. This change contains two effects: one is a pure age effect arising from use, wear and tear and the second one is a vintage effect arising from obsolescence due to improvements in the quality embodied in the assets. The first effect is called *physical decay* while the second one *obsolescence* or *quality change*. The rate of economic depreciation is a combination of these two:

$$1 - d = (1-\delta)\frac{q_{t-1}}{q_t} \tag{8}$$

Hall (1968) has demonstrated the fundamental inability to separately identify physical decay and embodied technological change with only a cross-sectional set of used asset prices. This fundamental identification problem implies that either physical decay or embodied technological change must be "observed" in some way. This is where equation (4) comes in handy. It identifies separately the term $\frac{q_{t-1}}{q_t}$ and, thus, $(1-\delta)$, given the Hulten-Wykoff estimates for $1-d$.[6]

The Hulten-Wykoff estimates of economic depreciation or their variants are used extensively in the construction of productive capital stocks. When the investment flows for capital assets are adjusted for quality change a problem arises. In a sense, these assets are "double-adjusted" for quality change when constructing capital stocks $\tilde{\tilde{k}}_t$.[7] This leads to deviations

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[6] Reality is more complicated, as usual. There is endogenous scrapping of (old) vintages of capital induced by obsolescence. Such scrapping may occur because there is a fixed operational cost (Whelan, 2002) or because workers and machines are used in fixed proportions. The estimate of $1-d$ includes the effect of this scrapping. The ratio $\frac{1-d}{\frac{q_{t-1}}{q_t}}$ still provides the appropriate depreciation rate for constructing productive capital stocks but is not a pure measure of physical decay due to wear and tear.

[7] Oliner (1993) and Gort and Wall (1998), among others, have brought attention to this point.

between $\tilde{k}_t$ and k_t as shown below:

$$\tilde{\tilde{k}}_t = q_t i_t + (1-\delta)\frac{q_{t-1}}{q_t} i_{t-1} q_{t-1} + \ldots + (1-\delta)^t \frac{q_0}{q_t} i_0 q_0. \tag{9}$$

This “double-adjusted” capital stock, $\tilde{\tilde{k}}_t$, grows slower than the correctly “quality-adjusted” capital stock, $\tilde{k}_t$. We will see below the implications for growth accounting exercises of this kind of measurement error. There is a second way to construct capital stocks incorrectly in the presence of embodied technological change: not to adjust for quality change at all. Define this ‘quality-unadjusted’ capital stock, $\hat{k}_t$, as follows

$$\hat{k}_t = i_t + (1-\delta) i_{t-1} + \ldots + (1-\delta)^t i_0. \tag{10}$$

3.2. Real output growth

A major conceptual step toward being able to do growth accounting is figuring out how to construct aggregate real output. The approach followed by the Bureau of Economic Analysis (BEA) in constructing the National Income and Product Accounts (NIPA) is to adjust all sectoral output for quality growth before aggregation. This follows the framework of Domar (1961) and Jorgenson (1966) and has also been advocated by Hulten (1992) and Licandro et al. (2002). Written as a Divisia index aggregate real output, Y_t, is:[8]

$$\frac{\dot{Y}_t}{Y_t} = (1-\mu_t)\frac{\dot{\tilde{i}}_t}{\tilde{i}_t} + \mu_t \frac{\dot{c}_t}{c_t} \tag{11}$$

where μ_t is the fraction of aggregate capital stock, measured in efficiency units, devoted to investment goods production. Equivalently, μ_t is the ratio of the output of the investment sector, $\tilde{i}$, to total output measured in terms of consumption,

$$\mu_t = \frac{i_t}{c_t + i_t} = \frac{P_t^i i_t}{P_t^c c_t + P_t^i i_t} \tag{12}$$

As shown by the last equality, the weight on each sector’s growth of output is the share of the sector’s nominal output in aggregate nominal output.

Decomposing the growth rate of aggregate real output into its sources we have the

$$\frac{\dot{Y}_t}{Y_t} = (1-\mu_t)\frac{\dot{z}_t}{z_t} + \mu_t\left(\frac{\dot{z}_t}{z_t} + \frac{\dot{q}_t}{q_t}\right) + \alpha\frac{\dot{\tilde{k}}_t}{\tilde{k}_t} + (1-\alpha)\frac{\dot{l}_t}{l_t} \tag{13}$$

This is the Domar aggregation scheme that Hulten (1978) shows obtains when there are intermediate inputs. As there are no intermediate inputs in our model the shares here sum to one. The TFP obtained after applying the growth accounting decomposition is a weighted average of the TFP in each of the two sectors with the weights given above.

What if aggregate output were not adjusted for quality?

In that case one can write total output in terms of consumption goods, $y_{t,}$ as:

$$\frac{\tilde{i}_t}{q_t} + c_t = i_t + c_t = y_t = z_t \tilde{k}_t^{\alpha} l_t^{1-\alpha} \tag{14}$$

As a reminder, i_t, in the above expression denotes the investment goods measured in terms of consumption goods (i.e. unadjusted for quality) and $\tilde{k}$ is defined in efficiency units (i.e. adjusted for quality). The last equality arises because capital-labor ratios are equalized across sectors and the sectoral production functions are homogeneous of degree one. It is easy to show that equation (14) may be written equivalently as:

$$y_t = z_t q_t^{\alpha} k_t^{\alpha} l_t^{1-\alpha} \tag{15}$$

where k_t is defined in (6) or equivalently:

$$k_t = \left(\frac{1-\delta}{\frac{q_t}{q_{t-1}}} \right) k_{t-1} + i_t \tag{16}$$

The bias due to the absence of capital quality adjustment is

$$\frac{\dot{y}_t}{y_t} - \frac{\dot{Y}_t}{Y_t} = -\mu_t \left(\frac{\dot{q}_t}{q_t} \right). \tag{17}$$

In other words, real output growth is underestimated by a term equal to the rate of embodied technological change multiplied by the share of investment in nominal output.

3.3 Growth accounting

For all measurement exercises in this paper we define the quantity of aggregate output in terms of a Tornqvist index:[9]

$$d\log(Y_t) = \overline{\mu}_t d\log(\tilde{i}_t) + \left(1 - \overline{\mu}_t\right) d\log(c_t), \tag{18}$$

where μ_t is defined in equation (12) to be the share of investment goods in nominal output and $1-\mu_t$ represents the average share between periods t and t - 1. It is clear that the contribution of TFP to growth in measured output is the weighted average of technological growth rates in the two sectors with the weights given in (18). The impact of the production and use of capital goods on output growth in the economy is twofold. The use of new capital as input in production contributes to output growth through the term

$$\alpha \left[\overline{\mu}_t d\log(\tilde{k}_{\tilde{i},t}) + \left(1 - \overline{\mu}_t\right) d\log(\tilde{k}_{c,t}) \right] \tag{19}$$

while the production of capital goods contributes through the term

$$\overline{\mu}_t \left[d\log(q_t) + d\log(z_t) \right]. \tag{20}$$

Note that the impact of embodied technological change on output growth is given by:

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[8] Actually, the NIPA employ the Fisher Ideal Index to create chain-weighted aggregates.

$$\left\{\overline{\mu}_t d\log(q_t)\right\} + \alpha\left\{\overline{\mu}_t d\log\left(\frac{\tilde{k}_{\tilde{i},t}}{\hat{k}_{\tilde{i},t}}\right) + \left(1-\overline{\mu}_t\right) d\log\left(\frac{\tilde{k}_{c,t}}{\hat{k}_{c,t}}\right)\right\} \tag{21}$$

The first component of the sum is the contribution of embodied technological change to aggregate TFP growth through the production of capital goods. The second component is the contribution of capital accumulation (the use of capital in production). In this second component, embodied technological change contributes through the growth of effective capital over and above what would have been the case if there were no quality growth.[10]

Growth accounting without quality adjustment

Under these circumstances measured aggregate output growth is lower as shown above. It is easy to show that in this case estimated TFP growth is $d\log(z_t) + \alpha d\log(q_t)$. The estimated contribution of capital accumulation to output growth is

$$\alpha\left[\overline{\mu}_t d\log(k_{\tilde{i},t}) + \left(1-\overline{\mu}_t\right) d\log(k_{c,t})\right] = \alpha\left[\overline{\mu}_t d\log(\tilde{k}_{\tilde{i},t}) + \left(1-\overline{\mu}_t\right) d\log(\tilde{k}_{c,t})\right] - \alpha d\log(q_t). \tag{22}$$

As shown in (7), the result is to bias downward the growth of effective capital stocks by an amount equal to the growth rate of embodied technological change. This translates into a lower estimated contribution to economic growth.

4. Empirical results

4.1. Capturing quality in price statistics

Capturing quality in price statistics is a difficult task for statisticians (e.g. Triplett 2003). The so-called *forced replacement* problem arises inside price index samples: some items that were in the index sample disappear and their disappearance forces selection of a replacement. Forced replacements require the statistical agency to make suitable quality adjustments for the quality changes between replacement items and the old items they replace in the sample. However, the impacts of quality change on price indexes goes beyond adjusting the fixed sample for forced replacements.

Equally important are the price impacts of entering new products varieties, new varieties that may not be in the sample at all. Thus the question is whether the fixed-sample designs systematically misses price changes from rapid turnover of product varieties. Statistical agencies typically draw product samples at some period and hold them fixed, or attempt to hold them fixed, over some interval. Even if originally representative, the longer the interval over which the sample remains fixed, the more likely that it will become unrepresentative if the universe of transactions.

It now is a widely debated question whether more sophisticated, including hedonic techniques are preferable to more conventional matched model methods. Hedonic methods have been designed to permit quality and price changes to be captured with greater accuracy (i.e. a deflation technique based on a regression of the prices of a basket of goods on a set of

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[9] This index, in general, gives similar results to the Fisher Ideal Index that BEA use to produce the official NIPA.

[10] Hulten (1992) provides a clear discussion of this decomposition. Greenwood et al. (1997), however, point out that this calculation is likely to underestimate the impact of embodied technological change on output growth as it does not adjust for the endogenous response of investment to changes in the rate of quality growth and the ensuing drops in relative prices.

qualities or characteristics of those goods, to identify price changes due to quality changes). Although Aizcorbe et al. (2000) showed that, under certain conditions, a conventional matched model approach can yield similar results to hedonics, in practice, countries applying more conventional techniques record, for example, smaller price declines in ICT goods than countries applying the hedonic technique. Therefore, the US-based deflator for information equipment is often applied to nominal European national accounts data (e.g. Schreyer 2001, Van Ark et al 2002, Vijselaar and Albers 2004).[11]

In this paper, we follow a similar approach, not only for IT hardware, but also for other equipment and software (E&S) categories.

4.2. Quality-adjusted price index for investment

While many statistical agencies expend significant efforts to adjust investment price deflators for quality, there is growing evidence that substantial biases remain. The study by Gordon (1990) has been instrumental in documenting and quantifying the extent of these biases for the United States. Gordon's quality-adjusted indexes have been used by some researchers (starting with Hulten, 1992) as a way of quantifying the extent of improvement in equipment quality. However, for Europe, there have been –to our knowledge- no similar attempts to establish quality biases in investment prices. Our basic premise is that there is insufficient quality adjustment in European national accounts data for investment price deflators, like in the United States. The main attempt of this empirical part is to establish how much of a problem it is.

To that end, we use the data underlying Cummins and Violante (2002) to construct alternative price deflators for the euro area. Cummins and Violante (CV) extended the Gordon (1990) dataset of constant-quality equipment price indexes to cover the years until 2000. These CV deflators can be applied to nominal euro area investment data. However, substituting CV-based deflators for the euro area national accounts deflators introduces another key assumption, namely that underlying (non-quality adjusted) price developments in E&S investment between the United States and Europe are broadly comparable. This assumption is standard and seems warranted by evidence that internationally highly-traded goods are following broadly comparable price developments. In particular, from the trade pricing literature we know that price pass-through, although far from being perfect, does follow a predictable pattern of (lagged) adjustment, especially between advanced economies. However, US deflators might differ from European deflators for a host of reasons, including compositional effects in aggregate deflators and country-specific inflationary developments. We try to deal with these potential biases in the following ways.

First, the compositional effect is taken into account by calculating CV deflators for the individual investment categories for which we have data, rather than establishing an overall E&S price deflator directly. In particular, the CV dataset contains price indexes for 25 investment goods. However, our data for euro area investment goods are not as finely disaggregated into E&S assets. Therefore, we aggregate the CV deflators to the five available asset categories: IT hardware, communication equipment, software, transport equipment, and other machinery and equipment. The appendix provides more details on how we performed the aggregation of the CV data from 25 into 5 asset categories. A composition bias could still remain. Due to lack of more disaggregated euro area data, there is, however, no obvious way to establish the size or sign of any remaining bias.

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[11] Hedonic methods are increasingly used in euro area countries for deflating IT hardware in particular. Currently, France uses a price index for PCs in the PPI (since 1990) and Germany in the CPI (since 2002).

Second, in an attempt to take account of country-specific inflationary biases, we used a correction factor to the CV-based deflators that were established after the first step. The correction factor we applied takes into account the difference in developments between the overall E&S investment price deflator of the euro area and the corresponding one for the United States. Again, the US price deflator was corrected for composition differences before being applied in the correction factor. The advantage of this factor is that it is confined to inflationary biases in investment goods in particular.

After performing these two steps we are ready to present baseline estimates for the euro area of: 1) the overall quality bias of E&S deflators (Table 1), 2) the rate of growth of technological change that is embodied in E&S (Table 2), and 3) embodied technological change by disaggregated investment asset category (Table 3).

There is an important concern that we need to address in applying this second step. The official US price deflators for IT already incorporate a substantial degree of quality adjustment in contrast to the corresponding EU ones. To test for robustness we used two alternative correction factors: one based on differences in E&S deflators excluding IT hardware prices (Robust 1) and another one based on differences in overall CPI inflation (Robust 2). More generally, as an overall check for robustness, we used an alternative dataset for European investment data (the GGDC Total Economy Growth Accounting Database). The results with this dataset are called Robust 3 and are obtained under the baseline deflation scheme.

By comparing the growth rate of the quality-adjusted price index for E&S to the original price index for E&S based on the euro area national accounts deflators, we can compute the implied quality bias in the original price index. This bias arises because the CV quality-adjusted deflators decline on average more rapidly than the original deflators. According to our estimates the average annual quality bias in theeuro area was 3.7 percent in the 1980s, increasing to 4.4 percent in the 1990s, see Table 1. The results of the robustness tests are shown in the Table as well. The lower quality bias resulting from the use of the GGDC dataset results from the fact that the constructors of this dataset apply to the euro area a harmonised IT deflation method based on the US deflator. Thus, the GGDC dataset already corrects for part of the quality bias.

Table 1. Quality bias (average annual percentage change)

	1981-1990	1991-2000	1981-2000
Central estimate	**3.7**	**4.4**	**4.1**
Robust 1	4.8	4.9	4.8
Robust 2	5.0	5.1	5.0
Robust 3	2.9	3.2	3.0

Following, Cummins and Violante (2002), we construct next an index of the state of embodied technology, q. As argued earlier, under certain conditions, we can identify the index q as the relative price of consumption over investment:

$$q_t = P_t^{\tilde{i}} / P_t^c \qquad (23)$$

(23)

where P_t^c is the overall private consumption price deflator from the national accounts. When $P_t^{\tilde{i}}$ is an aggregate price index for E&S (the CV based index), q_t indexes aggregate technology. Otherwise, it refers to specific sectors or capital assets.

The aggregate rate of embodied technological change grows rapidly, at an annual average rate of 4.7% in the 1980s and of 6.0% in the 1990s (see Table 2). These results are similar to those found by CV for the US. This is not surprising as the underlying asset price deflators are the same and the asset composition at our level of aggregation is broadly comparable in the US and the euro area.

Table 2. Embodied technological change (average annual percentage change)

	1981-1990	1991-2000	1981-2000
Central estimate	**4.7**	**6.0**	**5.4**
Robust 1	5.8	6.4	6.1
Robust 2	6.1	6.6	6.3
Robust 3	5.2	6.0	5.6

Table 3 shows the rate of technological change for each of the five E&S categories we distinguish separately. Not surprisingly the largest gains are in IT hardware. Software was the only category to show a deceleration from the 1980s to the 1990s. Although people are generally worried about ICT, our estimates show that ignoring quality growth in other equipment categories may be a serious mistake.

Table 3. Embodied technological change (average annual percentage change)

	1981-1990	1991-2000	1981-2000
Information equipment	0.10	0.13	0.11
Software	0.04	0.02	0.03
Communication equipment	0.08	0.12	0.1
Other Machinery and equipment	0.04	0.06	0.05
Transport equipment	0.03	0.03	0.03
Equipment	0.05	0.06	0.05
E&S	0.05	0.06	0.05

Sectoral developments

While the broad developments are reflected across sectors, there are clear differences in the degree of the bias at the sectoral level (see Chart 1 below and Table A1 in the Annex). The quality bias is highest in the sectors investing most in other machinery and equipment, and/or in IT hardware.

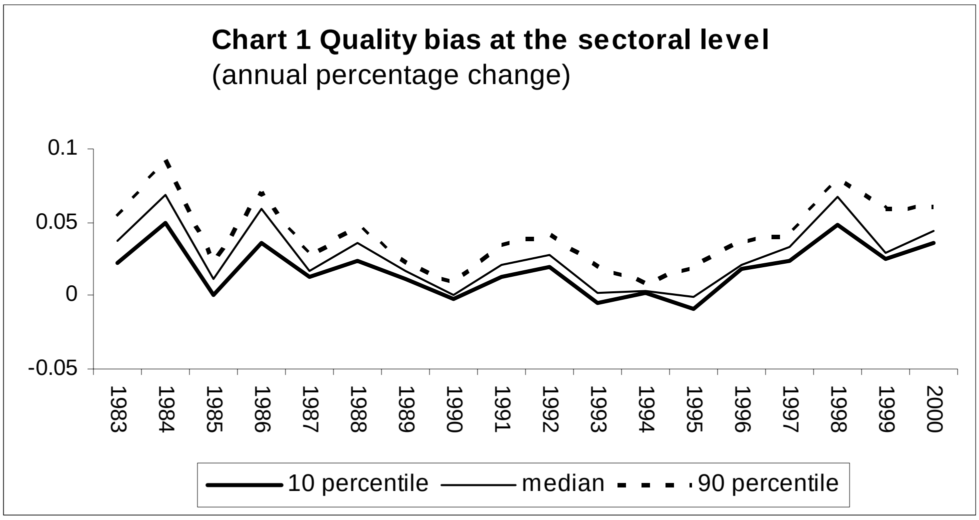


Chart 1 Quality bias at the sectoral level
(annual percentage change)

From the sectoral data, it is clear that technological change was rather stable across sectors up to 1995, but accelerated thereafter in line with an increased investment in IT hardware and communications equipment after 1995 (Chart 2 below and Table 2 in the Annex). An interesting fact that is evident in this Chart is that sectors leading in ETC jumped further ahead from the middle of the pack in the 1990s. By 2000 the distance between the 90th percentile of the distribution and the median, in terms of ETC, is the largest it has been throughout the two preceding decades.

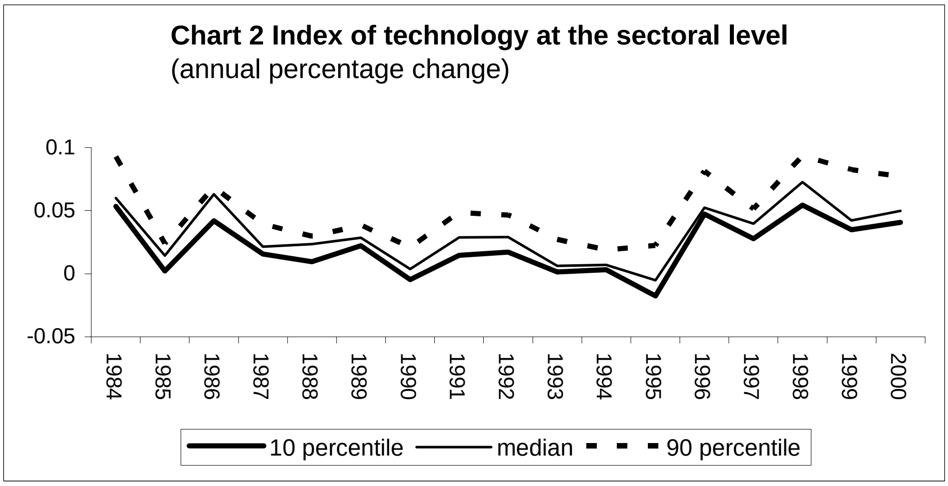


Chart 2 Index of technology at the sectoral level
(annual percentage change)

4.3. Quality-adjusted E&S capital stock and output

We use the following formula to construct the capital stocks:

$$k_{jt} = \sum_{b=0}^{b=mj} (1-□_j)^b \, i_{j(t-b)}, \qquad (24)$$

where i_{jb} represents real investment at time b in capital good j; $(1-□_j)^b$ is the efficiency at time t of investments in capital good j undertaken at time t-b, and m_j is the average service life of capital good j. When constructing conventional capital stocks (where original deflators are used) we use measures of economic depreciation rates, while when constructing quality-adjusted capital stocks (where CV-based deflators are used) we use measures of physical decay rates for δ_j. In line with BEA we use a geometric pattern of depreciation/decay.

We calculate physical decay rates by removing the quality-change component from the economic depreciation rate using our estimates of asset-specific quality improvement. More specifically, economic depreciation is the change in the value of an asset as it ages. The pure impact of ageing results from physical decay due to wear and tear. There is, however, an additional vintage effect that reflects obsolescence due to the change in the relative price of the asset. The physical decay rate can thus be calculated from the following formula:

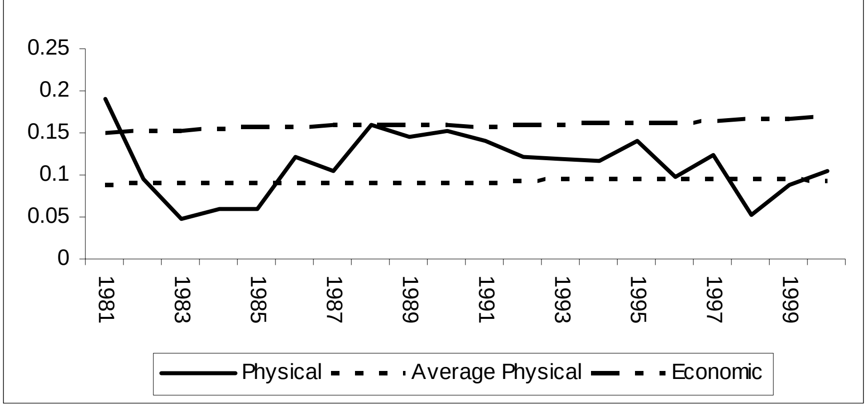
$$\delta_{j,t} = 1 - (1 - d_{j,t}) * (q_{j,t} / q_{j,t-1}) \qquad (25)$$

(25)

where δ is physical decay, d is economic depreciation and q is the relative price of an asset j.

When embodied technology improves, physical decay, δ, is lower than economic depreciation, *d*. Using the identity above, we calculate the physical decay rates and use these to construct our quality-adjusted capital stocks. Chart 4 shows the physical decay and the economic depreciation rate of E&S as an aggregate.[12] The economic depreciation rate is slightly increasing due to increased investment in assets with high depreciation rates, in particular IT hardware and software. Like CV, we find the physical decay rate to be rather volatile from year to year. In calculating the capital stocks, we therefore use the average of the physical decay rates across years.

Chart 4 Depreciation rates of euro area E&S



From Table 4 it is clear that the annual average growth rate of quality adjusted E&S capital stock where we use physical decay and CV-based deflators is about twice as high as the original E&S, where we use BEA style economic deprecation and non-quality adjusted deflators. The absolute difference in growth rates for the capital stock of IT hardware is larger. The decline in growth rate from the 1980s to the 1990s can be attributed in large part to the developments in the early 1990s, around the trough in economic growth when investment growth was relatively low.

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[12] As suggested by Whelan (2002), to derive an aggregate depreciation rate we aggregate asset-specific rates using as weights their shares in nominal capital stock.

Table 4 Quality-adjusted and original capital stocks
(annual percentage change)

	1982-1990	1991-2000	1982-2000
E&S quality adjusted	0.05	0.06	0.06
E&S original	0.03	0.03	0.03
difference	*0.02*	*0.03*	*0.03*
IT hardware quality-adjusted	0.15	0.12	0.14
IT hardware original	0.1	0.09	0.09
difference	*0.05*	*0.04*	*0.04*

After this adjustment of capital input, we now turn to calculating a quality-adjusted output growth series. To do so we use a Tornquist index on the growth rates of real investment output and real consumption (i.e. non-E&S output). The share used is the ratio of nominal investment to nominal output. It should be noted that the quality bias affecting machinery investment may simply affect imports rather than GDP (Schreyer 2001). Any upward correction due to investment is then cancelled by an equivalent downward correction of imports. As we do not have dataseries on the imports and exports of investment goods by type of asset compatible with our investment by type of asset series, we can not correct properly the downward bias. However, given the fact that the euro area is a net exporter for a number of investment goods, as indicated by the International Trade by Commodities Statistics of the OECD, it seems reasonable to assume that there is at least some downward bias in measured real GDP series due to the quality bias in price deflators.[13]

As expected, the quality-adjusted output growth is higher than the original output growth (see Chart 5). Note that quality adjustment has a substantial effect on real output growth in 1981-87, with an annual average difference of 0.4 percentage point, and 1994-2000, with an annual average difference of 0.7 percentage point, but not for the years in between, when the rate of technological change was relatively low, as was the equipment investment rate.

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[13] However, it should be noted here that the aggregation of GDP is not fully harmonised across euro area countries, as use is made of both chain-weighted (e.g. France) and fixed-weight aggregates (e.g. Germany). For countries that use a Laspeyres fixed-weight framework, upward biases may result in measured real GDP growth (e.g. Whelan 2000). The difference between the two methods is small as long as relative weights do not change significantly over time. However, in the event of strong changes in the relative weights, the use of a fixed basis leads to a distortion of the price and growth measurement, and this bias increases with the distance from the base period. According to EU standards for national accounts, all Member States should use annually chain-weighted measures by 2005.

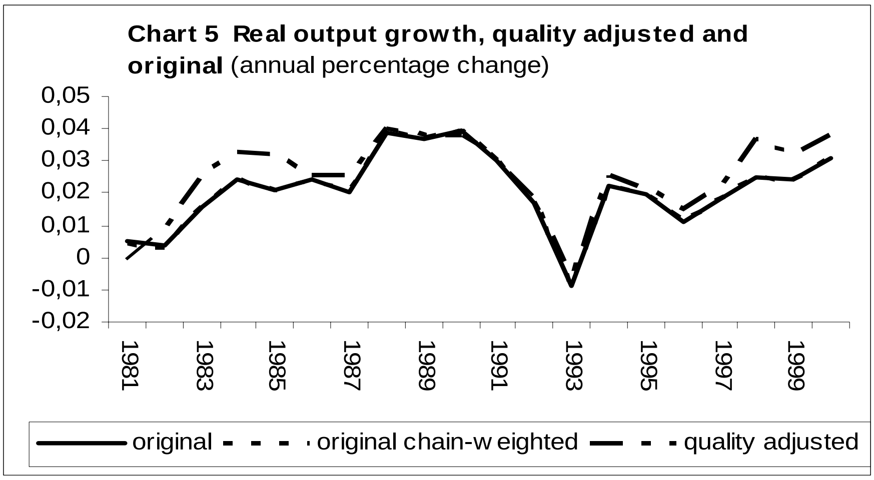

Chart 5 Real output growth, quality adjusted and original (annual percentage change)

4.4 Contribution of quality-adjusted capital to economic growth

To assess the contribution of capital to economic growth and to estimate the development of TFP, we carry out a standard growth accounting covering the period 1982-2000. The growth accounting framework was pioneered by Solow (1957) and further developed by Jorgenson and his associates (e.g. Jorgenson and Griliches, 1967; Jorgenson et al. 1987). The framework used here is similar to that used in Oliner and Sichel (2000).

In a growth accounting framework, the growth rate of output ($\dot{Y}$) is equal to the weighted growth rates of labour input ($\dot{L}$) and capital input ($\dot{K}$), plus growth in total factor productivity ($\dot{TFP}$). The following formulas were used here:

$$\dot{Y} = \alpha_L \dot{L} + \sum_j \alpha_{Kj} \dot{K}_j + \dot{TFP} \qquad (26)$$

which, after some rearranging, and assuming that $\sum_j \alpha_{Kj} = 1 - \alpha_L$, yields the following expression for ALP:

$$\dot{Y} - \dot{L} = \sum_j \alpha_{Kj} (\dot{K}_j - \dot{L}) + \dot{TFP} \qquad (27)$$

Time subscripts have been suppressed for simplicity of notation. Labour input growth is measured in total hours worked. Due to data limitations, no adjustment has been made for the quality of labour in this exercise.

As to capital inputs, in all, six categories of capital have been distinguished: our previously distinguished five categories of E&S plus the stock of non-residential construction. The latter stock is assumed to be unaffected by quality biases. Depreciation and efficiency decay are derived consistently, using a geometric rate of decline. The sum of the shares of the various types of capital is assumed to be equal to 1- α_L, a standard assumption in this kind of exercise reflecting constant returns to scale. The shares of the different types of assets in total capital input are based on the user cost of capital, i.e. the gross rate of return that must cover the internal rate of return (assumed common to all capital), the depreciation rate, and the capital gain/loss of the specific capital good. Tax considerations were not taken into account, but the impact of taxes on the user cost of capital is assumed to be captured by the internal rate of return.

The results of our estimates are shown in the tables below. From these tables it is clear that the contribution of quality-adjusted capital is much higher than previously calculated. Interestingly, this does not relate only to IT hardware, but most importantly to other machinery and equipment. Due to the effects of quality adjustment in output, TFP growth hardly differs from the original case in absolute terms. However, as a percentage of total output it declines: Quality adjustment subtracts 11 percentage points from the share of TFP in output growth and adds them to the contribution of equipments stock. As a memory item, ETC is identified in Table 5. The contribution to growth of ETC is substantial, and even increased from the 1980s to the 1990s, as a share of total output from 40% to over 50%.

As a final result of our exercise, we decomposed the sources of economic growth in percentages of overall output growth along the lines of ETC. Again it is clear that ETC is a major contribution to growth, with both the quality of capital and investment specific TFP increasing from the 1980s to the 1990s. As a final note, it is interesting to see that the investment specific component of TFP increased even though overall TFP decreased.

5 Contributions to output growth (percentage points)

	1982-1990		1991-2000		1982-2000	
	Quality adj.	original	Quality adj.	original	Quality adj.	original
Output	2.97	2.49	2.34	1.90	2.64	2.18
IT hardware	0.11	0.07	0.11	0.08	0.11	0.08
Software	0.07	0.07	0.07	0.07	0.07	0.07
Communication equipment	0.08	0.05	0.12	0.05	0.10	0.05
Other machinery and equipment	0.43	0.17	0.45	0.17	0.44	0.17
Transport equipment	0.04	0.05	0.12	0.06	0.08	0.06
Nonresidential structures	0.16	0.16	0.09	0.08	0.12	0.12
Labour	-0.12	-0.12	-0.07	-0.07	-0.09	-0.09
TFP	2.20	2.04	1.45	1.46	1.80	1.73
Embodied TC	1.15		1.27		1.21	

Table 6 Decomposition of output growth (percentage of total growth)

		1982-1990	1991-2000	1982-2000
Capital		**0.30**	**0.41**	**0.35**
	Quality of capital	0.19	0.27	0.23
	Quantity of capital	0.12	0.14	0.13
Labour		**-0.04**	**-0.03**	**-0.04**
TFP		**0.74**	**0.62**	**0.68**
	Investment specific E&S	0.20	0.27	0.23
	rest of TFP	0.54	0.35	0.45

5. Conclusion

Capital quality improvement is a general and widespread phenomenon that creates the necessity for proper accounting in order to avoid misleading statements about the sources of economic growth. Two adjustments need to be made in order to measure capital stock and output growth accurately. First, the prices of new capital goods need to be adjusted to reflect the improvement in quality embodied in them. Otherwise, output growth in the investment-good producing sector will be underestimated. Second, productive capital stocks (or more accurately, the service flows from capital that serve as input in production) should be constructed after deflating nominal investment flows by a quality-adjusted price index and depreciating old vintages with a rate that does not include quality change. Otherwise, the contribution of capital equipment to output growth is likely to be understated.

In our attempt to achieve the goal of proper accounting for euro area growth we apply the dataset of Cummins and Violante (2002) that provides quality-adjusted prices for disaggregated investment goods. Thus, we uncover substantial upward biases in the growth rates of euro area official price indexes. This has important implications for output growth itself as well as the sources of output growth. In particular, we ascribe a much more important role for capital in output growth and a correspondingly less important role for Total Factor Productivity. In itself, this reduction in the "extent of our ignorance" is very important. Furthermore, our results give rise to Embodied Technological Change as the key engine of growth in the euro area for the decades of the eighties and nineties.

Our analysis of growth in the euro area after adjusting for capital quality improvement also suggests the following:

- The slowdown in output growth in the 1990s is marginally more pronounced after quality adjustment.
- The contribution of TFP growth, in other words of technological change that is not embodied in capital goods, to the slowdown in output growth does seem more pronounced after quality adjustment.

These results suggest that the euro area has a problem with disembodied technological change. In fact, this problem is more acute than appears without proper accounting for capital quality growth. As Table 6 shows the contribution of TFP to total growth fell from 74% in the eighties to 62% in the nineties. This points to the need for adoption of microeconomic measures aimed at enhancing overall efficiency. Such measures would aim at a better business environment by easing regulatory and administrative burden and liberalizing energy and telecommunications markets. Additionally, they would aim at boosting innovation activity. We have not discussed much in this paper the role of labour input. Our focus has been on the contribution of capital quality. However, it should be clear that increased labour market flexibility could enhance TFP growth as it facilitates the process of reallocating resources to their most efficient uses.

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Annex. Sectoral results

Table A1. Quality bias (annual percentage change)

	1983-1990	**1991-2000**	**1983-2000**
Agriculture	0.00	0.03	0.03
foods	0.03	0.02	0.03
textiles	0.03	0.02	0.02
wood/pulp	0.02	0.02	0.02
mining	0.03	0.05	0.04
Chemicals	0.02	0.03	0.03
rubber/plastic	0.02	0.02	0.02
metals	0.03	0.04	0.04
Machinery and equipment nec	0.03	0.04	0.03
electrical and optical equipment	0.01	0.02	0.02
transport equipment	0.02	0.02	0.02
Electricity/gas/water	0.03	0.03	0.03
Construction	0.01	0.01	0.01
Wholesale and retail	0.02	0.02	0.02
hotels/restaurants	0.02	0.02	0.02
transport/storage/communication	0.03	0.02	0.03
financial intermediation	0.03	0.02	0.02
real estate, renting and business services	0.01	0.01	0.01
public administration	0.03	0.03	0.03
Education	0.02	0.02	0.02
health	0.03	0.03	0.03
other community services	0.03	0.02	0.02

Table A2. Embodied Technological change (annual percentage change)

	1984-1990	**1991-2000**	**1984-2000**
agriculture	0.03	0.04	0.04
foods	0.02	0.03	0.03
textiles	0.02	0.03	0.03
wood/pulp	0.03	0.03	0.03
mining	0.05	0.06	0.05
chemicals	0.04	0.04	0.04
rubber/plastic	0.03	0.03	0.03
metals	0.07	0.07	0.06
machinery and equipment nec	0.04	0.05	0.05
electrical and optical equipment	0.03	0.03	0.03
transport equipment	0.03	0.03	0.03
electricity/gas/water	0.03	0.04	0.03
construction	0.03	0.02	0.02
wholesale and retail	0.02	0.02	0.02
hotels/restaurants	0.04	0.04	0.03
transport/storage/communication	0.02	0.03	0.03
financial intermediation	0.03	0.03	0.03
real estate, renting and business services	0.02	0.02	0.02
public administration	0.02	0.03	0.03
education	0.03	0.03	0.03
health	0.03	0.04	0.03
Other community services	0.02	0.03	0.03

Appendix 1: Data sources and aggregation methods

Data at the aggregate level

Value added and investment: data for value added and investment by type of asset were taken from the national accounts of France Germany, Italy and the Netherlands. These countries represent over 75% of the euro area total value added. The country data were aggregated to a euro area total estimate (for aggregation methods see below). The structural break due to German re-unification has been corrected by applying West-German growth rates to all German levels back in time, a standard approach in the economic literature. Moreover, in the case of non-ICT investment, some series had to be backcast by applying growth rates of ESA79 data to the ESA95 time series in order to construct long-enough time series. The data and detailed information on the data sources are available from the authors upon request.

Labour hours: total employment data (in persons) were taken from national accounts and average working hours from OECD (2002).

Labour share: The income share of labour ($\square_L$) is calculated from the national accounts, by adding to total compensation of employees (which can be taken directly from the national accounts) the compensation of the self-employed, assuming that the income share of the latter category is proportional to the share of self-employed in total employment. The measure of gross value added is adjusted to exclude rental income from residential property, as residential capital is not included as a production factor in the growth accounting exercise (see below). The capital share is defined as 1 minus the labour share. In the growth accounting, variation of factor shares over time is taken into account by the use of a Törnqvist index.

Share of capital: The income share for each type of capital is calculated from the following equation:

$\square_{Kjt} = (c_{jt}\ K_{jt}) / (p_{yt}\ Y_t)$

where Y is real gross value added, K_{jt} is the gross current cost capital stock of the respective capital good, and c_{jt} the user costs of capital, which are calculated by using the following formula:

$c_{jt} = (r_t + \square_{jt} - \pi_{jt})$

where π_{jt} is the expected capital gain/loss and is calculated as a three-year moving average of the annual price change of the capital good in question (following CPB 2000 and Oliner and Sichel 2000), $\square_{jt}$ is the depreciation rate, r represents the nominal rate of return and is assumed to be equal over all types of stocks of capital goods.

Economic depreciation rates and average service lives are set equal to those used by the US Bureau of Economic Analysis (1999). In particular, economic depreciation rates and asset lives assumed are respectively 0.254 and 8 years for computers and related equipment, 0.15 and 11 years for telecommunications equipment, 0.1319 and 13 years for other machinery and equipment, 0.115 and 15 for transport equipment, and 0.0253 and 36 years for non-residential construction. Investment in residential dwellings is not taken into account. The depreciation rate and service life for software, which are not determined by BEA (1999), have been set at 0.4435 and 4 years, based on assumed service lives for pre-packaged and own account software in Oliner and Sichel (2000). In particular, the net value of an intangible asset such as software can be expected to be close to zero at the end of its assumed service life. This implies a relatively large declining balance rate and thus a relatively high depreciation rate.

The rate of return is thus calculated for each year as the ex post return from the equation:

$$\sum_j ((r_t + \square_{jt} - \pi_{jt}) K_{jt}) / (p_{yt} Y_t) = 1- \square_{Lt}$$

This is the most widely used method assuming perfect foresight. It fits in with the standard equilibrium assumption used in growth accounts and has the clear advantage of being straightforward. However, as also explained in Vijselaar and Albers (2004), this measure may not reflect conditions faced by firms making investment decisions at the beginning of the period. An alternative method would be to choose an exogenous expected rate of return. This, however, would have the disadvantage of having to underpin the chosen structure of expectations. Furthermore, it would make the total value of capital services differ from the non-labour income as determined in the national accounts and thus seems a less attractive option from a consistency point of view. For a more elaborate discussion see OECD (2001).

Data at the sectoral level

The main data source used is the OECD STAN database, which contains data on a detailed (two-digit ISIC rev.3) sectoral level for gross value added, investment by sector, and employment for a number of euro area countries (Austria, Finland, France, Germany, and Italy which represent over 75% of euro area total value added). The country data were aggregated to a euro area total estimate (for aggregation methods see below). Employment includes self-employed persons in all cases. For investment series, data from this database are not disaggregated. Here we used a RAS-procedure to construct investment series by asset and sector. In particular, this method uses the known row (investment by n sectors) and column (investment by m types of asset) totals for every year, to fill out the matrix cells of a n x m matrix. This is done via an iterative convergence process, based on an initial distribution of the matrix cells. US ratios of investment by sector and asset were used to fill out an initial matrix to start the convergence process. It should be noted that the country coverage does not fully match between the sectoral and aggregate economy data. Row totals therefore were (slightly) adjusted to match column totals.

Our dataset also contains data on output in services sectors, including public services. Value added in the services sector is notoriously hard to measure. This is even worse for public services. Any recorded value added in the latter sectors is imputed. The deceleration in value added growth for example over the 1990s in these sectors is the consequence of wage moderation in the public sector that implied a lower measured output growth. Thus, the measures of productivity and technical change in these sectors in particular, may be seen as controversial.

Aggregation of euro area data

Where appropriate, purchasing power parities were used to compute euro area aggregates, in accordance with standard practices for cross-country comparisons of economic growth (Van Ark 1996). 1996 EKS purchasing power weights as reported in OECD (1999) were applied. In particular, the expenditure PPPs by industry were matched to the sector distinguished for sectoral output, while investment PPPs by main type of asset were used for investment (the so-called 'proxy' PPP approach).

For lack of specific PPPs for ICT capital formation, equipment PPPs were used (this choice, while far from ideal, seems the only viable solution). The use of PPPs is motivated by the need for a conversion factor which takes cross-country differences in price levels and relative price differences among expenditure categories into account. However, the alternative of applying one common conversion factor, such as the aggregate weights used by Eurostat or those used in the Area-Wide model for the euro area (Fagan et al. 2001), does not change the results significantly. The alternative of conversion at current exchange rates is not appropriate, as it does not allow for difference in price levels among countries. Moreover, current exchange rates are volatile and affected by a number of factors, such as capital movements, trade flows, and the sentiment of financial markets, which makes them unsuitable to compare fluctuations in real economic activity across countries. Finally, it should be noted that in line with Eurostat standards, no attempt has been made to correct for the fact that some of the raw data are compiled on the basis of chain-weight indexes and some on the basis of fixed-weight indexes. It therefore can not be excluded that some index number biases remain in the aggregate data (see also footnote 15).

Aggregation of CV deflators

The Cummins and Violante (CV) dataset contains price indexes for 25 investment goods. Since our data for the euro area are not as finely disaggregated into E&S assets we aggregate the CV deflators to five asset categories: IT hardware, software, communication equipment, transport equipment, and other machinery and equipment.

It seems straightforward to chain-aggregate the US data using as weights the nominal investment share of every asset in the total investment of the category to which it belongs. However, the chain-aggregated price deflators thus calculated for the four categories we distinguish would not be equal to the implicit price deflator of these categories (defined as nominal investment divided by real investment). As a result, the chain-aggregated price deflators cannot be applied to the nominal euro area E&S investment series. The problem is that the composition within the asset categories is not known in the European case (it is for this reason that we need to aggregate the US data into fewer categories in the first place).

We therefore follow an alternative approach where we back out implicit price deflators and apply these deflators to construct quality-adjusted real E&S investment series for the euro area. In particular, we construct a volume index for each of our five asset categories by chain-aggregating US real investment growth from the underlying investment series using the nominal investment shares as weights. These volume series are subsequently brought to a 1995 US dollar basis. Finally, we divide the nominal investment series by the real investment series to back out the implicit price deflator for the five categories. Starting from the growth rates in real investment, rather than from the fast declining price deflators, safeguards from over-estimating real investment growth in the euro area.

Perhaps the potential bias problem of chain-aggregated deflators is best explained through an example. The clearest example to consider seems to be that of IT hardware. This asset category is constructed from three components in the US data: computer and peripheral equipment, photocopy and related equipment, office and accounting equipment. For the euro area, we only have the total investment in information equipment not the three components. How, then, should we calculate the euro area real series for investment in IT hardware? Our approach is to construct an implicit price deflator using the US real and nominal investment series for IT hardware. Chart 1 displays two alternative euro area series for real investment in IT hardware. Both are based on the nominal euro area series. For one series the US deflator used is directly chain-aggregated from the CV price deflators, whereas for the other series our preferred implicit price deflator is used from the "backing-out" approach described earlier. The Chart shows that the direct chain-aggregated price deflators vastly overestimate euro area real investment in IT hardware, especially in the second half of the 1990s.

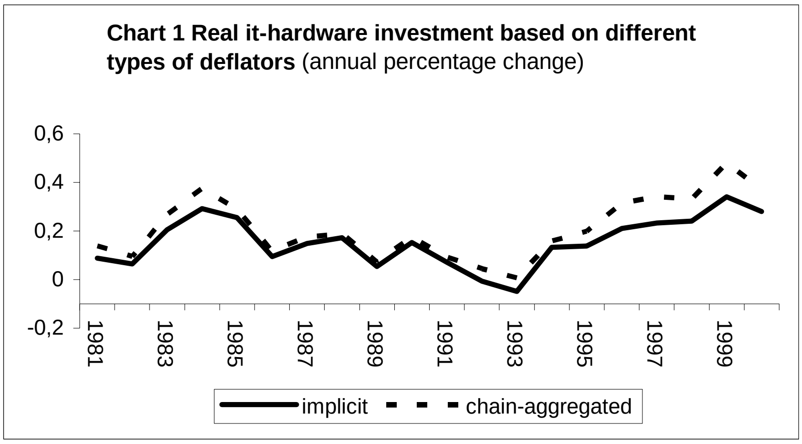
Chart 1 Real it-hardware investment based on different types of deflators (annual percentage change)

The implicit US deflators are used in a Tornquist procedure to aggregate the asset-level price indexes into a quality-adjusted price index for total E&S in the euro area. In particular, the change in the aggregate quality-adjusted price index for E&S is calculated using the formula:

$$\Delta \log P_{i,t} = \sum_{j} \log \left(P^{i}_{j,t} / P^{i}_{j,t-1}\right) / \left(\left(S^{i}_{j,t} + S^{i}_{j,t-1}\right)/2\right)$$

where, S^{i}_{j} is the nominal investment share of type of asset j, and P^{i}_{j} is the corresponding quality-adjusted price index. We then recover the level of the price index recursively. In doing so we allow for a different asset composition in the euro area.

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