The sensitivity of capital services measurement

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THE SENSITIVITY OF CAPITAL SERVICES MEASUREMENT: MEASURE ALL ASSETS AND THE COST OF CAPITAL

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The measurement of capital inputs is still a contentious issue: many choices have to be made that have potentially large effects on the resulting capital input series. This paper compares a large number of methodological choices and their impact on U.S. capital services at the industry and aggregate level. The results show that the set of capital assets covered and the choice for the rate of return matter substantially, while other choices are less important. I argue that land, inventories, and intangible capital should be included and that for pragmatic reasons, an external cost of capital is preferable to an internal rate of return because of its transparency and robustness to measurement error.

INTRODUCTION

A new building, piece of machinery, or software package will be used in production for a considerable period of time. For how long tends to differ: where buildings have service lives measured in decades, machinery has a productive life of around 10–20 years, and software needs to be replaced after 3–5 years. The key challenge in measuring capital as a production factor is how to account for these differences across assets and get an accurate measure of the overall service flow from these capital assets.

In this paper, I test the sensitivity of capital input measures to the methodological choices that are made.[1] The 2008 edition of the System of National Accounts (SNA; United Nations, 2008) provides statistical agencies with the option of including capital services as part of the National Accounts, so an analysis of the importance of various methodological choices will be useful for statistical agencies that want to follow this route. I show that the choice for the rate of return is particularly important as well as including a set of assets that is as complete as possible.

In current international comparisons, such as the EU KLEMS database (see O'Mahony and Timmer, 2009; www.euklems.net), only fixed reproducible assets could be included. However, land and inventories are also part of the productive

[1]The focus is on *productive* stocks of capital used in production, not wealth stocks; see Schreyer (2009) for more discussion on this distinction.

capital stock and I find that including them matters substantially.[2] Intangible investment is another important category. The 2008 SNA recommends that research and development spending should be recognized as an investment (see United Nations, 2008, ch. 10.104), just as much of software spending is already recognized as an investment. Using the data and classification of Corrado *et al.* (2005, 2009), I show that including intangible investment is of first-order importance for estimating capital services.

My approach in this paper is mainly pragmatic. It is obviously important to use capital input measures that are informed by economic theory, but as it turns out, some refinements that are important from a theoretical perspective turn out to have only a limited impact on the growth of capital input. Of key importance is accounting for the heterogeneity of assets. A dollar or euro worth of buildings will yield substantially lower productive services than a computer because the user cost of capital is lower. Jorgenson and Griliches (1967) were among the first to argue this point and it remains as important as it was back then.

However, the specification of the user cost is as contentious as ever. In brief, the user cost consists of a required rate of return on capital, the depreciation rate, an asset revaluation term, and an adjustment for the tax treatment of capital assets (see Hall and Jorgenson, 1967). In this paper, I do not discuss the estimation of the depreciation rate or the sensitivity to different depreciation rate estimates.[3] However, the other components of the user cost are dealt with in detail. Similarly, I also leave aside here the construction of the data on which capital stock estimates are based, namely the investment by industry and asset and "starting" capital stocks for the early years of the analysis. Both data elements are very important and changes to these will have first-order effects on the resulting capital services series. For this paper though, I take capital stocks by asset and industry as my starting point.

The entire sensitivity analysis is based on data for the United States. The main reason is that some data are not available for other countries. In particular, there is U.S. data on all the necessary tax parameters and capital stocks for land, inventories, and intangibles.[4] Most if not all of these data are lacking for other countries. This also highlights an important secondary aim of this paper. The main goal is to evaluate the sensitivity of capital input measures to the assumptions used, but the results can inform whether it is useful for other countries to develop measures for some concepts that they currently do not measure. In relying on U.S. data, this exercise is comparable to that of Harper *et al.* (1989) but the range of methodological choices considered is larger. An international comparison, such as Erumban (2008), is also very insightful but would restrict the range of methodological choices.

The results show the importance of including intangible assets and the choice for the rate of return. The inclusion of land and inventories and tax parameters are comparatively somewhat less important, but in my opinion would still merit

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[2]See, e.g. Diewert *et al.* (2005) for evidence from Japan, and Diewert (2008) for a general discussion.

[3]For more discussion on that topic, see the Schreyer (2009) manual on capital measurement.

[4]The basic investment data are from the BEA; taxes, land, and inventories are from the BLS; and investment in intangible assets are from Corrado *et al.* (2005, 2009).

further study and data collection. The specification chosen for the asset revaluation term and the treatment of negative user costs are of secondary importance. Choosing the rate of return is particularly contentious and there are broadly two alternatives. In the first alternative, the rate of return is chosen to equate capital compensation to residual income. This is commonly referred to as the internal rate of return, or sometimes balancing rate of return. The second alternative estimates the cost of capital using data from financial markets on the opportunity cost of capital; this is commonly referred to as the external rate of return.

Theoretical work on this topic has arrived at a definite prescription for using an internal rate only in restrictive circumstances (Berndt and Fuss, 1986). In more general settings, for example allowing for investment in more than one asset, predictions are more ambiguous (Oulton, 2007). Also, using an internal rate of return tends to lead to considerable practical problems, as will be discussed in detail below. The hybrid solution proposed by Oulton (2007) does not solve many of these problems and tends to lead to substantially higher capital growth rates than either the internal rate or external rate. Using an external measure of the rate of return avoids these issues and therefore seems preferable from a practical point of view.[5]

Conceptual Framework

To frame the discussion, I first discuss the basic approach to capital measurement.[6] Given investment (at constant prices) I in industry i, asset k at time t, and geometric depreciation rate δ, the capital stock A can be estimated using the perpetual inventory method as follows:

$$(1) \qquad A_{i,k,t} = (1 - \delta_k) A_{i,k,t-1} + I_{i,k,t}.$$

This assumes that investments made in different years (different vintages of capital) are perfect substitutes after accounting for depreciation. We are interested in the service flow from each of the assets rather than the value of assets accumulated, and the value of stock A is in general not a good indicator of the contribution of A to overall capital services. For example, buildings make up the largest part of the total stock by value, but the long service life of a building implies a long flow of services from these buildings. To capture the marginal product of a capital asset, a user cost of capital is estimated, following Hall and Jorgenson (1967). This requires assuming that firms are price takers in the market for capital assets, and hence marginal costs equal the marginal product of capital. The basic user cost formula of Hall and Jorgenson (1967) is:

$$(2) \qquad u_{i,k,t} = \frac{1 - ITC_{k,t} - \tau_t Z_{k,t}}{1 - \tau_t} \left(R_{i,t} + \delta_k - v_{i,k,t} \right) + \tau_t^P \equiv T_{k,t} \left(R_{i,t} + \delta_k - v_{i,k,t} \right) + \tau_t^P,$$

[5]Note that this is also the choice made by Statistics Netherlands in their productivity accounts, mostly in order to make the fewest number of theoretical assumptions (see Balk, 2008).
[6]See other studies for the formal derivations of what follows, e.g. Oulton (2007), Harper *et al.* (1989), or Berndt and Fuss (1986).

with *ITC* the investment tax credit rate, τ the corporate tax rate, Z the present value of depreciation allowances, R the rate of return on capital, v the asset revaluation term, and τ^P the property tax rate. How the rate of return and asset revaluation term is implemented in practice will be discussed below. Given the user cost, the income stream associated with the asset, capital compensation C, can be calculated as:

$$(3) \qquad C_{i,k,t} = r_{i,k,t} A_{i,k,t} \equiv u_{i,k,t} p^I_{i,k,t} A_{i,k,t}$$

where r is the rental price of the capital asset and p^I the investment price. Capital services K can be calculated as a Törnqvist aggregate of individual capital stocks, using capital compensation as weights.[7] The two-period capital compensation shares are given by:

$$(4) \qquad c_{i,k,t} = \frac{1}{2}\left(\frac{C_{i,k,t-1}}{\sum_k C_{i,k,t-1}} + \frac{C_{i,k,t}}{\sum_k C_{i,k,t}} \right),$$

so that the growth in capital services can be calculated as:

$$(5) \qquad \Delta \ln K_{i,t} = \sum_k c_{i,k,t} \Delta \ln A_{i,k,t}.$$

The key issue is how to implement equation (2) in practice. Jorgenson and associates (see, e.g. Jorgenson *et al.*, 2005) assume a linearly homogenous production function, perfect foresight, and perfect competition in their approach to measuring capital input.[8] In that case, v is the actual price change of the investment good during that period, so that (2) can be rewritten as:

$$(6) \qquad u_{i,k,t} = T_t\left(R_{i,t} + \delta_k - \Delta \ln p^I_{i,k,t} \right) + \tau^P_t.$$

Furthermore, the assumption of perfect competition implies that the sum of capital income equals residual income, i.e. industry output minus intermediate purchases and labor compensation. Denoting residual income by *CAP*, R can be solved from the following equation:

$$(7) \qquad CAP_{i,t} = \sum_k C_{i,k,t} = \sum_k \left(T_t\left(R^I_{i,t} + \delta_k - \Delta \ln p^I_{i,k,t} \right) + \tau^P_t \right) p^I_{i,k,t} A_{i,k,t}.$$

R^I is referred to as the internal rate of return. This approach has the advantage of a consistent system of accounts as all output is attributed to factor income.

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[7]As Diewert (1976) has shown, the use of a Törnqvist aggregate explicitly relates this aggregate to an economic model of production.

[8]See, e.g. Hall (1990) on growth accounting when there is imperfect competition. In that case, the cost share is multiplied by the returns to scale factor to arrive at output elasticities.

Rate of Return

The theoretical basis for the Jorgensonian implementation in equation (7) is fairly restrictive though, relying on perfect competition and foresight. In the somewhat more realistic setting of Berndt and Fuss (1986), firms first choose their capital investments, and when uncertainty about input prices, demand, and technology is resolved in the next period, they choose their other inputs. This means that firms have to make an ex ante judgment about the user cost of capital to inform their investment decision, but the output elasticity of capital will depend on the realized, *ex-post*, user cost. In practice, this would mean that to explain investment behavior, one would use the opportunity cost of funds of the firm, for example an estimate of the weighted average cost of capital (WACC). But to determine the productive effect of capital, one would use an internal rate of return.

This prescription seems straightforward, but alas, it depends on further restrictive assumptions. In particular, Berndt and Fuss (1986) only consider investment in a single capital asset rather than the multitude of different assets (buildings, machinery, etc.) that is available in practice. As Oulton (2007) shows, the conclusions are much less clear-cut in a world with many assets and with no single appropriate rate of return. Oulton (2007) ends up advocating a *hybrid* approach that uses an external rate of return to aggregate across different capital assets and an internal rate of return to determine the overall output elasticity of capital.

But aside from theoretical concerns, it is important to consider the difficulties in practical implementation as well.[9] A key assumption in the background to all these models is that we know investment in each asset of a certain firm without error. In practice though, statistical agencies face the challenging task of allocating total investment in each asset across industries (rather than firms) and total investment by each industry across assets. This also assumes that we know exactly what are investments and what are expenses, while this is less than straightforward in practice. For example, spending on research and development (R&D) is currently classified as an expense rather than an investment even though R&D is typically involves a pay-off in the future. However, it is difficult to determine what this pay-off is and how the value of past investments evolves over time (see, e.g. Nakamura, 2010).

Finally, to correctly implement equation (7), we need an accurate estimate for total capital income. However, in industries where the number of self-employed is high, this is problematic since they earn "mixed" income, i.e. compensation for both their labor and capital input.[10] Estimating the capital income component of mixed income thus involves the efforts of researchers or a statistical agency. Taken together, it is clear that measurement error will play a sizeable role and by using equation (7), the measurement error will in part show up in variation of the internal rate of return, leading to, for example, drastically different user costs for the same asset across industries. Using an external rate of return would avoid these problems.

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[9]See Diewert (2008) for a more extensive discussion of these topics.

[10]Furthermore, Basu *et al.* (2010) have shown that at least in banking, current output measurement is by no means without error, implying even greater challenges.

Moreover, even in the (restrictive) worlds of the Berndt–Fuss and Oulton models, an external rate of return has a role to play. As mentioned above, firms make an ex ante assessment of the future user cost of capital in making their investment decisions. Indeed, Gilchrist and Zakrajsek (2007) use corporate bond data to construct firm-specific user costs of capital and find a strong relationship between this user cost and firm investment. In any specific year, the actual ex post rate of return will deviate from the ex ante rate, but on average over time the two should be similar.[11]

From the point of view of my sensitivity analysis, it makes sense to compare the three main approaches that have been advanced. The first is to use an internal rate of return as in equation (7). The second is to use an external rate of return. Harper *et al.* (1989) use the yield on corporate bonds with a BAA rating as their external rate of return, but this only measures the cost of debt, not of equity. Here I will estimate a weighted average cost of capital, to be discussed in more detail below. The third and final approach is Oulton's (2007) hybrid approach, where I use the external rate of return to calculate aggregate capital services growth and the internal rate of return to calculate the contribution of capital to economic growth.

Asset Revaluation

Another source of many practical problems in user cost calculation is the asset revaluation term. In the case of perfect foresight or under the Berndt and Fuss (1986) assumptions, realized asset price changes would be the appropriate measure for this term. Outside this setting though, it is much less clear. Using realized asset price changes also has practical consequences. Asset prices tend to fluctuate substantially from year to year and in practice, using annual realized asset price changes for the asset revaluation term could even lead to negative user costs when asset prices are rising rapidly. Of course, a firm can always decide *not* to use a particular asset in production (which would mean the asset makes no contribution to output), so it is justifiable to constrain user costs to be non-negative. But even without negative user costs, large year-to-year swings in the user cost of capital would imply that the contribution of a capital asset to output would show considerable variation over time driven by some exogenous rate of asset inflation.

There is less guidance when it comes to specifying the asset revaluation term should one want to depart from using current asset price changes. From an ex ante point of view, what matters is the expected asset price change, but this expectation will depend on the (unknown) information set of the firm. As a practical matter, Verbrugge (2008) uses sophisticated VAR forecasting models to estimate the asset revaluation term for U.S. residential housing and shows that there is very little correspondence between ex ante user costs and observed rents at an aggregate level. Garner and Verbrugge (2009) show a similar divergence at the level of individual houses. Rents and ex ante user costs are only similar when highly inaccurate forecasting models are used to estimate the asset revaluation term.[12]

[11]More precisely, a rational firm should not make systematic prediction errors.
[12]A frictionless user cost estimate assuming no asset revaluation (in the short run) provides the best approximation of rents. Whether this finding generalizes to other assets is unknown.

There is thus little guidance from either theory or empirical findings. Not surprisingly, there have been many alternatives used in the literature, such as the average price change across assets,[13] moving averages (Gilchrist and Zakrajsek, 2007), ARMA models (Oulton, 2007), and VAR models (Verbrugge, 2008). Given this situation, it seems most sensible to compare some alternatives and evaluate their impact on capital services growth. If negative user costs do occur, it is desirable from an economic point of view to constrain them to be non-negative.[14]

Data

For the empirical analysis that follows, I use data for the United States as this allows for the widest range of scenarios to be examined. The core data consists of investment at current and constant prices in 47 assets for each of 30 industries in the EU KLEMS database for the period 1901–2005. These data are mostly based on the detailed fixed asset tables published by the BEA on 46 non-residential fixed assets. We supplement these data with information on investment by the government and investment in residential buildings.[15] We then classify these investment series to the EU KLEMS industries.[16] I have chosen to use the set of EU KLEMS industries, as this is the most relevant for international comparisons. The analysis itself focuses on the 1977–2005 period, as all the complementary data are available for this period.

The data on investment in fixed reproducible assets (henceforth referred to as BEA assets) is supplemented by data on residual income CAP from the EU KLEMS database, where CAP is calculated by subtracting labor compensation from value added. Value added as given by the BEA in the GDP by industry accounts includes net taxes on products and production.[17] However, from a production-theory point of view, net taxes on products, such as sales taxes in the U.S., should be excluded. Net taxes on production, mainly property taxes in the U.S., should be included, however. A breakdown between these two types of taxes is only available at the aggregate level. At the industry level, these two types of taxes are distinguished by assuming that all subsidies are subsidies on production

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[13]Using the average price change across assets is equivalent to using a constant real rate of return as advocated by Diewert (2005); see Harper *et al.* (1989).

[14]In what follows, I do not show the sensitivity of capital services to different methods for dealing with negative user costs as it turns out to be quantitatively unimportant, partly due to the infrequent occurrence of such negative user costs. Results are available on request.

[15]The BEA data on government investment are only available for a number of types of buildings and overall equipment and software. To distinguish between different types of equipment and software, data on government investment from the 1997 Use Table is used in combination with the 1997 Capital Flow Table to bridge investment in commodities to investment in BEA capital assets. This asset distribution is held constant over the sample period, in part because older Use Tables did not count software expenditure as a capital investment.

[16]Some EU KLEMS industries, such as motor vehicle trade and repair (NACE 50) are not available in this dataset. We split up industries using data on value added, assuming constant asset shares and assuming constant value added shares before 1977. So in this example, we estimate investment for motor vehicle trade and repair by splitting up wholesale trade, retail trade, and other services (which includes motor vehicle repairs).

[17]Even though the tax variable in the BEA dataset is referred to as "taxes on production and imports, less subsidies"; but see, e.g. Guo and Planting (2007).

and that an industry pays taxes on production in proportion with the industry's share in the capital stock of structures. Taxes on products are then calculated as a residual.[18]

Labor compensation of employees is also directly available from the BEA industry dataset but an imputation needs to be made for the labor compensation of self-employed workers. Here I use the assumption that a self-employed worker earns the same average wage as an employee in each industry. Refinements to this can be made, for example by taking the characteristics (age, sex, education) of self-employed workers into account or by separately estimating labor and capital income and using these estimates to divide up mixed income.[19]

My source for the tax parameters (see equation (2)) is the Bureau of Labor Statistics (BLS). These data cover the period 1987–2005 and I assume constant tax parameters for the 1977–87 period. The BLS also provides data on stocks of land and inventories. Here, I was able to combine the data for the 1987–2005 period with data based on the old SIC87 industrial classification for the 1977–87 period. The BLS in turn uses data on inventories from the BEA and Census as their source. Data on land capital stocks is subject to more assumptions. A study for counties in Ohio from 2001 provides information about the value of land relative to the value of structures by industry, and this land–structures ratio is used for the entire period. Land prices are set equal to the average price of structures (see BLS, 1997, 2007). It would obviously be preferable to have more current information about the importance of land in production, but the discussion in Jorgenson *et al.* (2005, p. 166) suggests this is problematic.[20]

For the final set of capital data, I use newly available estimates of investment in intangible assets from Corrado *et al.* (2005, 2009). This adds data on investment in computerized information, scientific R&D, non-scientific R&D, brand equity, and firm-specific resources. These additional investments are either intermediate inputs or labor inputs that are reclassified as investments.[21] Currently, these data are only available for the private U.S. economy, but for the comparison of aggregate capital services growth, this is already quite useful.

To complete the data used in the analysis, I construct a measure for the weighted average cost of capital. Based on corporate finance theory, the opportunity cost of capital for a firm should take into account the cost of both equity

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[18]This procedure has a risk that in some industries, the estimate of taxes on production is so high that taxes on products would be negative. This problem is more widespread if value added shares are used instead of the industry share in the structures capital stock. To avoid negative taxes and ensure that both types of taxes add up to the correct aggregate, an initial estimate of taxes on production is made, which is equal to the amount based on the share in structures capital or equal to total industry taxes. Next, an RAS procedure is used to ensure industry taxes add up to the correct aggregate.

[19]The first method is applied in Jorgenson *et al.* (2005), the second by the BLS (1997).

[20]See Diewert *et al.* (2005) for evidence from Japan using higher-quality data.

[21]Note that in the case of reclassified labor input, these expenses are now equal to the value of "production of intangible assets" and added to total output since an asset needs to be produced before it can be used. At the industry (or firm) level, this leads to the curious situation that the output of an industry will consist of products sold to customers as well as production of intangibles that the firm then uses in its own production process. In either event, labor expenses on, for example, R&D should still be part of overall labor expenses.

and debt; the funding structure of the firm; and the tax-deductibility of interest payments:[22]

$$(8) \qquad WACC_t = s_t^E C_t^E + \left(1 - s_t^E\right)(1 - \tau_t) C_t^D.$$

In equation (8), $WACC_t$ refers to the weighted average cost of capital, which is equal to the cost of equity, C_t^E, times the share of equity in total funding, s_t^E, plus the cost of debt, $(1 - \tau_t) C_t^D$, times the share of debt in total funding. The cost of debt reflects the tax-deductibility of interest payments as I multiply the debt yield by one minus the corporate profit tax rate, τ_t. Note that all elements of this calculation are year-specific, as denoted by the subscript t. I do not estimate a WACC by industry, as this would require considerable extra data construction efforts.

As it is, construction of this WACC measure already entails a number of choices regarding data and concepts. To get the share of equity financing for the (non-farm, non-financial) business sector,[23] I use the Flow of Funds data from the Federal Reserve, which provides information on total assets and total financial liabilities. This calculation shows the share of equity in total financing decline from 64 percent in 1977 to 56 percent in 2005, reflecting the increasing debt burden of American firms. As a measure for the cost of equity, I use the earnings yield plus the dividend yield of the S&P 500 from Datastream. On average over the period, this was 10 percent and is fairly stable over the period (between 4 and 19 percent). This is in sharp contrast with using the annual change in the S&P price index or in the total return index,[24] which show on average a similar annual increase, but with much larger swings (−18 to +29 percent for the price index). As the cost of equity should be positive for plausible results, I use the earnings plus dividend yield measure. For the first part of the cost of debt, C_t^D, I use the yield on corporate bonds with a BAA rating, the lowest investment-grade rating. This yield averaged 10 percent over the period, in comparison with a 9 percent yield on corporate bonds from AAA firms (i.e. those with the highest credit rating). I use the BAA yield, as it is more likely to be representative of the cost of debt of all firms compared to the AAA yield and other bond yields are not available for a sufficient time span. As the final piece of information, I use the marginal corporate tax rate from the Institute for Fiscal Studies.[25]

[22]See Modigliani and Miller (1958, 1963).

[23]The financing structure of the financial sector is considerably different from that of non-financial firms with equity representing only a small fraction of all financing. However, most of this financing is not used for financing fixed assets but for lending, the main purpose in non-financial firms. The financial structure of farms is not available from the Flow of Funds but would represent only a small fraction of the overall economy.

[24]The price index does not take dividends into account, while the total return index also includes dividend reinvestment returns. The change in the total return index can be roughly approximated as the change in the price index plus the dividend yield.

[25]See Devereux et al. (2002). The data used are an updated version of those used in the paper and can be downloaded at http://www.ifs.org.uk/corptax/internationaltaxdata.zip.
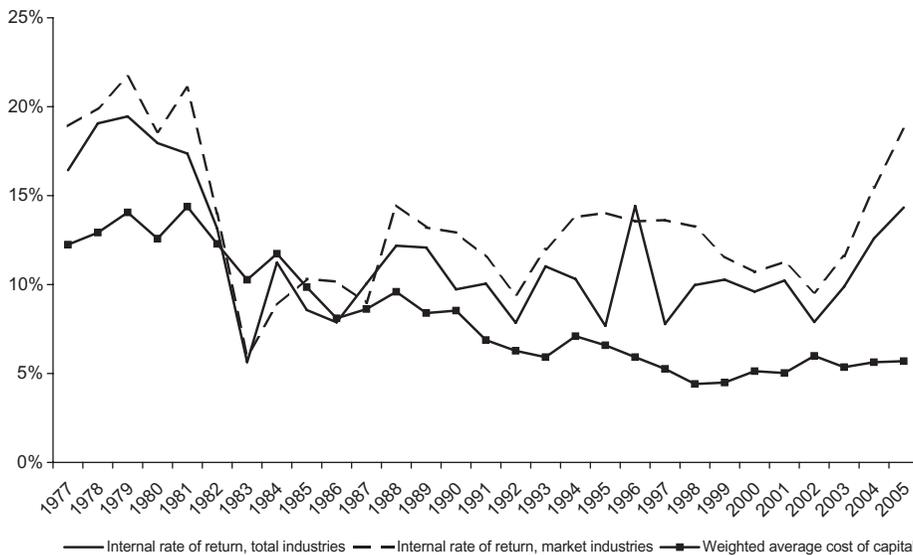
Figure 1. Internal Rate of Return for Total U.S. Industries and Weighted Average Cost of Capital, 1977–2005

Results

In analyzing these data, I follow a bottom-up approach. I first analyze the rates of return and asset prices, before turning to the implications of these differences for industry-level capital growth and aggregate capital growth. Finally, I look at the contribution of capital to output growth at the aggregate level and the sensitivity to the assumptions made in capital aggregation.

Rates of Return

Figure 1 plots the aggregate internal rate of return for all industries and all market industries as well as the external rate of return, the weighted average cost of capital, for the 1977–2005 period.[26] The internal rates are based on the standard set of fixed, reproducible assets, excluding land, inventories, and intangible assets. The figure shows that both the level and pattern over time of the internal rates of return differ considerably from the cost of capital. While the average cost of capital is only 8 percent over this period, the internal rate across all industries is 12 percent and for market industries it is 13 percent. The time pattern is also different, with, for example, rapidly rising internal rates after 2000, but a fairly constant cost of capital. The "total industries" series is not the best basis for comparison as part of capital income used in calculation is based on imputed returns to government

[26]Market industries excludes government, health, and education because much of their output is not directly observed in the market, which means that an internal rate estimate is mostly based on the rate that the statistical office imputed for this industry. The real estate industry is also excluded because the imputed rental value of owner-occupied housing makes up most of the output of this industry.

TABLE 1
COST OF CAPITAL AND MARKET ECONOMY INTERNAL RATES OF
RETURN, 1977–2005

	Average	Correlation with Cost of Capital
Internal rate of return		
Fixed reproducible assets	13.4%	0.48
plus land & inventories	10.3%	0.57
plus intangible	9.8%	0.64
Weighted average cost of capital	8.2%	

activities and residential buildings. For market industries, the correlation between the internal rate and the cost of capital is 0.48.

However, the internal rate of return in Figure 1 suffers from at least one drawback, namely the set of assets that is covered. Table 1 shows the effect of expanding the asset set, first with land and inventories and then with intangibles. Including land and inventories leads to a substantial decline in the internal rate. This is to be expected as the capital stock increases, while capital income stays the same. The effect of adding intangible investment is smaller because it involves reclassifying expenditure on certain services as investment, so capital income also rises. The overall result of adding these assets is to decrease the gap between the internal rate and the cost of capital; the correlation also increases notably from 0.48 to 0.64. This suggests that the aggregate internal rate of return is reasonably comparable to the cost of capital, but only once all assets are measured.

The industry detail in this dataset provides a further ground for testing the economic relevance of an internal rate of return. Since intangible investment data is not yet available at the industry level, the internal rates are calculated based on all reproducible fixed assets, land, and inventories. It turns out that in 21 of the 26 market industries, the internal rate of return is positively correlated with the cost of capital; the average correlation is 0.34.

But while the pattern of internal rates over time is not unreasonable, the *level* of the internal rates provides more cause for concern. Figure 2 shows the average internal rate for each industry over the entire period. The first observation is that there is considerable heterogeneity between industries. For example, the transport industry shows an average internal rate of only 3 percent and the finance industry a rate of almost 18 percent.[27] In most industries, the average internal rate is actually lower than the average cost of capital. This is not just caused by the early 1980s, when most industries had a rate of return lower than the cost of capital, but occurs in many other years as well.

Figure 2 also shows information on the relative risk of an industry, based on the standard deviation of the capital income rate (*CAP* from equation (7) divided by gross output). This is an admittedly crude measure of riskiness but it is based on the same capital income measure used in calculating the internal rate of return. The

[27]The internal rate of return for finance is overstated, however. Much of the output of banks is estimated and as Basu *et al.* (2010) show, current statistical methods overstate bank output at current prices considerably. Their estimates of bank output imply an internal rate of return much closer to that of the market economy.
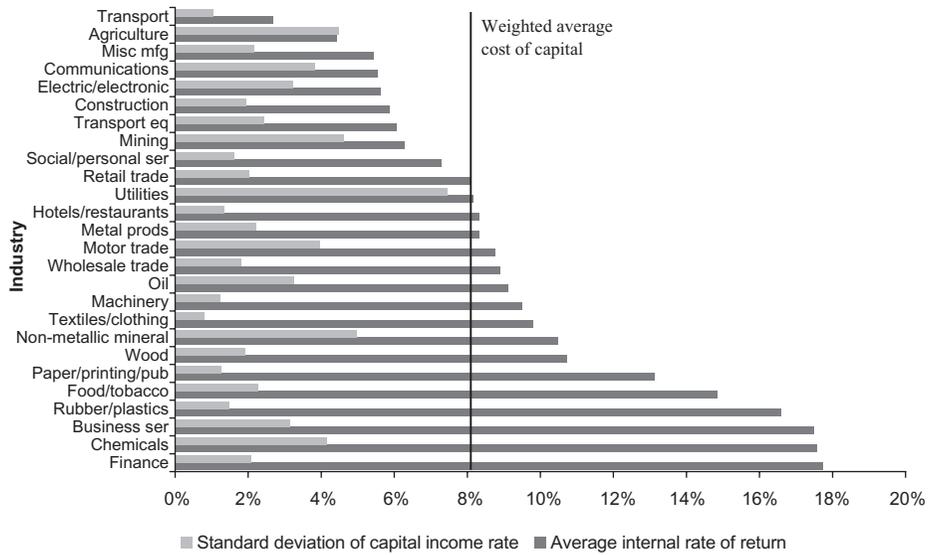
Figure 2. Average Internal Rate of Return and Output Variability in U.S. Industries, 1977–2005

information in the figure shows no positive relationship, with some industries with highly variable capital income rates, like agriculture, showing low returns, and firms with stable capital income rates, like rubber and plastics, showing high returns. The correlation between the two series is −0.07. A lack of competition could also lead to higher internal rates, but a comparison of concentration ratios and internal rates shows no positive correlation either.[28] I have examined just one indicator of risk and one of competition, but it does raise the question of what might explain the large differences in the internal rates of return across industries.

Aside from these broader concerns about what the internal rate of return measures and reflects, a more pragmatic concern is that for many countries, data on the stock of land and inventories is not easily available. Even in the U.S., the data on the stock of land is subject to more assumptions and estimations than other types of capital. However, internal rates based on an incomplete set of assets are too high compared to the cost of capital (Table 1). The relationship over time between the cost of capital and industry-level internal rates also becomes weaker once land and inventories are omitted.[29] The broader significance of these concerns for capital measurement will be discussed below.

Asset Prices

Apart from the rate of return R in equation (2), the asset revaluation term v also needs to be implemented. In the Jorgensonian framework discussed above the actual asset price changes are used, but this poses problems similar to the use of an

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[28]For the concentration ratio the revenue share of the four largest firms in 2002, as given in the Economic Census, is used. This is a crude measure for competitive intensity (see, e.g. Boone, 2008), but it could have had explanatory power.

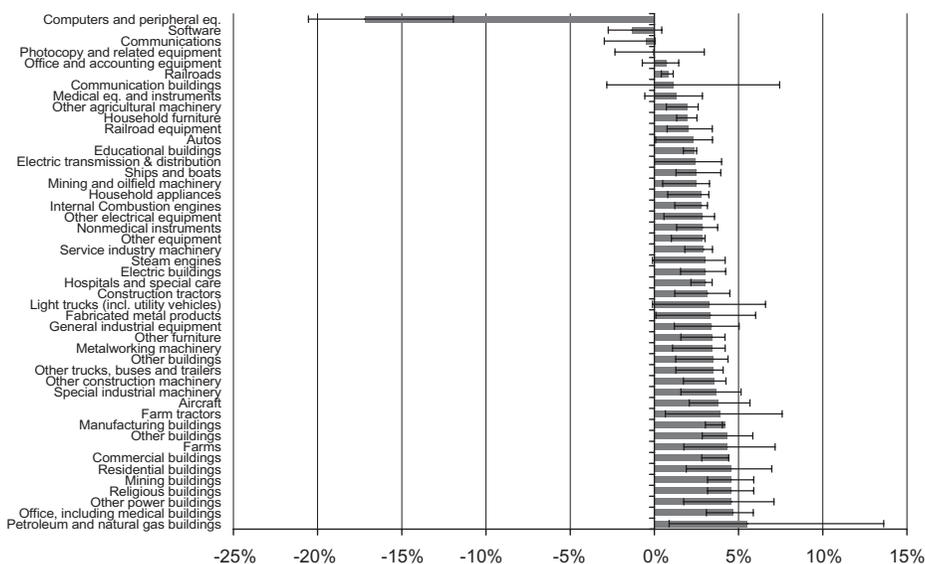[29]In 23 of 26 industries, the correlation is lower.

Figure 3. Asset Price Changes 1977–2005, Average and Inter-Quartile Range

internal rate of return. Under uncertainty, actual asset price changes will have both a random and a systematic component. Over long periods of time, investment prices of equipment tend to decline relative to other prices (e.g. Greenwood *et al.*, 1997), but short-run fluctuations can distort this expected pattern.

In a practical sense, this problem becomes most visible if the prices of structures rise rapidly. Since their depreciation rates are low, the user cost of capital can actually turn negative. In practice, this is a relatively rare problem: in the U.S. dataset little over 1 percent of the user costs are negative, regardless of whether an internal or an external rate of return is used. The need for some type of adjustment is also discussed in Jorgenson *et al.* (2005, p. 169), who smooth their asset inflation rates in periods with negative user costs. As discussed in the previous section, replacing negative user costs by zeros is justifiable as a firm can always choose not to use an asset, implying a zero contribution to output. An alternative, advanced by Diewert (2007), would set the user cost equal to the maximum of the standard user cost as in equation (6) and the observed rental price for such an asset from an outside firm. This would of course require more detailed data from renters of real estate and equipment.

Any method used for asset revaluation should at least preserve the broader trends, such as the rapid price decline of computers. Figure 3 illustrates this pattern for all fixed reproducible assets by plotting the average annual price change over the 1977–2005 period and the inter-quartile range to indicate the variability. Computer prices are in a clearly separate class, with three-quarters of all price declines between 12 and 21 percent per year. These large price declines, in combination with the large depreciation rates[30] put a considerably larger weight on this

[30]Fraumeni (1997) reports a rate of 30.5 percent for computing equipment.

asset than suggested by the dollar value of the asset stock. However, this large weight does seem justified by recent research based on used PC prices by Doms *et al.* (2004). The prices of most other assets rise on average, with most buildings showing larger price increases than equipment. Price swings can also be substantial, in particular for some types of structures. This suggests that using some type of moving average is likely to do justice to the differing trends, while smoothing out some of the extreme swings. How the specification of the revaluation term influences capital services growth will be discussed below.[31]

Industry Capital Growth

The discussion above suggests a series of options in calculating capital services at the industry level:
- The rate of return: an internal rate or the weighted average cost of capital.
- The coverage of assets: only reproducible assets, or also land and inventories.
- Tax parameters: include these or not.
- Revaluation term: current prices or a moving average.[32]

The coverage of assets is important because in international settings, land and inventories are not available for nearly all countries. Similarly, information on the treatment of capital in the tax system is not readily available for most countries either. The specification of the rate of return and the asset revaluation term are mostly important to evaluate the importance of the methodological debate on these issues. With four different parameters and two options per parameter, there are 16 different options for 26 different industries and 29 years. To make the analysis manageable, I focus on the average growth in capital services across all years. For increased insight, I will compare the average growth between each of the two options for each parameter, holding the other parameters constant. Of the 16 options, half include tax parameters and half exclude them, so the average growth between these two sets can be compared.

Table 2 shows the results of this comparison. The first row shows an average growth in capital services across all industries and options of 3.69 percent per year. The choice between an internal rate of return and the cost of capital is most important, with average absolute difference in growth between the two of 0.55 percentage points. In most industries, using the cost of capital leads to higher average growth. This is because the cost of capital is lower than the internal rate (on average), which means that the share in capital compensation of short-lived ICT assets is greater and these assets have grown faster than other assets over this period. This explanation is confirmed, as the difference between internal and external rates is largest in ICT-intensive industries like finance and business services.

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[31]Given the small sensitivity of capital growth to the asset revaluation specification as discussed below, I decided not to employ the more sophisticated modeling strategy of Verbrugge (2008).

[32]How to deal with negative user cost is another, but quantitatively minor issue. Even using current asset prices, only 1.3 percent of user costs are negative. Setting those to zero, replacing them by the average user cost across assets, or using the year-average asset price change to recalculate user costs has a negligible effect on capital services growth.

TABLE 2
SENSITIVITY OF INDUSTRY CAPITAL SERVICES GROWTH, 1977–2005

	Average Difference	Maximum Difference
Average growth	3.69	
Parameters		
Rate of return (internal/cost of capital)	0.55	2.36
Assets (incl/excl land & inventories)	0.32	1.34
Tax parameters (include/exclude)	0.09	0.33
Revaluation term (current/moving average)	0.08	0.24

Notes: For each industry, average annual growth in capital services is calculated based on all combinations of parameters that are listed in the table (leading to 16 combinations in total). The first line shows the average growth across all industries and combinations. To determine the importance of, for example, the choice for the rate of return, the 8 combinations using an internal rate are averaged as are the 8 combinations using the cost of capital. The difference between these two averages is calculated and averaged across industries, resulting in the column "Average Difference." The value for the industry with the largest difference is shown in the column "Maximum Difference."

Whether land and inventories are included is somewhat less important on average, with an average absolute difference of 0.32 percentage points.[33] The differences are also more concentrated in a few industries. The difference is largest in finance, where including land and inventories subtracts 1.3 percentage points from average growth, followed by agriculture where it adds 1.2 percentage points. In other industries, like hotels and restaurants, the effect is negligible. Taking the tax system into account is already a minor issue, with an average impact of 0.09 percentage points. The effect is largest in finance and in business services, mostly because capital services growth is highest in these industries.

The specification of the revaluation term matters even less for average growth. The difference between using the current asset price change and a five-year moving average is only 0.08 percentage points. It also does not substantially smooth the resulting capital growth series: the average standard deviation of capital growth is 2.60 percent and the difference in standard deviation between current asset prices and a five-year moving is only 0.09 percentage points on average. In contrast, the choice between an internal rate of return and the cost of capital leads to an average absolute difference in the standard deviation of 0.34 percentage points.

Finally, it is useful to examine the effect of using an internal rate of return with an incomplete set of assets compared to a more complete set. As Table 1 shows, omitting land and inventories leads to an overstatement of the internal rate, so the difference in capital services growth between the internal rate and the cost of capital should be larger if land and inventories are omitted. This is indeed the case, but it is quantitatively less important. The difference in capital growth between an internal rate and the cost of capital is 0.50 percentage points if land and inventories are included and 0.63 if they are omitted.

[33]The modest impact may partly reflect poor data quality, as Diewert *et al.* (2005) find much larger effects for Japan.

TABLE 3

SENSITIVITY OF MARKET ECONOMY CAPITAL SERVICES GROWTH,
1977–2005

Average Annual Growth of Capital Services	
Rate of return	
Internal rate	4.58
Cost of capital	4.57
Hybrid	5.26
Assets	
Fixed reproducible assets	5.08
plus land & inventories	4.77
plus intangible	4.56
Tax parameters	
Included	4.71
Excluded	4.89
Revaluation term	
Current asset prices	4.79
5-year moving average	4.82

Notes: For the market economy, average annual growth in capital services is calculated based on all combinations of parameters that are listed in the table (leading to 36 combinations in total). Average annual growth is shown for each set of combinations with the listed parameter in common. See Notes to Table 2 for more detail.

Aggregate Capital Growth

In addition to the aggregation options at the industry level, I also consider Oulton's (2007) proposal for estimating aggregate capital services growth. He proposes a hybrid between using an internal and external rate of return, where the external rate (i.e. the cost of capital) is used to aggregate across assets and internal rates are used to aggregate across industries. Furthermore, at the market economy level, intangible assets can also be included. Table 3 shows the average growth rates for each of the parameters, averaging over the results based on the other parameters as in Table 2. This table shows how the main findings from the industry-level also show up at the aggregate. The specification of the revaluation term matters very little: average growth is 4.79 and 4.82 percent using current prices and a moving average. Including tax parameters decreases capital growth by 0.18 percentage points, a bigger effect than for most industries, but modest given overall growth. Again, the set of assets and the rate of return matter most. The widest asset boundary, including both land and inventories and intangibles, shows the slowest average growth of only 4.56 percent. This is half a percentage point lower than if those assets were excluded. The growth based on the internal rate is surprisingly close to growth based on the cost of capital compared with the differences shown in Table 2. Moreover, at the industry level growth based on the internal rate was often lower, while here there is no difference. The reason for this is that industries like finance and business services might have lower growth rates using an internal rate of return, but their growth is still considerably higher than the average. Furthermore, their high internal rates of return (cf. Figure 2) imply that the share of the industry in total residual income *CAP* is much higher than that based on the cost of capital.
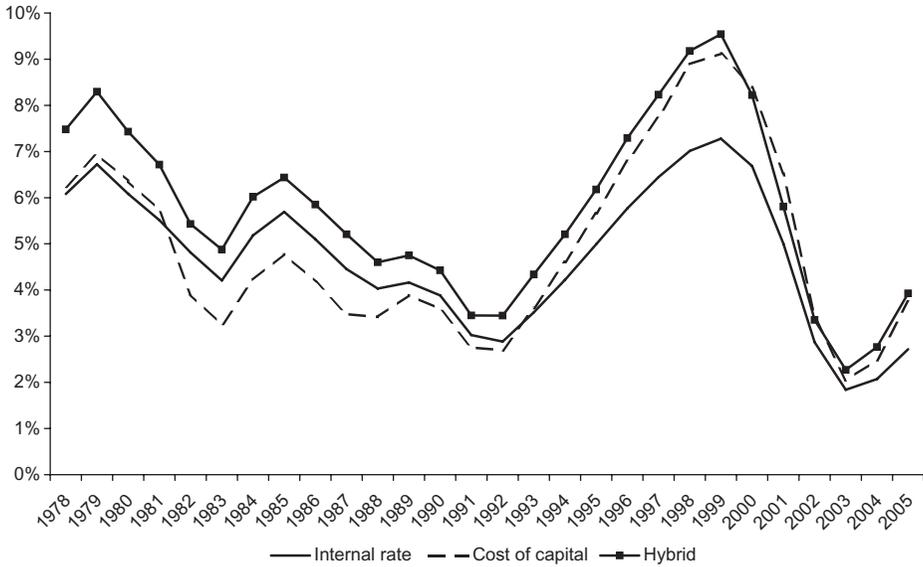
Figure 4. U.S. Market Economy Capital Services Growth: Different Rates of Return, 1977–2005

These two effects cancel out at the aggregate. This also explains why the hybrid option leads to higher aggregate growth than both alternatives: it combines high industry growth with a higher share of high-growth industries.

In addition to the period averages, it can be useful to compare the growth pattern over time for a number of alternatives. As the specification of the revaluation term matters very little, I use current asset prices since this is the most straightforward in practice. Similarly, I omit tax parameters. Figure 4 compares aggregate growth calculated using different rates of return based on the set of fixed reproducible assets. First, the hybrid option shows higher growth in almost every year than the other two options. Furthermore, even though the average growth based on internal rates and the cost of capital is very similar, differences are larger in some periods than others. In particular, during the ICT investment boom in the late 1990s, aggregate growth was around two percentage points higher based on the cost of capital than on internal rates, while it was a percentage point lower during most of the 1980s. The comparison is similar for the set of assets including land and inventories.

Figure 5 compares growth based on the three different sets of assets from Table 3 and shows that the main differences are in the late-1990s.[34] If land and inventories are included, growth is about half a percentage point lower, while also including intangible assets lowers growth by about two percentage points in total. After 2000 though, growth with intangibles included is 0.5–1 percentage points

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[34]Figure 5 is based on the external rate of return. The comparison is very similar for the other options for the rate of return.
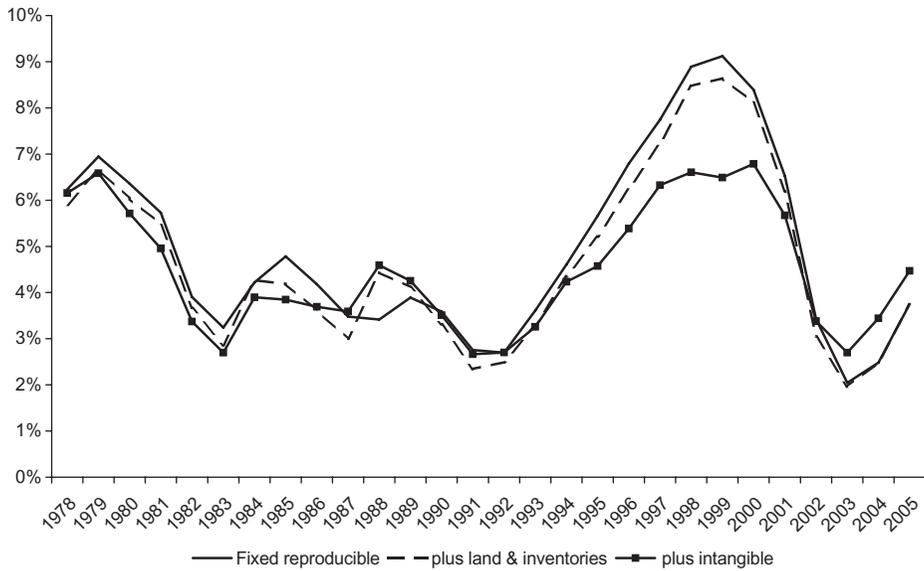
Figure 5. U.S. Market Economy Capita Services Growth: Different Assets, 1977–2005

higher. In summary, the choice for the rate of return and the set of assets matters substantially at the industry level and the aggregate level. Moreover, the differences are not constant over time.

The Contribution of Capital to Growth

The analysis from the previous sections has established the quantitative importance for capital services growth of different approaches to capital aggregation across assets and industries. As these data are often used in growth accounting, it is useful to place the results in a broader context. In growth accounting, the contribution of capital is estimated as the share of capital in total costs times the growth of capital. Under perfect competition, total costs equal total output, but as long as returns to scale are constant, the more general expression holds (Hall, 1990).[35]

The first issue is how the contribution of capital to growth varies depending on the set of assets that is covered. The combination of an internal rate of return and an incomplete set of assets is likely to be particularly problematic as the underlying assumption is that all residual income *CAP* can be attributed to the income from the set of assets that is covered. The second issue is how capital compensation estimated using the cost of capital compares to value added. Since in this approach capital compensation does not add up to residual income *CAP*, there will be economic profits or losses and it should be informative to evaluate its size and pattern over time.

[35]Under increasing returns, the contribution from capital can be calculated as the cost share of capital times capital services growth times the returns to scale parameter.

TABLE 4

SENSITIVITY OF THE MARKET ECONOMY CONTRIBUTION OF CAPITAL TO OUTPUT GROWTH, AVERAGE 1977–2005

Rate of Return Tax Parameters	Internal Rate		Cost of Capital		Hybrid	
	Excl. Tax Param.	Incl. Tax Param.	Excl. Tax Param.	Incl. Tax Param.	Excl. Tax Param.	Incl. Tax Param.
Capital contribution to output growth (%)						
Fixed reproducible assets	1.48	1.50	1.06	1.19	1.80	1.72
plus land & inventories	1.41	1.43	1.13	1.30	1.70	1.58
plus intangible	1.67	1.70	1.44	1.57	1.87	1.79
Capital share in total costs (%)						
Fixed reproducible assets	31	31	22	26	31	31
plus land & inventories	31	31	25	31	31	31
plus intangible	38	38	33	38	38	38
Growth of capital services (%)						
Fixed reproducible assets	4.72	4.78	4.95	4.63	5.74	5.47
plus land & inventories	4.48	4.56	4.69	4.33	5.42	5.04
plus intangible	4.43	4.50	4.48	4.27	4.95	4.75

Table 4 shows the results for the contribution of capital to market economy growth of value added. The top panel of the table shows the contribution of capital to output growth, the middle panel shows the share of capital in total costs, and the bottom panel shows the growth of capital services.[36] Current asset prices are used for the revaluation term throughout. The first column shows that when using internal rates of return and excluding tax parameters, growth of capital has contributed 1.48 percentage points to output growth if only fixed reproducible assets are covered. This contribution drops to 1.41 if land and inventories are included and rises to 1.67 if intangibles are included as well. The contributions are almost identical if tax parameters are included. The pattern is also similar for the hybrid case, except that the contributions are higher because of a higher growth in capital services. In both cases, including land and inventories decreases the contribution because growth of those assets is slower than average while the amount of capital income is unchanged at 31 percent of value added (since total costs equal output in both cases). Including intangibles adds around 11 percent to GDP, leading to a capital share that is 7 percentage points higher, so even though capital growth including intangibles is lower (cf. Table 3), the contribution of capital to output growth is higher.

Using the cost of capital in calculating user costs leads to a monotonically increasing contribution of capital if more assets are covered, since capital compensation increases with each addition. However, the contribution to output growth is always lower than in the other two rate of return options. The reasons for this vary, but for the case when only fixed reproducible assets are included, the lower capital share is the main reason compared to the internal rate of return. Adding more assets and including tax parameters decrease the gap until the point

[36]Note that for the internal rate and hybrid options, the average annual growth in capital services times the average capital share is almost equal to the average annual contribution. The difference is more noticeable for the cost of capital because, as discussed below, the capital share is more variable.
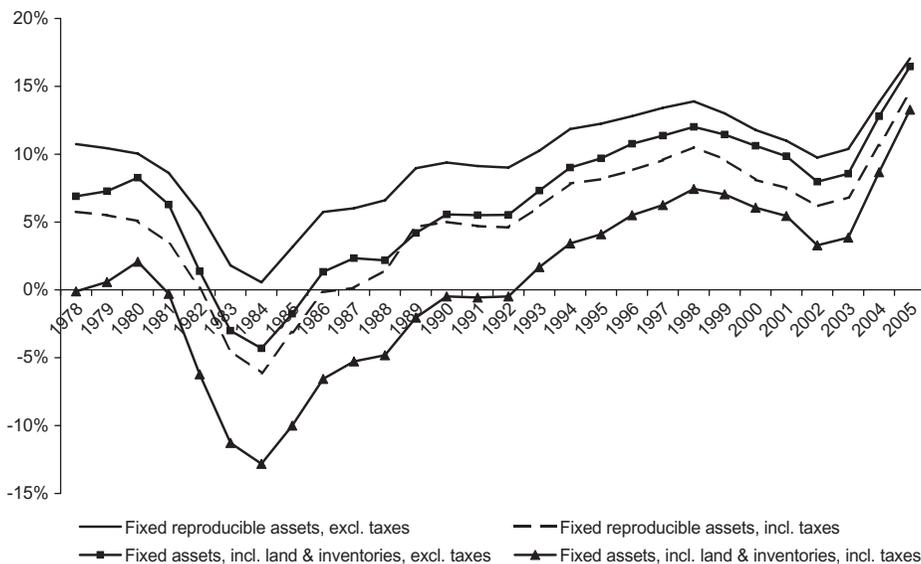
Figure 6. The Capital Share in the U.S. Market Economy, 1977–2005: Capital Cost vs. Residual Income

where, in terms of the average contribution, using internal rates or the cost of capital matters little. Unlike for the other options, including tax parameters is an important factor, mostly because it increases the capital share. The results also illustrate the bias in estimating the capital contribution by using an incomplete set of assets in combination with internal rates of return. While the "cost of capital" contributions show that fixed reproducible assets contribute at most 1.19 percentage points to output growth, the "internal rate" contributions are at least 1.43 percentage points.

The differences in contribution are also vary stable over time, with the contribution based on the cost capital the lowest, the hybrid the highest, and the internal rate as an intermediate version. Figure 6 shows a more revealing picture, comparing the capital share based on residual income *CAP* to the capital shares implied by using the cost of capital to estimate capital compensation, all without taking intangible assets into account. The residual income share is fairly constant over this period, varying between 30 and 34 percent of output, while capital compensation is much more variable. The figure shows the difference between these two concepts for four cases, namely including and excluding land and inventories and including and excluding tax parameters. The basic pattern is similar in these four series but the differences in the level are considerable. In most years, the difference is positive, implying that residual income is larger than capital compensation, but in the mid-1980s, capital costs were so high that capital compensation was larger than residual income. The most comprehensive capital compensation measure, including land and inventories and tax parameters, is higher than residual income for 13 of the years covered, implying substantial economic losses. Figure 7 shows that also including intangibles leads to a very similar picture,
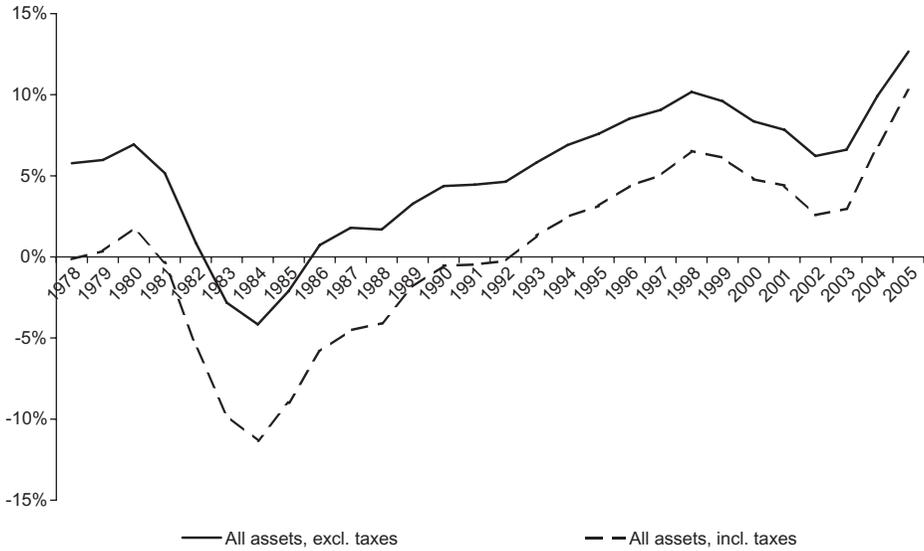
Figure 7. The Capital Share in the U.S. Market Economy Including Intangibles, 1977–2005: Capital Cost vs. Residual Income

except that underlying residual income increases from around 35 to 41 percent of output.

At the industry level, the difference between residual income and capital compensation closely mirrors the pattern of internal rates of return from Figure 2. This is of course no surprise since an internal rate in excess of the cost of capital signifies that residual income is higher than the compensation required for the capital stock. The number of industries with higher capital compensation than residual income on average over the entire period varies substantially between the different alternatives. If tax parameters and land and inventories are excluded, only the transport and storage industry has higher capital compensation than residual income, but if both are included, capital compensation is higher in 11 of 26 industries.

As was the case for the internal rate of return, there does not seem to be a straightforward explanation that can explain the wide disparity, both over time and across industries. In all likelihood, measures of risk and competition factor into the equation. Measurement errors also cannot be ignored as the conceptual discussion illustrated. Since CAP is calculated as residual income, any measurement problems in output or labor compensation end up here. The estimation of self-employed labor compensation is a particularly important source of uncertainty here. Data on investment and capital income are also not collected from the same sources, and since capital services are not (yet) part of the National Accounts, any discrepancies between sources is not taken into account in the reconciliation process by statistical offices. These measurement issues suggest that caution is needed, in particular in interpreting industry-level results but also at the aggregate level.

Despite these health warnings, a number of observations stand out from the analysis of capital contributions to output growth. First, the combination of internal rates of return and an incomplete set of assets can lead to misleading results as it implies too large a contribution of fixed reproducible assets. Using the cost of capital is less hazardous in this respect, but necessitates a careful consideration of the tax system to avoid underestimating the share of capital in total costs. Finally, the hybrid solution proposed by Oulton (2007) implies much higher capital contributions to output growth than any of the other methods.

Conclusions

Measuring capital is hard. Economic theory is a useful guide for part of the way but sooner or later choices have to be made on pragmatic grounds. The aim of this paper has been to illuminate the impact of these choices to focus attention and (hopefully) research on the most pressing issues. Some issues have not been dealt with here: time series for investment by industry and assets in both current and constant prices have been taken as given, like the starting capital stocks for the early years in the analysis. I have also not discussed depreciation rates and to what extent we should rely on them. For these and other issues related to capital measurement, see the *OECD Manual* (Schreyer, 2009). This paper has taken industry capital stocks by asset as given and asked how these should be aggregated to get an informative measure of productive capital input into production. For my sensitivity analysis, I have used data for the United States for the period 1977–2005, since I can examine all the alternatives that may be relevant.

Central in the aggregation problem is the user cost of capital, which consists of a rate of return, depreciation rate, asset revaluation term, and tax parameters. For each of these components, different choices and assumptions can be justified based on the literature, and I compare how these choices impact the results. It turns out that many of the choices matter only little. For example, for the revaluation term, moving averages can be specified instead of using the current asset price change, but this matters little. What is important is that asset-specific price changes are taken into account, in particular because computer prices have fallen very rapidly, and this should be reflected in a higher weight in capital services.

The choice for the rate of return is more consequential. Estimates of the internal rate of return are not easy to reconcile with economic fundamentals such as the relative risk of industries or the cost of capital in financial markets. This suggests that broader measurement problems are important: the internal rate of return will only be an economically useful concept if capital income is measured in a fully correct fashion and all relevant capital assets are correctly accounted for. Neither of these is likely in practice. Oulton's (2007) hybrid approach does not solve this issue, and hence I would favor Balk's (2008) argument for an external rate of return. In this paper, I have constructed a weighted average cost of capital based on the financing structure of U.S. firms, the cost of debt, and the cost of equity. This measure is a theoretically preferable measure for the opportunity cost of capital of firms and in future work, it can be extended to the industry level and other countries. Compared to the internal rate of return, this cost of capital measure is on average lower, while the pattern over time shows some similarity.

This means that capital cost does not fully exhaust revenue and the size of capital costs will vary depending on whether tax parameters are included and which assets are covered. At the aggregate level, on average over time, capital cost is comparable in size to residual income once taxes are accounted for and land and inventories are covered. Not accounting for either of these will understate the contribution of capital input growth to output growth. Finally, most intangible assets are not yet considered part of the standard set of capital assets and there are many conceptual issues. For example, the question how and how much knowledge (in the form of R&D) depreciates is still not answered in a satisfactory fashion (see, e.g. Nakamura, 2010). However, using the same assumptions as Corrado *et al.* (2009), I show that including intangible assets is very important as well.

In conclusion, I would therefore argue for a greater effort by statistical agencies to expand the asset boundary. Including land and inventories turns out to be quite relevant, even with the imperfect U.S. data. Covering intangible assets should likewise be a priority, while research on appropriate methods for pricing and depreciating these assets should also be taken up. Finally, economic theory provides only limited justification for using an internal rate of return, and at the same time, using an internal rate of return can emphasize measurement error in the underlying data and lead to wrong conclusions when a limited set of assets is covered. Using an appropriately constructed external cost of capital therefore seems to be a preferable alternative.

REFERENCES

Balk, B. M., "Measuring Productivity Change without Neoclassical Assumptions: A Conceptual Analysis," *Mimeo*, 2008.

Basu, S., R. Inklaar, and J. C. Wang, "The Value of Risk: Measuring the Service Output of U.S. Commercial Banks," forthcoming in *Economic Inquiry*, 2010.

Berndt, Ernst R. and Melvin A. Fuss, "Productivity Measurement with Adjustments for Variations in Capacity Utilizations and Other Forms of Temporary Equilibrium," *Journal of Econometrics*, 33, 7–29, 1986.

BLS (Bureau of Labor Statistics), *BLS Handbook of Methods*, BLS Bulletin 2490, U.S. Department of Labor, Washington D.C., 1997.

———, *Technical Information About the BLS Multifactor Productivity Measures*, U.S. Department of Labor, Washington D.C., 2007.

Boone, J., "A New Way to Measure Competition," *Economic Journal*, 118, 1245–61, 2008.

Corrado, C. A., C. R. Hulten, and D. E. Sichel, "Measuring Capital and Technology: An Expanded Framework," in Carol A. Corrado, John C. Haltiwanger, and Daniel E. Sichel (eds), *Measuring Capital in the New Economy*, University of Chicago Press, Chicago, 11–41, 2005.

———, "Intangible Capital and U.S. Economic Growth," *Review of Income and Wealth*, 55, 661–85, 2009.

Devereux, M. P., R. Griffith, and A. Klemm, "Corporate Income Tax Reforms and International Tax Competition," *Economic Policy*, 35, 451–95, 2002.

Diewert, W. E., "Exact and Superlative Index Numbers," *Journal of Econometrics*, 4, 114–45, 1976.

———, "Issues in the Measurement of Capital Services, Depreciation, Asset Price Changes and Interest Rates," in Carol A. Corrado, John C. Haltiwanger, and Daniel E. Sichel (eds), *Measuring Capital in the New Economy*, University of Chicago Press, Chicago, 479–542, 2005.

———, "The Paris OECD–IMF Workshop on Real Estate Price Indexes: Conclusions and Future Directions," UBC Discussion Paper 07-01, 2007.

———, "What Is To Be Done for Better Productivity Measurement," *International Productivity Monitor*, 16, 40–52, 2008.

Diewert, W. E., H. Mizobuchi, and K. Nomura, "On Measuring Japan's Productivity, 1955–2003," UBC Discussion Paper 05-22, 2005.

Doms, M. E., W. E. Dunn, S. D. Oliner, and D. E. Sichel, "How Fast Do Personal Computers Depreciate? Concepts and New Estimates," in J. M. Poterba (ed.), *Tax Policy and the Economy*, Vol. 18, MIT Press, Cambridge, 37–80, 2004.

Erumban, A. A., "Rental Prices, Rates of Return, Capital Aggregation and Productivity: Evidence from EU and US," *CESifo Economic Studies*, 54, 499–533, 2008.

Fraumeni, B. M., "The Measurement of Depreciation in the U.S. National Income and Product Accounts," *Survey of Current Business*, July, 7–23, 1997.

Garner, T. I. and R. Verbrugge, "Reconciling User Costs and Rental Equivalence: Evidence from the US Consumer Expenditure Survey," *Journal of Housing Economics*, 18, 172–92, 2009.

Gilchrist, S. and E. Zakrajsek, "Investment and the Cost of Capital: New Evidence from the Corporate Bond Market," NBER Working Paper No. 13174, 2007.

Greenwood, J., Z. Hercowitz, and P. Krussel, "Long-Run Implication of Investment-Specific Technological Change," *American Economic Review*, 87, 342–62, 1997.

Guo, J. and M. A. Planting, "Integrating U.S. Input–Output Tables with SNA: Valuations and Extensions," Paper Presented at the 16th International Input–Output Conference in Istanbul, Turkey, July 2–7, 2007.

Hall, Robert E., "Invariance Properties of Solow's Productivity Residual," in Peter A. Diamond (ed.), *Growth/Productivity/Employment: Essays to Celebrate Bob Solow's Birthday*, MIT Press, Cambridge, 1990.

Hall, R. E. and D. W. Jorgenson, "Tax Policy and Investment Behavior," *American Economic Review*, 57, 391–414, 1967.

Harper, M. J., E. R. Berndt, and D. O. Wood, "Rates of Return and Capital Aggregation Using Alternative Rental Prices," in D. W. Jorgenson and R. Landau (eds), *Technology and Capital Formation*, MIT Press, Cambridge, 331–72, 1989.

Jorgenson, D. W. and Z. Griliches, "The Explanation of Productivity Change," *Review of Economic Studies*, 34, 249–83, 1967.

Jorgenson, D. W., M. S. Ho, and K. J. Stiroh, *Information Technology and the American Growth Resurgence*, MIT Press, Cambridge, 2005.

Modigliani, F. and M. H. Miller, "The Cost of Capital, Corporation Finance and the Theory of Investment," *American Economic Review*, 48, 261–97, 1958.

———, "Corporation Income Taxes and the Cost of Capital: A Correction," *American Economic Review*, 53, 433–43, 1963.

Nakamura, L., "Intangible Assets and National Income Accounting: Measuring a Scientific Revolution," forthcoming in *Review of Income and Wealth*, 2010.

O'Mahony, M. and M. P. Timmer, "Output, Input and Productivity Measures at the Industry Level: The EU KLEMS Database," *Economic Journal*, 119, F374–403, 2009.

Oulton, N., "Ex Post Versus Ex Ante Measures of the User Cost of Capital," *Review of Income and Wealth*, 53, 295–317, 2007.

Schreyer, P., *OECD Manual Measuring Capital*, OECD, Paris, 2009.

Verbrugge, R., "The Puzzling Divergence of Rents and User Costs, 1980–2004," *Review of Income and Wealth*, 54, 671–99, 2008.

United Nations, *System of National Accounts 2008,* joint with European Commission, International Monetary Fund, OECD, and World Bank (http://unstats.un.org/unsd/nationalaccount/sna2008.asp), 2008.