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Productivity growth in the Norwegian manufacturing sector 1993 - 2002

A comparison of two methods

Statistics Norway/Research Department

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Abstract:

Productivity is an important topic for the society. Therefore measuring it properly is highly desirable for academia, business and policy-making. There are a number of methods which can be used to measure productivity, but they seem to produce different estimates. For this reason, we compare two methods of measurement, but which represent two different approaches of measurement, the so-called Index Numbers and the Parametric Methods. As it is more meaningful to measure productivity growth rather than level, we look at the development of productivity growth at the industry-level in the manufacturing sector in Norway over 1993 – 2002. We first apply a Thörnqvist based index to obtain estimates for the growths of labor productivity, total factor productivity and factor intensity in all but two industries of the Norwegian manufacturing sector. We compare the estimates of total factor productivity growth from this index with those obtained from another Index Numbers based methodology that assumes constant factor elasticities over the whole period, which we call Overall Average. We find that these estimates are practically the same. This implies that when applying the Index Numbers approach we may safely use simpler computations which consider factor elasticities constant during the whole period. We also compare the estimates of total factor productivity growth from the Thörnqvist index with those obtained from a Cobb-Douglas based Parametric Method. Our construction of this parametric method is designed to deal with the so-called "endogeneity", but which we argue can be more appropriately interpreted as specification bias when measuring aggregate productivity, heteroscedasticity (believed to be accentuated by measurement errors for the value added output) and autocorrelation. The most interesting finding is that the estimates from the two methods differ considerably across industries. This leads us to form an important hypothesis: 'There are differences in the estimates obtained from different methods, though maybe not very much so because of the methods themselves, but possibly because of some industry features that make these methods' productivity estimates differ to varying degrees'. To start with, we consider one candidate as such an industry-specific factor, the industry's capital elasticity, but do not find any significant effect of the differences in the estimations of this factor in explaining the differences in the estimations of productivity growth from the two methods. The relationship of other industry-specific factors with the differences between the estimates from different methods is worth being investigated. While the role of information and communication technologies in the output and productivity growth has recently attracted increasing interest, one area not yet investigated is to assess the role of (the use) of these technologies in the measurements of productivity from different methods. Since the usage of these technologies is considered to be closely linked with other non-technological issues, factors embedded in the deployment of such technologies might also need to be considered.

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Summary

Broadly speaking, this document is about productivity. As the word 'productivity' suggests on its own, it has to do with production. On a general level, we may define productivity as the relationship between output and input across different production units and over time. From the producer point of view at least, since production involves costs, there is a direct interest to keep track of how much output is produced and how much input is spent.

The next important step is how to measure the output-input relationship. The reason why productivity measures are important is because they may serve a number of purposes. A common purpose is to trace the level of technology. In particular, productivity growth rates are often interpreted as the measure of technical change. Another purpose is to identify the presence of inefficiencies by comparing the production units with each other.[1] A more detailed analysis of the efficient versus inefficient units could be helpful to find out the causes of inefficiencies. One more purpose is to asses the standard of living. Especially measures of productivity at the macroeconomic level are often considered as an indication of the living standards. Finally, productivity measures can also be used for international comparisons. Based on measures of the output-input relationship at the macroeconomic level for a number of countries, we could compare different economies with other.

The main aim of this document is to review some main types of productivity measures and the issues related to them theoretically and assess two of them empirically.

As far as the theoretical part is concerned, the concept of productivity is introduced through three measures that illustrate how the output-input relationship can be measured. All of these measures belong to the same type of measures among the methods of productivity measurement, called the Index Numbers method (or better say approach to include different methods, but which view productivity in similar way). Two issues that need to be addressed right from the start are quantity and aggregation.

In an economy with different kinds of output and input, it might be difficult to use productivity measures that estimate quantities of output and input used in comparing the relative performance of different production units. Such comparisons might be difficult not only because

[1] Grosskopf in the book edited by Fried et al. (1993) views productivity as the combined effect of both technical change and efficiency: "Although many consider productivity growth and technical progress as synonymous, I belong to a small but growing group who distinguish the two concepts. I define productivity growth as the net change in output due to change in efficiency and technical change, where the former is understood to be the change in how far an observation is from the frontier of technology and the latter is understood to be shifts in the production frontier" (p. 160). Our starting definition is even broader.

of the problem of non-comparability, but also because of the need to add subjective judgment on the relative importance of each output and input. The situation becomes even more complex if a large number of outputs and inputs are in place. One way to avoid these problems is to use some degree of aggregation and instead of quantities make use of the money values, holding one year as the reference year. This means that the aggregated production units, say to industry level, can be compared based on a common unit of measurement, which is the common currency. However, even in this case there is another problem that might appear with the money value measurements in each industry. This is what is called the 'non-additivity' problem. Basically, this means that the sum of values of each product of industry calculated taking into account only quantity changes from the base year is not equal to the industry's value calculated taking into account both quantity and price changes from the base year. Even though basic in nature, this problem is actually encountered in practice, since while it is relatively easy to trace the total value changes of an industry, it is more difficult to trace quantity and price changes separately.

These issues are only a part of the complexity related to productivity measurement. More complicated issues have to do with measures of productivity level. As an illustration of these issues is the impossibility to construct Index Numbers type of measures of relative productivity levels based on base year values for different industries. Efforts to construct such measures would result in constructing in practice measures of productivity growth, not productivity levels. Recognizing difficulties in obtaining meaningful measures of productivity levels, the practice of the Organization for Economic Cooperation and Development (OECD) is to construct measures of productivity growth. The most common method is the Index Numbers method, which is applied with output measured as gross or value added output with the use of one or more inputs.

Although a number of issues are avoided when measures of productivity growth are obtained instead of levels, other issues that have to do with the choice of the method are still present. In addition to the Index Numbers method, two other methods are Data Envelopment Analysis and Parametric Methods. It is interesting to evaluate how these methods perform relative to each other because it is not clear whether the estimates obtained from a method differ significantly from estimates obtained from others. Even when one has chosen the method or approach of estimating productivity, there are still problems in obtaining reliable productivity estimates because changes in the methodology used to construct different kinds of input may also affect productivity estimates.

Notwithstanding these issues, productivity measures may differ not only between methods, but also between different studies. For example, different conclusions about the contribution of the manufacturing sector in the newly industrialized countries of East Asia are found in different studies, which once again points to the importance of measurement. A rather contemporary topic of investigation related to productivity is the role of information and communication technologies in output and productivity growths, which, from the mid 1990s, seems to have bounced back again to high figures. Evidence suggests that computers in general have had a considerable contribution to the high output growth rates, but especially to labor productivity growth rates, which means that it is the use of technology that is more important than the technology itself as stock capital.

As far as the empirical part is concerned, three main directions are pursued. First, a Thörnqvist based index, a representative of the Index Numbers method, is constructed where the factor elasticity is computed as an average of firms' factor elasticities in industry that are common over every two years. This is applied to the Norwegian manufacturing sector to look at the development of productivity growth from 1993 to 2002. Based on the results from this method, over 1993 – 2002, total factor productivity growth in the manufacturing sector in Norway has grown by 1.0%, average labor productivity has grown by 2.2%, and capital intensity has grown by 5.5%. However, it needs to be noted that these figures hide significant differences in the averages of each industry.

The second direction is to compare the results from this index with another index based methodology, which assumes constant factor elasticities over the whole period. We call this methodology Overall Average because it computes the factor elasticity over the whole period as an average of factor elasticities of all firms in all periods. Estimates from these two methodologies are practically the same.

The third direction is to compare estimates of total factor productivity growth from the index based method with estimates from a parametric method. We construct a Cobb-Douglas based parametric method that accounts for what we view as specification bias (as opposed to the so-called "endogeneity"), deals with heteroscedasticity (possibly aggravated by measurement error in value added output) and autocorrelation. Estimates from the Index based and parametric methods differ considerably. For example, according to the parametric method total factor productivity growth in Norway over 1993 – 2002 has grown by merely 0.3%. Also, the degree of correlation between the estimates from the two methods differs widely across industries. In trying to explain these differences, we examine the effect of differences in factor elasticity estimates between the two methods on the degree of correlation of total factor productivity growth estimates. We do not find any significant effect of the differences in the estimates of factor elasticities. We propose that other industry-related factors need to be considered, for example, the role of the (use of) information and communication technologies.

This document is organized into four parts and ends with some concluding remarks.

1. Introducing Some Productivity Measures

The concept of productivity

In a society there are different kinds of output and input and several ways of converting inputs into outputs. Therefore, one would expect to find different kinds of input-output relationships as well as different ways and measures representing this relationship. When expressed in absolute terms, a productivity measure can reveal productivity level, which could be further used to show the relative productivity of different production units (be they firms, industries or economies) in a given period of time. When expressed in percentage terms, productivity measures could reveal productivity growth, which could be used to show how this relationship develops over time for one or more production units. For any production unit, a simple measure (or index) of productivity is the ratio of output to input as in Eq 1-1 below.

Eq 1-1: $A(t) = \frac{O(t)}{I(t)}$,

where *O* is output, *I* input, *t* time and *A* productivity.[2]

Assuming that it is possible to express the different kinds of outputs and inputs that exist respectively by *O* and *I*, the measure of productivity denoted by *A* in time *t* could be used in different ways. We could observe whether the same production unit achieves higher or lower productivity at different times, compare productivity of different production units in one period of time or assess the development of productivity growth over time.[3]

The index *A(t)* in Eq 1-1 is the same as the productivity measure one would derive from a production function of the form in the equation below:

Eq 1-2: $O(t) = A(t) * I(t)$,

which expresses a constant returns-to-scale production technology which either produces one single output, *O*, or different kinds of output aggregated into *O*. Similarly for the inputs, this technology either uses one single input, *I*, or different kinds of input aggregated into *I*.

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[2] About the notation, 'Eq' is short for equation and for the sake of omitting repetition, in most of the cases, we do not repeat the explanation of each notation in the succeeding formulas if an explanation of a notation is provided in an earlier formula.

[3]For example, by either looking at the ratio *[A(t)-A(t-1)] /A(t-1)* or at the difference of natural logarithms *A(t)*, lnA(t) – lnA(t-1), where 'ln' means natural logarithm.

In practice, two different kinds of inputs, or factors of production are considered as the main ones: capital, denoted usually by *K*, and labor, denoted by *L*. *K* may include all types of capital (machinery, buildings, plants, land) used directly in the production process. *K* may also include other factors used indirectly, such as infrastructure (roads, information and communication networks) and power (electricity). *L* would include hours worked or the man-hours that are used in the production. Maintaining a constant returns-to-scale technology, the production function of Eq 1-2 can be extended by including *K* and *L* into a Cobb-Douglas specification of this technology.

Eq 1-3: $O(t) = A(t) * K(t)^{\alpha} * L(t)^{1-\alpha}$

In Eq 1-3, *A* is the variable for productivity as before, which is usually interpreted as the measure of the state of technology. A positive shift in *A* over time means technological progress, or increased knowledge or more advanced techniques that help make capital and labor more productive. One assumption about *A* is to consider it as exogenous, which implies that its growth rate is given. As such it is not a factor of production in the sense that it is paid for: Firms benefit from it, but do not pay for using it. Whether *A* is exogenous or not is a long debate within the area of economic growth[4], however, treating *A* as exogenous can be a good starting point to study productivity as such as we do in this document. As presented in Eq 1-3, *A* is also called Hicks-neutral because technological progress is output-augmenting.[5]

With production functions like in Eq 1-3 one might question whether there are other important factors, which are not included in the production function, but which could affect output. Romer (2001, p 37) extends Eq 1-3 to include natural resources and land as in:

Eq 1-4: $O(t) = R(t)^{\beta} * T(t)^{\gamma} A(t) * K(t)^{\alpha} * [*L(t)]^{1-\alpha-\beta-\gamma}$,

where *R* is natural resources and *T* is land.

R and *T* are in limited supply and cannot be stocked like capital or reproduced like labor force. For this reason Romer (2001) refers to *R* and *T* as 'drags' on output growth, while to technological progress as a 'spur' to growth. Although, at first, natural resources and land may appear important for the output because of their limited supplies, based on estimations of their

[4] The argument for treating productivity as endogenous is that it can be influenced by factors such as innovation, research and development, quality of education, property rights, etc., which could themselves depended on productivity.

[5] If Eq 1-3 is expressed differently as $O(t) = [A_K * K(t)]^{\alpha} * L(t)^{1-\alpha}$, technological progress is presented as capital-augmenting and if it is expressed as $O(t) = K(t)^{\alpha} * [A_L * L(t)]^{1-\alpha}$, it is presented as labor-augmenting or Harrod-neutral. We use here only the Hick-neutral form.

impacts on productivity growth made by Nordhaus (1992), Romer (2001) states that '… the evidence suggests that there would have to be very large changes for resource and land limitations to cause income per worker to start falling' (p. 40). An important empirical implication of such finding is that specifications with only *K* and *L* as in Eq 1-3 could be used as a good approximation for expressing the production function in general and for measuring productivity in particular.

Focusing on productivity measurement, it should be noted that this is usually done by measuring its growth rate rather than its level because, when considering productivity as the state of technology, its level per se may neither have any economic meaning nor be the main interest. A well-known methodology that is used for measuring productivity growth is the so-called *growth accounting*[6], which is basically an explanation of output growth by the growth of all of the factors of production as well as productivity. Using Eq 1-3, the growth of output would be expressed as:

Eq 1-5: $$\frac{\dot{O}(t)}{O(t)} = \alpha * \frac{\dot{K}(t)}{K(t)} + (1-\alpha) * \frac{\dot{L}(t)}{L(t)} + \frac{\dot{A}(t)}{A(t)},$$

where the dot on the top means the derivative with respect to *t*.

If the interest is instead in the growth of output per man-hour spent, by rearranging the terms in Eq 1-5, we obtain output per man-hour or the so-called labor productivity growth.

Eq 1-6: $$\frac{\dot{O}(t)}{O(t)} - \frac{\dot{L}(t)}{L(t)} = \alpha * [\frac{\dot{K}(t)}{K(t)} - \frac{\dot{L}(t)}{L(t)}] + \frac{\dot{A}(t)}{A(t)},$$

In competitive markets where no rent is earned, it is known that the elasticity of capital α is the share of capital in the total expenditure (income) and hence can be measured by looking at the data on the share of income that goes to capital. With data on growth rates for *O*, *K* and *L* as well, we can measure productivity growth by the residual term $\frac{\dot{A}(t)}{A(t)}$, which is also the so-called Solow residual.[7]

In Eq 1-5 and Eq 1-6, α is implicitly assumed to be constant over time. However, as noted, since α is sometimes interpreted as the cost (or income) share of capital, even in competitive markets it may change over time as well as across production units. Whether this is

[6] Initiated by Abramovitz (1956) and Solow (1957).

[7] After Robert Solow who contributed into the study of growth in the 1950s.

true or not is an empirical question, but for the purpose of introducing measures of productivity one may start with the assumption that the income share of capital is constant over time and across production units. Relaxing this assumption means that one may either assume that income shares of production factors change over time but not across production units (say firms) or they change over time as well as across firms.

With changing income shares over time or over time and across firms in place one can measure productivity in different ways. For the purpose of introducing measures of productivity we present in the following in a simple way some of the main index methods in the literature[8] and the discussion of other methods is in section 2.2.

The first measure is based on what is called the Divisia index, the second on the Thörnqvist index and the third is called the trans-log multilateral index.

The Divisa index

A general production function would be expressed:

Eq 1-7: $O(t) = f(X_V(t), t)$,

where *f* denotes function, X_V is a vector of all factors of production, which in what follows we consider as variable *1*, and *t*, as earlier, is time, which in what follows we consider as variable *2*.

With this general production function, the growth of output is accounted for by the growth of the factors of production as well as the growth of all other factors not included into X_V, but which are picked up by *t*. Let f'_{1i} denote the partial derivative with respect to the *i*'th element of $X_V(t)$ and f'_2 the partial derivative with respect to the second argument, *t*,. Then:

[8] Our presentation of the index based measures presented here draws on Møen (1998).

Eq 1-8: $\frac{\dot{O}(t)}{O(t)} = \frac{\sum_i [f_{1i}^{'} * \dot{x}_i(t)] + f_2^{'}}{f} = \sum_i [f_{1i}^{'} * \frac{x_i(t)}{f} * \frac{\dot{x}_i(t)}{x_i(t)}] + \frac{f_2^{'}}{f} = \sum_i [\alpha_i(t) * \frac{\dot{x}_i(t)}{x_i(t)}] + \frac{f_2^{'}}{f}$,

where x_i is the *i*'th element of X_V, $\alpha_i(t)$ is the elasticity of output with respect to factor x_i at time *t* and $\frac{f_2^{'}}{f}$ is the part of output growth that is not accounted for by the growth of production factors used in production. That is, the part attributed to productivity growth and, as mentioned earlier, in competitive markets, elasticity $\alpha_i(t)$ is equal to the share of income that goes to factor *i*.[9]

The Divisia index is the index of the growth rate of factor inputs. It is the arithmetic weighted sum of the growth rates of production factors, where (in competitive markets) the weights equal factor shares. That is:

$$\text{Divisia Index} = \sum_i [\alpha_i(t) * \frac{\dot{x}_i(t)}{x_i(t)}] = \sum_i [\frac{w_i(t)}{p(t)} * \frac{x_i(t)}{f} * \frac{\dot{x}_i(t)}{x_i(t)}].$$

With data for income shares and growth rates of each factor one can, theoretically at least, construct the Divisa index, subtract it from the growth rate of output, and then obtain what is called total factor productivity (*TFP*) growth:

$$\frac{T\dot{F}P(t)}{TFP(t)} = \frac{f_2^{'}}{f}.$$

As mentioned earlier, since the effect of fixed factors (land, natural resources) is usually negligible, we could approximate the general production function by including only capital and labor as inputs in it, in which case *TFP* growth would be expressed as:

Eq 1-9: $\frac{T\dot{F}P(t)}{TFP(t)} = \frac{\dot{A}(t)}{A(t)}$

Theoretically, the use of the Divisia index is a useful tool for measuring productivity growth. However, since it is expressed in continuous time, in practice, it needs to be approximated using data in discrete time. This is usually done by the so-called Thörnqvist index, which is discussed next.

The Thörnqvist index

The formula for the approximation of the Divisia index is:

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[9] To see this, note that a profit maximizing (cost minimizing) firm at time *t* with given product price, *p(t)*, and factor price for x_i, $w_i(t)$, uses this factor so that $f_{i1}^{'} = \frac{w_i(t)}{p(t)}$. The income (cost) share of factor $x_i(t)$ is then equal to factor elasticity $\alpha_i(t)$ because: $\alpha_i(t) = f_{i1}^{'} * \frac{x_i(t)}{f} = \frac{w_i(t)}{p(t)} * \frac{x_i(t)}{f}$.

$$\sum_i \{\frac{1}{2} * [\frac{w_i(t)}{p(t)} * \frac{x_i(t)}{f(t)} + \frac{w_i(t-1)}{p(t-1)} * \frac{x_i(t-1)}{f(t-1)}] * \ln \frac{x_i(t)}{x_i(t-1)}\}$$

This implies that total factor productivity growth in discrete times is expressed as:

Eq 1-10: $$\frac{f_2^{'}}{f} = \frac{T\dot{F}P}{TFP} = \ln \frac{O(t)}{O(t-1)} - \sum_i \{\frac{1}{2} * [\frac{w_i(t)}{p(t)} * \frac{x_i(t)}{f(t)} + \frac{w_i(t-1)}{p(t-1)} * \frac{x_i(t-1)}{f(t-1)}] * \ln \frac{x_i(t)}{x_i(t-1)}\},$$

where the growth of output measured by: $\ln \frac{O(t)}{O(t-1)} = \ln O(t) - \ln O(t-1)$

and the growth rate of each factor x_i is measured by: $\ln \frac{x_i(t)}{x_i(t-1)} = \ln x_i(t) - \ln x_i(t-1)$.

Equivalently, we could use elasticities, $\alpha_i(t)$, and rewrite Eq 1-10 as:

Eq 1-11: $$\frac{T\dot{F}P}{TFP} = \ln \frac{O(t)}{O(t-1)} - \sum_i \{\frac{1}{2} * [\alpha_i(t) + \alpha_i(t-1)] * \ln \frac{x_i(t)}{x_i(t-1)}\}$$

As seen, the Thörnqvist index assumes factor shares over the period *(t-1)* to *t*, approximated by the arithmetic averages of factor shares in each period, to be equal across all production units, but which would change over time when *t* takes consecutive values. Relaxing the first part of this assumption leads to another measure of productivity, called the trans-log multilateral index, which is viewed to be more suitable when making pair-wise comparisons.

The trans-log multilateral index

This index is proposed by Caves, Christensen and Diewert (1982). With the use of this index one can measure the relative productivity of a real (existing) production unit to that of a constructed (hypothetical) reference unit, which is common for the whole sample (population). The hypothetical unit produces output, uses input and has factor elasticities that are constructed with the data from the real units. Each real unit is assigned factor shares that are calculated as the averages of factor shares of the real unit itself and of the hypothetical unit. More specifically, referring to Caves, Christensen and Diewert (1982), the hypothetical unit produces the (simple) geometric average of the output of real units in the sample, uses the (simple) geometric average of each factor used by real units and has factor elasticities equal to the arithmetic averages of factor elasticities of the sample units. The output, factor use and factor elasticity (share in competitive markets) of this hypothetical unit are respectively as in Eq 1-12, Eq 1-13 and Eq 1-14.

Eq 1-12: $O^h(t) = \{\prod_{j=1}^{N(t)} O^j(t)\}^{\frac{1}{N(t)}}$,

Eq 1-13: $x_i^h(t) = \{\prod_{j=1}^{N(t)} x_i^j(t)\}^{\frac{1}{N(t)}}$,

Eq 1-14: $\alpha_i^h(t) = \frac{1}{N(t)} \sum_j [\frac{w_i(t)}{p(t)} * \frac{x_i^j(t)}{f^j(t)}]$,

where *h* stands for the hypothetical unit, *j* the real unit, *N* the sample (or population) size (where all firms in the sample in period *t* take product price *p(t)* and factor prices $w_i(t)$ as given).

When applying the trans-log multilateral index, the factor shares assigned to each real unit, *j*, are calculated as averages of factor shares measured for this unit and of the hypothetical unit, *h*, which, when using an arithmetic average, are:

Eq 1-15: $\overline{\alpha}_i^{jh}(t) = \frac{1}{2}[\alpha_i^j(t) + \alpha_i^h(t)]$,

With the use of a common hypothetical unit, the relative productivity of firms can be assessed by comparing the productivity measure of each real unit *j* to the hypothetical unit *h*, which would look like:

Eq 1-16: $\ln \frac{TFP^j(t)}{TFP^h(t)} = \ln \frac{O^j(t)}{O^h(t)} - \sum_i [\overline{\alpha}_i^{jh}(t) * \ln \frac{x_i(t)}{x_i(t)}]$,

where the relative productivity of each real unit *j* to the hypothetical unit *h* is measured by the natural log of the ratio of their respective *TFP*'s in time *t*.

These index-type measures are based on relationships between output and inputs, which are expressed in terms of quantities produced and used in the production process. Hence, quantity is a basic concept in relation to productivity measurement that needs to be addressed when introducing productivity measures, which we discuss next.

Quantity

The measurement of quantity is an important aspect of productivity. It would be difficult to evaluate and keep track of what we have produced (and even consumed) if we do not have some measure of the quantities involved at our chosen periods of time. When these quantities are obtained, as seen from in the previous, one could construct productivity measures, which express the *level* or *growth* of the output-input relationship. When constructing productivity levels, an issue is their comparability because of the different kinds of output and input used.

As a simple example take an economy with two industries which have production functions like in Eq 1-2, each producing one kind of output, say clothes and food, and using the same input. By tracing how much input is used and how much output is produced in each industry we can easily conclude whether there is a rise or not in productivity for each industry by the simple measure in Eq 1-1. However, how would we interpret these results for both industries relative to each other? What can we say about the relative performance of productivity in these two industries if, for example, in period $t+1$ we have a change by C units of clothes per unit of input and a change by F units of food per unit of input compared to period t? In order to say something meaningful we have to include other elements, such as economic and technologic factors, or even subjective judgments on, for example, the relative importance of clothing compared to feeding. This is just an unrealistically simple example and even this involves a number of elements that demonstrate the issues, as intertwined with different kinds of beliefs and interests, which exist and might not be so easy to reconcile with measures that involve quantity.

Furthermore, although what is meant by the term 'quantity' is easily understood for tangible outputs, like clothes and food, in practice however, it might not be so for intangible outputs, like services, counseling, entertainment, and alike. The quantities of such intangible outputs are more difficult to measure. The economy consists of many different kinds of outputs and inputs that change over time, which makes it difficult to trace the levels and the relative importance of all the quantities produced (and consumed).

What is usually done in practice is to make use of the growth of quantities instead of the levels. By measuring the growth in each period for each production process, the comparison between industries and groupings within them may become somewhat easier. This is usually done with the help of index numbers, some of which were discussed in the previous section. Although the problem of units of measurement is removed when using index-based growth measures, other problems like measuring the quality of products, accounting for the innovations or keeping track of quantity as well as price changes over time still remain.

Such problems are usually avoided by applying price indexes. Making use of price indexes not only helps to keep track of price changes but also to account for quality changes and new products introduced. To mention here, according to the European Commission (2001), the methods that account for the quality changes when computing price indexes are: 'Overlapping', 'Unadjusted price comparison', 'Automatic linking', 'Matched models only', 'Option prices', 'Production costs', 'Judgmental approach', 'Hedonic adjustment', and 'Re-sampling'. Among these, two methods that are more preferable in the practice of OECD, and which do not differ much from each other, are the hedonic adjustment and re-sampling.[10]

If one uses money values instead of quantities, the above problems with comparability, measurement and quality could be less worrisome, but there are still further issues encountered. As mentioned earlier, economies consist of a large number of different and diverse products (goods and services) and although the use of index numbers and methods that account for changes in the products' quality help avoid some problems caused by measures expressing levels, the task of constructing productivity growth measures for each single product would become unmanageable. This means that one needs to use some degree of aggregation. On the other hand, while aggregation helps decrease the number of measures needed, the aggregation itself is not completely unproblematic. Some issues related to aggregation are presented in the following section.

Aggregation

One can freely choose the degree to which measures of output and input are aggregated. There may be at least three levels of aggregation: whole economy (country), industry and firm. Most of the productivity measures in use are at the industry level. The justification for industry level measures lies in the crucial assumption that the units of production within a common industry have similar production functions (and activities). Hence, aggregation is justified as long as the industry is defined as: 'An industry consists of a group of establishments engaged on the same, or similar, kinds of production activity' (System of National Accounts 1993).[11] Assuming profit maximization or cost minimization behavior, several types of measures of the output-input relationship can be obtained for industries that consist of similar establishments according to the definition above. As noted in the previous section, in avoiding issues related to quantity, some of these measures make use of money values. The value in money terms in year t is simply output (or quantity) multiplied by price.

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[10] See 'Handbook on price and volume measures in national accounts' (European Commission, 2001, pp. 19 – 22) for a more detailed discussion of the methods that account for quality changes when computing price indexes.

[11] On http://unstats.un.org/unsd/sna1993/introduction.asp choose 'Glossary', then choose the letter 'I' and then 'industry'.

Eq 1-17: $V(t) = O(t) * P(t)$,

where *V* is the value in money terms, *O* output, *P* price and *t* time.

If prices over time in Eq 1-17 are held fixed, making use of money values it is easier to see the comparable contribution of productivity changes into the output in one industry compared to the contribution of productivity changes into the output in another industry than when using quantities. With fixed prices, we can look at how much more or less value in money terms is generated by each industry in each period due to output changes only, which although does not the issue of relative importance, it does resolve comparability.

However, when an industry does not have one single product, but consists of many close substitute products, one would need to aggregate these products in order to get the money value for the whole industry. It is in this kind of aggregation where the so-called problem of 'non-additivity' occurs, which is encountered in the practice of producing industry level indexes. This happens because while holding one year as the base year, the sum of values calculated based on changes in both quantity and price indexes is not the same as the sum of values calculated based on changes only in quantity indexes of the products that belong to the same industry. The reason why although the problem is known, it cannot be practically completely because of the difficulty of keeping track of the myriad of quantities alone that exist in an economy over time, notwithstanding here the presence of new products and elimination of others from consumption (and subsequently production).

This problem can be illustrated by the following tables where industry *Ind.* Consists of two firms (establishments), one that produces item *A* and the other *B* (which are close enough substitutes). Assume the following values are given.

Table 1.1: Money values, quantity and price indexes in industry *Ind.* with products *A* and *B*

	Value 90	**Index 91 to 90**		**Value 91**		**Index 91 to 92**		**Value 92**	
	With current prices (90)	Quantity	Price	With prices of 90	With current prices (91)	Quantity	Price	With prices of 91	With current prices (92)
	(1)	(2)	(3)	(4 = 1*2)	(5 = 3*4)	(6)	(7)	(8 = 5*6)	(9 = 7*8)
A	100.0	1.050	1.100	105.0	115.5	1.020	1.080	117.8	127.2
B	300.0	1.100	0.950	330.0	313.5	0.900	1.050	282.2	296.3
Ind.	400.0	1.088	0.986	435.0	429.0	0.932	1.059	400.0	423.5

Source: Adapted from the 'Handbook on price and volume measures in national accounts' (European Commission,. 2001, p. 16).

The quantity (or volume) indexes of the industry in each year in columns 2 and 6 are obtained as averages of the quantity indexes of each product using weights from the values of the previous year with current prices (columns on the left, respectively columns 1 and 5). This is the Laspeyres volume index. The industry's change in output from year 90 to 91 is obtained by the quantity index as: 1.088 = 1.050*(100.0/400.0) + 1.100*(300.0/400.0). The price indexes of the industry in columns 3 and 7 are obtained as averages of the price indexes of each product using weights from the values of the current year with prices of the previous year (columns on the right, respectively columns 4 and 7). This is the Paasche price index. The industry's change in prices from 90 to 91 is: 0.986 = 1.100*(105.0/435.0) + 0.950*(330.0/435.0). For the period 91 to 92, industry's quantity index is: 0.932 = 1.020*(115.5/429.0) + 0.900*(313.5/429.0), and its price index is: 1.080*(117.9/400.0) + 1.050*(282.2/400). In particular, since *Ind.*'s quantity index for 91 to 92 (column 6) is obtained using weights from the value for 91 with current prices (91), it takes into account both quantity changes as well as price changes and not only quantity changes.

From the values in table 1.1 we can also obtain the quantity indexes and the money values due to quantity (output) changes alone for each year holding year 90 as the base year, which are shown in table 1.2 in the following. In addition, in table 1.2, holding 90 as the base year, there is also presented the quantity index of *Ind.* based on table 1.1, as it is usually computed in practice, and the quantity index of (*A*+*B*) as the average of quantity indexes of products *A* and *B* with constant weights based on the value of the base year (90). The use of unchanged weights as from the base year is to show the combined effect of only quantity changes of products *A* and *B* compared to the base year. These figures are in table 1.2.

Table 1.2: Quantity indexes and money values with 90 as the base year (90 =1)

	Quantity index base year 90	**Value 90 - base 90**	**Quantity index 90 to 91**	**Value 91 - base 90**	**Quantity index 90 to 92**	**Value 92 - base 90**
	(1)	(2)	(3)	(4)	(5)	(6)
A	1.000	100.0	1.050	105.0	1.071	107.1
B	1.000	300.0	1.100	330.0	0.990	297.0
Ind.	1.000	400.0	1.088	435.0	**1.014**	405.6
(A + B)	1.000	400.0	1.088	435.0	**1.010**	404.1

Source: Adapted from the 'Handbook on price and volume measures in national accounts' (European Commission,. 2001, p. 16).

In column 3 of table 1.2, the quantity indexes of products *A* and *B* as well as of *Ind*. for 90 to 91 are taken from column 2 of table 1.1. The quantity index of (*A*+*B*) for 90 to 91 is computed as a weighted average of quantity indexes of *A* and *B* using weights from the base year (90). This means that it is equal to the quantity index of *Ind*. by construction. In column 4 of table 1.2, the quantity index of *A* for 90 to 92 is obtained as the product of its quantity index for 90 to 91 and its quantity index for 91 to 92: 1.071 = 1.05*1.02 (where 1.05 and 1.02 are taken respectively from column 2 and 6 of table 1.1). The quantity index of *B* is obtained likewise. However, for 90 to 92 the quantity index of *Ind*. is not anymore equal to our constructed quantity index of (*A*+*B*), which are shown in bold figures in column 5 of table 1.2. The reason is because when calculating the quantity index of *Ind.* in practice, the price changes from 90 to 91 affect *Ind*.'s index, but they do not affect (*A*+*B*)'s index. Specifically, for 90 to 91 the quantity index of *Ind.* in column 5 of table 1.2 is obtained as: 1.014 = 1.088*0.932 (where 1.088 and 0.932 are taken respectively from column 2 and 6 of table 1.1).

As shown earlier, the computation of *Ind*.'s index of 0.932 in column 6 of table 1.1 is affected by the price changes from 1991 to 1992 (because the weights used to get 0.932 are from column 5 of table 1.1, which is affected from price changes in column 3 of table 1.1). But, our constructed quantity index of (*A*+*B*) for 90 to 92 is obtained using the weights from the value of the base year (90): 1.010 = 1.071*(100.0/400.0) + 0.990*(300.0/400.0). This means that it is not affected from price changes from 91 to 92 but only quantity changes.

Because of these discrepancies of the quantity indexes, there will be discrepancies of the values in money as shown in the last column 6 of table 1.2. It is recommended that, when reporting real life figures, such discrepancies should not be removed but instead left and explained because they do not show any lack of reliability in obtaining the money values, but rather reflect the practical problems when making aggregations. Despite how aggregation is done, an important element of this exercise that remains valid is that prices affect the results. Hence, when one uses money values instead of quantities, depending on whether it is possible to aggregate by including price effects or not, the conclusions about the contribution of productivity changes on the industry's output might differ considerably if the price effects are large enough. Extending on the role of prices in relation to some other issues related to productivity measures, we present the main findings by Baumol and Wolff (1984) who argue that when trying to obtain absolute productivity measures making use of base year money values, it may not be at all possible to obtain such measures. Their arguments and the methods that are used to measure productivity are discussed in the next section.

Other Issues of Productivity Measures

After introducing the concept of productivity and some basic issues related to quantity and aggregation, we look at some further issues that extend those of the preceding section and end the presentation of productivity measures with a review of the main methods.

Measures of productivity level and growth

In section 1.3 on aggregation was stated that using money values instead of quantity could be advantageous in avoiding some of the issues related to quantity (for example, the comparison between different types of output being easier and maybe more meaningful). Furthermore, leaving aside problems like 'non-additivity', when quantities are difficult to measure, with money values in each period one can obtain index measures of output by the use of price indexes. For example for a one-year period from (*t-1*) to *t*:

Eq 2-1: $$\frac{V(t)}{PI_{t,t-1}} = \frac{O(t)*P(t)}{P(t)/P(t-1)} = O(t)*P(t-1),$$

where $PI_{t,t-1}$ is the yearly price index.

Eq 2-1 gives the money value of output in *t* measured in fixed prices, using (*t-1*) as the base year, based on which we can obtain an index of output by simply dividing by *V(t-1)*.

Holding one year as the reference year, it seems that one is able not only to derive conclusions about the relative productivity level in each industry by allocating the contribution of the levels of output alone (since prices are kept constant), but also to compare such contributions based on equal units of measurement, that is money. As attractive as they look, *such measures of absolute productivity could in fact be misleading for exactly the same reasons* *that they are supposed to be meaningful*, which is an important by Baumol and Wolff (1984). Their main aim is to assess the measures of absolute productivity currently in use and find any meaningful measures of absolute productivity. Referring to a number of studies that have made use of absolute productivity measures[12], Baumol and Wolff question the very meaning of comparing industry productivity differences based on the measures obtained from the use of reference year price indexes. They find that a comparison of absolute productivity measures of different industries based on reference year price indexes is meaningless. The reason for this is because, by the choice of the reference year, one can basically make such measures as large or as small as one wants. As follows, we present briefly why Baumol and Wolff (1984) argue that this is indeed the case.

First, to get an absolute measure of productivity over time by holding one year as the reference year, Eq 2-1 is extended by replacing the price of the output in the previous period with the price of output in the reference period. A similar construction is done for the inputs as well. Calling the reference year (period) as year *0*, in a given year *t* we would have the value of the revenue from selling the output as in Eq 2-2 and the cost of using an input as in Eq 2-3.

Eq 2-2: $R_{t,0} = O(t) * p(0)$,

where $R_{t,0}$ is the revenue from selling product *O* in period *t* evaluated with the product's price *p* of period *0*.

Eq 2-3: $C_{t,0} = I(t) * w_I(0)$,

where $C_{t,0}$ is the cost of using input *I* in period *t* evaluated with the input's price w_I of period *0*.

Industries or sectors of an economy have different kinds of output and input, each with their own market prices. To include many (or possibly all) of the outputs and inputs we can further extend Eq 2-2 and Eq 2-3 and obtain a measure that is often claimed to be a measure of the *TFP* level of sector *s*:

[12] Stigler (1947), Nordhaus (1972), Denison (1973), Kutscher et al. (1977), Denison (1979b), Thurow (1980) and Baily (1982).

Eq 2-4: $M^{s}_{TFP}(t) = \dfrac{\sum_j R^{j}_{t,0}}{\sum_j C^{j}_{t,0}} = \dfrac{\sum_j O^j(t) * p^j(0)}{\sum_i x_i(t) * w_i(0)}$,

where M_{TFP} means that it is a measure of *TFP*[13] at time *t*.

That is, the claim is that an absolute *TFP* measure of a sector is obtained by dividing the revenues from outputs with the cost of inputs, holding prices constant as of period *0*. While this measure (or similar) is actually used often to compare levels of absolute productivity in different sectors[14], Baumol and Wolff argue that *this in fact is a measure of the productivity growth and not of productivity level (in money terms, with prices of period 0)*.

To see how this important conclusion is reached, one can assume that in each unit of production *j* outputs grows at a rate δ and, without any loss of generality, the usage of each input has no growth: $x_i(t) = x_i(0)$. This means that over the period of time from year *0* to year *t*, Eq 2-4 could be written as:

Eq 2-5: $M^{s}_{TFP}(t) = \dfrac{\sum_j O^j(t) * p(0)}{\sum_i x_i(t) * w_i(0)} = \dfrac{\sum_j e^{\delta t} O^j(0) * p(0)}{\sum_i x_i(0) * w_i(0)} = e^{\delta t} * \dfrac{\sum_j O^j(0) * p(0)}{\sum_i x_i(0) * w_i(0)} = e^{\delta t} * M^{s}_{TFP}(0)$

As seen from Eq 2-5, rather than the absolute productivity, $M_{TFP}(t)$ measures in fact the rate at which productivity in sector *s* has grown from time $t = 0$ measured by $M_{TFP}(0)$ in the reference year. As Baumol and Wolff point out, even if the different kinds of outputs and also inputs grow at differing rates, it is still difficult to interpret $M_{TFP}(t)$ as an absolute measure of productivity because it is more appropriate to consider it like a weighted average of the growth of $M_{TFP}(t)$ rather than an absolute measure of productivity.

Turning to the issue of comparing the absolute productivity of different industries with the measure obtained in Eq 2-4, the argument by Baumol and Wolff goes on by assuming that there are only two sectors, *a* and *b*, with productivity (output to input) growth *u* and *v* ($u>=v$) respectively. Furthermore, in the equilibrium with competitive markets and no rent earned by firms, in each sector *s* revenues are equal to costs and hence: $M_{TFP}(0)=1$. From Eq 2-5, the relative productivity of sector *a* compared to sector *b* in period *t* is given by:

[13] Why it is not specified that it is a measure of absolute productivity is clarified in the following, and, as will be seen, the reason is because it is in fact found to be a measure of relative rather than absolute productivity.

[14] Here we use the term sector, which, in practice, usually means a number of industries that belong to that sector. However, Eq 2-4 can similarly be used to obtain *TPF* measures of industries by summing over firms.

Eq 2-6: $\frac{M^{a}_{TFP}(t)}{M^{b}_{TFP}(t)} = \frac{e^{ut}}{e^{vt}} = e^{(u-v)t}$

The implication of this formula is that a comparison of productivity levels between industries, with measures as in Eq 2-4, is basically dependent on *t* and hence dependent on the choice of the reference year. This implies that one can make it as large or as small as one wants by a proper choice of the reference year.

After reaching this conclusion, Baumol and Wolff further investigate whether it is at all possible to compare productivity levels across industries by making use of current prices instead of reference year's prices. However, what they find is that, because of the market mechanisms, which in equilibrium would tend to allocate resources from the low productivity sectors to the higher productivity ones, measures that are based on current prices will tend to obtain measures of productivity levels that are equal across all industries in the economy.[15]

Though illuminating, these findings are also a bit unfortunate for the purpose of comparing the productivity levels of different industries, or as Baumol and Wolff put it: '… we have failed to provide a measure on whose basis it is possible to say convincingly that sector a is 1.5 times as productive as sector b' (Baumol and Wolff, 1984, p. 1032).

But, fortunately, measures of the growth rate of productivity are still valid. Some of the main index based measures of productivity in use in the Organization for Economic Co-operation and Development (OECD) countries, summarized in table 2.1, are discussed next.

Table 2.1: Summary of some main measures of productivity growth used from the OECD

Type of output measure	**Type of input measure**		
	Single factor productivity measures		**Multifactor productivity (*MFP*) measures**
	Labor (*L*)	**Capital (*K*)**	**Capital and labor (*MFP*)**
Gross output	Labor productivity based on gross output	Capital productivity based on gross output	Capital-labor MFP based on gross output
Value added	Labor productivity based on value added	Capital productivity based on value added	Capital-labor MFP based on value added

Source: Some of the main measures in 'Measuring productivity: OECD manual', OECD (2001, p 13).

[15] To find out more see Baumol and Wolff (1984, sections IV and V, pp. 1025 – 1028).

As seen from table 2.1, one main division of the productivity measures in use among the OECD countries is based on whether one measures the output in terms of gross or value added. If some, or all, of the output produced in an industry is used as input from another industry, when constructing productivity measures for a number of industries altogether (or the whole economy), it is important to distinguish between the measure of output as gross or value added output. The reason for this is because: 'A value-added function presents the maximum amount of current-price value added that can be produced, given a set of primary inputs and given prices of intermediate inputs and output' (OECD, 2001, p. 26). Based on this definition, the most appropriate measures at the economy level would be value added based, though in practice gross based are also used.

Another main division is whether one uses measures for one or more inputs, which leads to obtaining single factor or multifactor productivity (*MFP*)[16] measures. A short interpretation of the rationale for the use of measures in table 2.1 is provided as follows.[17]

"*Labor*" *productivity*

When based on gross and value added output, labor productivity is respectively measured as in Eq 2-7 and Eq 2-8.

Eq 0-7: $ALI_G = \frac{QI_G}{QI_L}$,

where QI_G is quantity index for gross output, QI_L is quantity index for labor input and ALI_G is labor productivity index with gross output.

Eq 0-8: $ALI_{VA} = \frac{QI_{VA}}{QI_L}$,

where QI_{VA} is quantity index for value added output and ALI_{VA} is labor productivity index with value added output.

Even though they are both called labor productivity measures, ALI_G and ALI_{VA} are supposed to capture a great deal of all of the factors that affect productivity considering that the productive use of labor force is dependent on two main factors. First, workers themselves become more productive, and second, the use of capital and intermediate inputs (for ALI_G only), technical, organizational and efficiency changes, etc. will also make workers more productive.

[16] Instead of multifactor productivity (*MFP*), as seen in chapter 1, another term that is commonly used when the inputs are capital and labor is total factor productivity (*TFP*). We use *TFP* instead of *MFP* in the empirical analysis.

[17] For a more detailed (through a short guide) discussion see 'Measuring productivity: OECD manual, Measurement of aggregate and industry-level productivity growth' (OECD, 2001, pp. 13 -18).

In addition, value added labor productivity is often interpreted as a measure of the living standards (usually involving the use of prices also). Measures of labor productivity are called partial measures because they are based on only one factor, and although constructed with the thought of capturing a myriad of factors, in certain cases they are still misinterpreted as either expressing the technical change or the productivity of workers.

"Capital" productivity

Measures of capital productivity based on gross output and value added are:

Eq 0-9: $AKI_G = \frac{QI_G}{QI_K}$,

where QI_K is quantity index for capital input and *AKI* is capital productivity index.

Eq 0-10: $AKI_{VA} = \frac{QI_{VA}}{QI_K}$

Similar to labor productivity, capital productivity measures reflect the influence of not only how productive the use of capital alone has been but also of other factors, like labor and intermediate inputs (for AKI_G only), technical, organizational and efficiency changes, etc., which make the use of capital more productive. Although constructed with the thought of capturing a myriad of factors, these measures also are sometimes perceived as productivity of capital only.

Capital and labor MFP

Measures of capital-labor *MFP* based on gross output and value added are:

Eq 0-11: $MFPI_G = \frac{QI_G}{QI_{Combined}}$,

where $QI_{Combined}$ is quantity index for capital and labor combined and *MFPI* is capital-labor *MFP* index.

Eq 0-12: $MFPI_{VA} = \frac{QI_{VA}}{QI_{Combined}}$

MFPI measures show how both capital and labor are used over time. In practice, *MFPI* measures do not capture the effect of technical change only, but rather the influence of organizational and efficiency changes, economies of scale, etc.

Among these index based measures discussed, the most used ones in practice are ALI_G, ALI_{VA}, AKI_{VA}, and $MFPI_{VA}$.

After discussing issues related to absolute productivity measures and introducing some index based measures in use, we present a summary of the main methods that exist for measuring productivity and discuss their possible effect on the productivity estimates obtained.

Methods of measuring productivity

The methods of measuring productivity fall into two main categories, called non-parametric and parametric methods. Van Biesebroeck (2003, 2004) discusses and evaluates these methods with Colombian data (2003) and Monte Carlo simulations (2004). Following the discussion in these two studies, the non-parametric methods are of two kinds, Data Envelopment Analysis (DEA) and Index Numbers (IN).

Without going into its technical details, the DEA method can be considered as mainly empirical since based on a number, or all, of the observations units that produce the largest output with given inputs are deemed as being 100% (or "fully") efficient. Once these "fully" efficient units are found, an efficiency frontier can be constructed consisting of the levels of outputs and inputs used by these units against which other (less efficient) units are compared.[18]

Different kinds of IN measures used in the practice of OECD were introduced in the previous section and the main methods based on the Index Numbers approach were discussed in section 1.1 (the Divisia index, the Thörnqvist index and the trans-log multilateral index).

In addition to these, related to DEA and IN, another (non-parametric) index is the so-called Malmquist index or the Malmquist firm specific index. This index is usually constructed based on the concept of the 'distance function' or 'output distance function'. This is a function that shows how far the observed output is from the maximum feasible output with the given technology over time or across production units. In this way the Malmquist index can be interpreted as a measure of either productivity growth over time or relative productivity across different production units. Intuitively, the range of this output distance function is (0, 1], where the higher the value of the function the more efficient a production unit is considered to be. We have excluded 0 because it shows complete inefficiency, which is the same as producing 0 units of output with the given inputs and in practice this usually means no production activity.[19]

Non-parametric methods do not rely on a particular production function and productivity measures are computed without referring to a specific technology. On the other hand, parametric methods assume specific production functions. The parameters of interest are estimated using the observations that are available. In turn, they can be used to measure relative productivity across different units or productivity growth for the same unit. A specific

[18] The DEA method can be used to measure both relative productivity level or productivity growth. The method was introduced by Farell (1957).

[19] Details and original references of the Malmquist index can be found in Grosskopf (section 4.4.1) and Lovell (section 1.7.5) in Fried et al. (1993), eds.

production function that is most commonly used is Cobb-Douglas. Parametric methods estimate the factor elasticity parameters, which with two inputs, capital (*K*) and labor (*L*), can be presented as in Eq 2-13:

Eq 0-13: $\ln O^j(t) = \beta_0 + \alpha_K * \ln K^j(t) + \alpha_L * \ln L^j(t) + \ln A^j(t) + u^j(t)$,

where $u^j(t)$ is an error term with expectation 0 in each period and $lnA^j(t)$ is an unknown term for the productivity of firm *j* at time *t*.

As seen from Eq 2-13, when estimating the parameters, everything unexplained as well as the errors will be interpreted as productivity difference since the disturbance term for Eq 2-13 is in fact: $e^j(t) = \ln A^j(t) + u^j(t)$. After estimating the parameters in Eq 2-13, productivity growth for each unit *j* can be measured by the difference of residuals:

Eq 0-14:

$$\hat{e}^j(t) - \hat{e}^j(t-1) = \ln \frac{\hat{A}^j(t)}{\hat{A}^j(t-1)} + [\hat{u}^j(t) - \hat{u}^j(t-1)] =$$
$$= \ln \frac{O^j(t)}{O^j(t-1)} - \hat{\alpha}_K * \ln \frac{K^j(t)}{K^j(t-1)} - \hat{\alpha}_L * \ln \frac{L^j(t)}{L^j(t-1)},$$

where the hat is for estimated.

However, when trying to estimate parameters in Eq 2-13 we are faced with what is called in problem of endogeneity problem because the choice of *K* and *L* from firms is dependent on their own productivity level, which is known to firms, but unknown to us. Three estimation procedures are used to overcome such endogeneity problems, which are instrumental variable, stochastic frontier and semi-parametric methods of estimation.[20] Although these techniques would presumable help avoid some of the possible effects on estimations, we would argue in support of a different view of productivity measurement with the parametric methods.

Our view is that, with N production units (firms) in place, parametric methods cannot be used to measure productivity at the firm level (A_i, where i = 1 to N) because when this is attempted the number of estimations is strictly greater than the number of observations (A_i + Number of parameters > N). Hence, parametric methods can be more appropriately used to measure of average productivity of an aggregation of firms rather than of each unit itself. This being the case, the main problem in estimating productivity by the disturbance term is better viewed as a misspecification (because of not controlling for productivity) rather than endogeneity. With the interest in measuring the average productivity of an aggregated number

[20] For a detailed discussion, which points to the original and later references, of each method see Van Biesebroeck (2003) and Van Biesebroeck (2004).

of firms (be it industry, sector, etc.) one can easily re-specify Eq 2-13 to accounts for the omission of average productivity across all of the observations as we do in section 4.3 (where we discuss this in more detail referring to the method that we choose to measure productivity).

After this short presentation of the main methods that are used to measure productivity, when addressing the issue of efficiency and technical change, as seen earlier in the definition of productivity by Grosskopf (1993), it should be noted that the DEA and the Malmquist index can be adapted to allow accounting for efficiency and technical change separately. Since these methods measure productivity based on empirical benchmarks whose efficient frontiers or output functions equal to 1, these methods seem more suitable for such purpose. However, parametric methods are also adapted to allow accounting for efficiency and technical change, usually incorporating a variable for time in their specifications.[21]

An especially interesting part in the two studies by Van Biesebroeck is the assessment of estimates of productivity obtained from the different methods. However, although interesting the findings are somewhat confusing. The reason is because there are contradictory findings on the consistency of estimates obtained by different methods. In 2003 study it is concluded that:

'… "Does it matter which method we use to estimate productivity," I answer with a qualified no' (Van Biesebroeck, 2003, p. 36). But, in 2004 the conclusion on this issue is changed into:

'It does matter what method is used to estimate productivity. For different assumptions on the evolution of productivity, an inherently unobservable phenomenon, different methodologies are preferred' (Van Biesebroeck, 2004, p. 43).[22]

These two contradictory statements make it interesting to engage into producing estimates based on different methods, which we do for a parametric and a non-parametric method, with the results discussed in section 4.3.

Before ending this section we illustrate a situation where even when choosing the main method of estimation, there are still revisions and reasons for changes in the methodology applied in terms of the kinds of output and input included. This has been recently the case with the production of official measures of productivity by the Office for National Statistics (ONS) in the UK. A detailed discussion of the review of the methodologies used by ONS is done in Barnes and Williams (2004) where they also present the changes adopted (which affect the way

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[21] Details on how this is done are found in Grosskop (section 4.4.2) and Lovell (1.7.1) in Fried et al. (1993), eds.

[22] About terminology, we use the term "method" to refer to the overall approach that is based on a main technique used to measure productivity. We reserve the term "methodology" for the way how inputs or outputs are constructed when applying a

labor input is calculated when obtaining index measures similar to Eq 2-8). For the whole UK economy, while previously the two main official measures of productivity published were ‘gross value added per job filled’ (‘output’ per job’) and ‘gross value added per hour worked’, since 2004 the former is replaced by the ‘gross value added at base (reference) prices per worker’ or just ‘output per worker’.[23] For the industry level, the main measure will continue to be ‘output per job’ because of the difficulty to split the workers who have jobs in different industries.

Considering the changes in the methodologies used to construct input measures, for the same period of time, Barnes and Williams (2004) report that they get quite different estimates: 'Using the new methodology, the new headline whole economy productivity series (output per worker) grew by 1.9 per cent in the year up to the first quarter of 2004. The growth in the output per job measure using the new methodology is 2.0 per cent. The whole economy output per job measure using the old methodology grew by half a per cent higher at 2.5 per cent in the year up to the first quarter of 2004' (p. 1). As seen, when changing the methodology, the measure ‘output per job’ differs considerably (by 25% compared to new methodology based estimate).

In the next section we continue with the discussion of the differences in the measures of productivity by reviewing a number studies.

Some productivity estimates in practice

In section 1 was mentioned that productivity could be measured from the so-called Solow residual by the use of the growth accounting technique. Young (1995) uses this technique to estimate *TFP* growth and provides an explanation of the factors behind the high output growth rate in the newly industrial countries in East Asia over the period 1966-1990. The countries studied are Hong Kong, Singapore, South Korea and Taiwan. The method of estimating *TFP* growth is the trans-log multilateral index, adapted to estimate the growth rather than the relative levels. The data are gathered from a number of sources, for example, Hong Kong Statistics, Singapore and South Korea National Accounts, Taiwanese Government, etc. (see Young, 1995, pp. 675-678 for a complete list). Inputs are the two basic inputs, capital and labor. Young compares his estimate of *TFP* growth with estimates of other studies in these

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main technique. For example, by including or excluding certain inputs or outputs into the way how they are measured, the methodologies may differ though the method is still the same. Van Biesebroeck uses them interchangeably.

[23] The main difference between ‘output per job’ and ‘output per worker’ measures is that in the latter the unpaid workers in the family are also included into the labor force and the calculation of labor input, but in the former they are not included.

countries. The differences between these estimates illustrate once more the importance of the methodology chosen. Taking for example South Korea, in table 3.1 are his and other studies' results, where the annual *TFP* growth is reported for the whole economy as well as for the manufacturing sector (which is the sector thought to have driven the high output growth over 1966 – 1990).

Table 3.1: Comparison of *TFP* growth estimates by Young (1995) with *TFP* growth estimates by some previous studies of South Korea's productivity and output growth

Study	**Period**	**Economy**	**Manufacturing**
Young (1995)	1966-1990	1.7	3.0
Christensen and Cummings (1981)	1960-1973	4.1	Not applicable
Kim and Park (1985)	1963-1982	2.7	Not applicable
Pyo and Kwon (1991)	1960-1989	1.6	Not applicable
Pyo et al. (1993)	1970-1990	1.3	1.1
Moon et al. (1991)	1971-1989	Not applicable	3.7
Dollar and Sokoloff (1990)	1963-1979	Not applicable	6.1

Source: Young (1995), table XI, p.666.

From the results in table 3.1, it is seen that, adjusting for the differences in the periods of study, for the same country, different studies have reported different *TFP* growth estimates. Notwithstanding differences in the periods, Young (1995) points also to the differences in the construction of variables for capital and labor (pp. 664 - 670). As will be seen in the next section, the sector that we have studied in this document is manufacturing. For this reason, it is particularly interesting to concentrate in table 3.1 on the results for this sector. Since the period in the last two studies together, Moon et al. (1991) and Dollar and Sokoloff (1990), covers the years from 1963 to 1989, it is seen that, based on these two studies together, during 1963-1989, *TFP* growth has been between 3.7% and 6.1%. However, for the period 1966-1990, Young (1995) reports that *TFP* grew by only 3.0%. Unless something drastic has happened from 1989 to 1999, the estimates are considerably different from each other. At the same time, for a period that is only 4 years shorter than in Young (1995), *TFP* growth in the manufacturing sector reported by Pyo et al. (1993) is reported to be merely 1.1%.

Though not presented here, for two other countries, Young (1995) reports that for the manufacturing sector, over 1970 – 1990, *TFP* growth in Singapore was actually negative at -1.0% (table VI, p. 658) and, over 1966 – 1990, *TFP* growth in Taiwan was 1.7% (table VIII, p.

661). That productivity growth in the manufacturing sector has not been high in the newly industrialized countries of East Asia is actually an especially interesting finding by Young (1995) because it runs contrary to the previous belief that the high productivity growth in these countries was mainly driven by the high productivity growth in the manufacturing sector. After not having found high *TFP* growth rates, Young (1995) assesses the effect of other factors to explain the high growth rates of output that were seen in these countries. He finds that these high growth rates of output came primarily from other factors than *TFP*, like the rise of labor force participation rates, the rise of educational attainment and the high investments in machinery (pp. 673 - 675).

There are two main lessons from this study. First, it matters how total productivity is measured, as seen from the different estimates in table 3.1. Second, the belief that the TFP growth in the manufacturing factor is the driving force of the overall growth, at least for the four countries studied by Young (1995), may not hold.

While the countries above were studied with the aim of examining the role of productivity in the high growth rates of output seen in some of the South East Asian countries, other studies in the US and other industrialized countries have been examining two other interesting phenomena that took place the early 1970s until the end 1990s. In the US and other industrialized countries, over 1970 – mid-1990s, it was first seen a prevalence of lower productivity growth compared to the period before 1970 and then a bounce back to higher productivity growth rates in the late 1990s. A candidate factor to explain these higher growth rates has been the information and communication technologies (ICT-s) and the presence and use of computers. A number of studies have investigated whether ICT-s have played a role in raising the observed productivity growth rates from the late 1990s, and if yes, how. Findings of a few studies that address these questions are presented in the following.

Whelan (2000) looks at the impact of computers on the US productivity growth in the US private business sector. The private business sector is: GDP minus output from government and non-profit institutions and the imputed income from owner-occupied housing (Whelan, 2000, p. 20). For labor productivity growth, as the indicator of the 'use' rather than the 'stock' of computers, contributions of computer-related and other factors are given in table 3.2.

Table 3.2: Contributions of computer-related and other factors to labor productivity growth in the US business sector, 1974 - 1998

Growth in:	Period 1974 - 1995	Period 1996 - 1998
Total computer-related factors	0.50	1.23
All other factors	0.66	0.92
Overall labor productivity	1.16	2.15

Source: Adapted from Whelan (2000), Table 4, p. 34.

Compared to the period 1974-1995, during 1996-1998, the contribution of computer-related into labor productivity growth has more than doubled. Also, compared to other factors, from less than half in the first period (0.50/1.16<0.5), the relative contribution of computer-related factors accounts for more than half in the second period (1.23/2.15>0.5). However, Whelan (2005) reports also that these findings should be interpreted with some caution because of the need to follow-up with other empirical studies which not only address the same topic, but at the same time address the issue of measurement.

Later in the same year, Oliner and Sichel (2000) look at the impact of information technology (IT) on output growth rates in the United States for the second half of 1990s and actually obtain different estimates for the effect of the use of computers. The data are taken from the Bureau of Economic Analysis and the Bureau of Labor Statistics in the US. They measure the contribution of five inputs to growth. These inputs are: computer hardware, computer software, communication equipment, other (non-IT) capital, labor hours, and labor quality. Table 3.3 shows the contribution of each of these inputs to the growth of non-farming output and table 3.4 shows contributions to labor productivity growth in the US during the period 1974 – 1999, which is divided into three periods.

Table 3.3: Contributions (%) to growth of real non-farming output in the US (1974 – 1999)

Growth rates of:	1974 - 1990	1991 - 1995	1996 – 1999
Output	3.06	2.75	4.82
Inputs:			
Information technology capital total	0.49	0.57	1.10
--- Hardware	--- 0.27	--- 0.25	--- 0.63

--- Software	--- 0.11	--- 0.25	--- 0.32
--- Communication equipment	--- 0.11	--- 0.07	--- 0.15
Other capital	0.86	0.44	0.75
Labor hours	1.16	0.82	1.50
Labor quality	0.22	0.44	0.31
Multifactor productivity (or TFP)	0.33	0.48	1.16

Source: Adapted from Oliner and Sichel (2000), Table 1, p.10.

As seen from table 3.3, information technology has had an important impact on the growth in the period 1996-1999 (1.1%), but its contribution is not the highest. The most important factors are *TFP* and labor hours (or hours worked). However, it is often perceived that a more important effect of the information technology is its use than its presence. Oliner and Sichel (2000) look also at the contribution of IT to labor productivity growth as Whelan (2000) does.

Table 3.4: Contributions (%) to labor productivity growth of real non-farming output in the US (1974 – 1999)

Growth rates of:	1974 - 1990	1991 - 1995	1996 - 1999
Labor productivity	1.37	1.53	2.57
Inputs:			
Information technology capital total	0.44	0.51	0.96
Other capital	0.37	0.11	0.14
Labor quality	0.22	0.44	0.31
Multifactor productivity (or TFP)	0.33	0.48	1.16

Source: Adapted from Oliner and Sichel (2000), Table 2, p.13.

It is now seen that the contribution of information technology is relatively more important. This leads to the conclusion that it is the use of computers that contributes more importantly to growth rather than the presence of information technology as capital stock. However, when compared with the results reported by Whelan (2000) in table 3.2, the contribution is lower by 0.27% (1.23-0.96). The explanation of Oliner and Sichel for this discrepancy is: 'Whelan (2000) estimate of the growth contribution from computers exceeds ours mainly because of a difference in measurement' (Oliner and Sichel (2000), p. 13). Without going into the details of the measurements used in each study, the implication, as noted earlier when discussing the study by Young (1995), is that the way how measurement is done might have implications for the results.

Despite the differences in their estimates, it is clear in both studies that overall the information technology, and especially its use, has had a considerable role in raising the growth rates during the late 1990s. A similar conclusion is also reached by Jorgenson and Stiroh (2000): 'Both labor productivity and TFP growth have jumped to rates not seen for such an extended period of time since the 1960s. While a substantial portion of these gains can be attributed to computers, there is growing evidence of similar contributions from software and communications equipment - each equal in importance to computers' (p. 32).

After presenting these empirical findings related to productivity estimates' differences and some currently studied factors that are thought of having a considerable impact on its growth, we continue next with our estimations of productivity growth in the Norwegian manufacturing sector over 1993 – 2002 and a comparison of two methods of measurement.

Measuring productivity growth

In this section we present the development of productivity growth in the Norwegian manufacturing sector by comparing two methods of measurement, one based on the Index Numbers and one on the Parametric approach. First, the index based model, the data and the variables are discussed. Next, the results applying our operationalised index are presented. Finally, these results are compared with those obtained from a parametric method.

The index based model and the data

The index applied to measure productivity growth

As it is custom in the practice of OECD to measure productivity growth at the industry level with the Index Numbers approach (or method) using the growth accounting technique, we have followed this by applying a Thörnqvist index in the Norwegian manufacturing sector. With data at the firm level we first obtain the productivity level for each firm and then aggregate these levels to measure productivity growth for the industry. This procedure considers the measure of each firm's productivity level as one observation to be used in obtaining the industry's measure of productivity growth.[24]

There are two main reasons why we have chosen a Thörnqvist based index to look at the development of productivity growth. First, it is easy to operate when constructing the variables of interest, which will be explained in the next section and where we assume competitive markets. Second, based on the discussion of this index in section 1.1, factor elasticities (shares) are computed as a moving average of every two years over the whole period of study (which are equal for all units over the two years). An implicit assumption in doing this is that factor elasticities do not change much from year to year. Although this would justify the use of a moving average, the consequence is that one uses two different, assumedly close, estimates of factor elasticity for each year (except for the start and end period years). Looking at the implications of using constant elasticities instead, we assess the estimates based on this assumption with other estimates based on the assumption that factor elasticities do not change at all over the whole period. If the differences in productivity estimates obtained based on these two methodologies are negligible, then instead of using changing factor elasticities for the same year (and subsequently for the same production units) one could apply the (simpler) methodology using constant factor elasticities over the whole period. In the following we discuss how we have operationalised the Thörnqvist index to measure productivity growth.

An operationalisation of the Thörnqvist index

A construction of the Thörnqvist index to measure productivity growth over time can be done by computing first factors shares of each unit as in the following two steps.

First, in each period of time *t* (say year), annual factor shares for that year are obtained as the average of calculated factor shares (elasticities) of all units that exist at that time:

Step 1: $\alpha_i(t) = \frac{1}{N(t)} \sum_j [\frac{w_i(t)}{p(t)} * \frac{x_i^j(t)}{f^j(t)}]$,

where Step 1 is the same as Eq 1-14 (under the discussion of the trans-log multilateral index, but $\alpha_i(t)$ refers here to all of the real units rather than being an estimate of the elasticity of an hypothetical unit.

Then, these factor shares, which are assumed equal over every two years, are computed as a moving average of annual factor shares over the two-year period.

[24] Hence, avoiding using one observation to obtain one estimate as would be the case if productivity at the firm level was to be measured, which is similar to our earlier note on the appropriateness of measuring productivity at an aggregate level rather than firm level in discussing the parametric method in section 2.2.

Step 2: $\overline{\alpha}_i(t-1,t)=\frac{1}{2}[\alpha_i(t)+\alpha_i(t-1)]$

As seen from the steps above, when applying this procedure, the factor shares obtained for years (*t-1*) and *t* may be different from the factor shares for years *t* and (*t+1*). As noted, the implication of this is that for the same year we may use different estimates of factor shares and the justifying assumption for this is that factor shares change "slowly" or "not much" over time. Whether this is true or not is an empirical question, which, as noted, we have addressed using constant elasticities over the whole period (with the results presented in section 4.2).

Total factor productivity (*TFP*) level for each firm is measured using a constant returns-to-scale production function with two inputs, capital (*K*) and labor (*L*), with value added output (*O*). Using the notation as in section 1, productivity level for each firm is:

Eq 0-1: $\ln TFP^j(t)=\ln O^j(t)-[\overline{\alpha}_t * \ln K^j(t)+(1-\overline{\alpha}_t)*\ln L^j(t)]$,

where $\overline{\alpha}_t$ denotes the capital elasticity at time t and is computed as a moving average of the annual capital shares of the industry: $\overline{\alpha}_t=\frac{1}{2}[\alpha(t)+\alpha(t-1)]$ (as in step 2 above).

The annual capital share of the industry is computed based on the cost minimization principal: $\alpha(t)=\frac{1}{N(t)}\sum_j[\frac{C_K^j(t)}{C_K^j(t)+C_L^j(t)}]=\frac{1}{N(t)}\sum_j[\alpha^j(t)]$ (as in step 1 above), where C_K and C_L are respectively cost of capital and cost of labor.

A measure of total productivity growth (TFP_g) in time *t* for the whole industry is obtained by the difference of the natural log *TFP* level for the industry in time *t* with the natural log *TFP* level for the industry in time (*t-1*):

Eq 0-2: $TFP_g=\ln TFP(t)-\ln TFP(t-1)$,

where *lnTFP(t)* is the natural log *TFP* level for the industry in time *t*.

The natural log *TFP* level for the industry is obtained as a weighted arithmetic average of natural log *TFP* levels (or the *TFP* level for the industry is the weighted geometric average of *TFP* levels) of each firm to give more weight to the productivity performance of larger firms. For this reason, we choose labor (*L*) to construct the weights because larger firms are expected to have larger *L*.[25] The industry's natural log *TFP* level in each year is:

[25] *L* is actually often used as a measure of firm's size.

Eq 0-3: $\ln TFP(t) = \sum_j \frac{L^j(t)}{\sum_j L^j(t)} * \ln TFP^j(t)$

As for the choice of the (weighted) geometric average for the *TFP* measure, it is the same kind of average that we use for the measures that involve output, capital and labor based on which we obtain the *TFP* growth estimates (presented in section 4.2).

We have used data on the value added (*O*), capital (*K*) and labor (*L*) in order to obtain the measures of productivity level for each firm as well as data on the costs of capital and labor in order to obtain the measures of capital shares for each firm. These and the construction of each variable are presented next.

The data and construction of variables

We have used in this document data from the database of the Statistics Norway called the capital database. This database contains data for all the manufacturing joint stock companies on a number of selected variables from accounts statistics and it is especially built with the aim of constructing data on tangible fixed assets. The period covered in this database is from 1993 to 2002. In 1993, all the joint-stock companies made up 65% of the value added and man-hour worked of the total of manufacturing industry, and in 2001, their share was 80% (Raknerud et al., 2004). Another database that is used is the producer price index database at the Statistics Norway[26], which contains monthly price indexes from January 1977 to December 2004. As follows, we describe how we have obtained the variables needed to estimate productivity growth by making use of the relevant variables in these databases.

Value added (O). Real value added in each year is obtained by dividing the variable 'value added at factor prices' from the capital database with a constructed 'yearly producer price index'. The variable 'value added at factor prices' in the capital database is constructed by subtracting operating expenses and adding the depreciation and rent or leasing costs to the operating income. To obtain 'yearly producer price indexes', we have constructed an average of the 'monthly producer price indexes' from the producer price index database (base year is 1993).

Cost of capital (C_K) *and capital (K)*. The cost of capital is the sum of the cost of the use of buildings and land (C_{BL}) and other tangible assets (C_{OtherA}):

$$C_K = C_{BL} + C_{OtherA}$$

The cost of buildings and land in year *t* is:

[26] Accessible at: http://www.ssb.no/maanedshefte/sm0842n.sdv (in Norwegian).

$$C_{BL}(t) = R_{BL}(t) + (\delta + \lambda_{BL}) * \frac{V_{BL}(t) + V_{BL}(t-1)}{2}$$

where $R_{BL}(t)$ is the firm's cost of buildings and land by renting or leasing and $V_{BL}(t)$ is the current market value at the end of year *t* of the stock of buildings and land owned by the firm. The value that belongs to year *t* is the average of the value in the end of the previous year and the value at the end of the current year. For 1993, this is the current year's value. δ is the real rate of return, which, for the period 1993 to 2002, we calculated to be 0.042% as the average annual *real* rate of return on 10-year government bonds. The figures for the nominal rate of return on governmental bonds and the rate of inflation are taken from Statistics Norway.[27] The real rate of return of the year is calculated as the difference between these two figures. λ_{BL} is the average depreciation rate for buildings and land, which, for the period 1993 to 2002, we found it to be 0.056%. The computation of the depreciation rate is based on the calculations in Raknerud et al. (2003).[28]

Similarly, the cost of other tangible assets is:

$$C_{OtherA}(t) = R_{OtherA}(t) + (\delta + \lambda_{OtherA}) * \frac{V_{OtherA}(t) + V_{OtherA}(t-1)}{2}$$

where R_{OtherA} is the rental value of other assets and V_{OtherA} is the value of other assets at the end of year *t* (as in the capital database). δ is again 0.042% as above. For the period 1993 to 2002, based on the calculations in Raknerud et al. (2003) we found λ_{OtherA} to be 0.27%.

Capital (*K*) in real terms is calculated as the ratio of the computed cost of capital (C_K) with the price index for new investments in tangible fixed assets. This price index is in the capital database.

Cost of labor (C_L) and labor (L). The cost of labor (C_L) is the variable for the wages and labor (*L*) is the variable for man-hours worked, which are both in the capital database.

With the use of these variables we have obtained productivity growth measures for the manufacturing sector in Norway applying the Thörnqvist index discussed in the previous section. This sector contains the industries that belong to section D in the Standard Industrial Classification (SIC94). The productivity growth estimates are for the 2-digit NACE (Nomenclature génerale des Activités économiques dans les Communautés Européennes) level. All firms that belong to the 2-digit level are assumed to have the same kind of production function and the same factor elasticity over every the two periods. In cases when the number of

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[27] The figures that we used are in a table that contains averages of different rates of return from 1953 to 2003. This table is accessible at: http://www.ssb.no/aarbok/tab/t-1101-569.html (in Norwegian).

[28] The Discussion Paper No. 365, which is available at http://www.ssb.no/publikasjoner/DP/pdf/dp365.pdf.

observations was small, we have considered industries as being closely related to each other and merged two-three of them.[29] However, two industries (with NACE codes 19 and 23 as in table 4.1 below) with a very few observations were not included into such merges because we considered them as not close enough to others. Because of only a very few observations they were not analyzed. The description of each industry and their codes are given in table 4.1, where more than one code refers to the industries that are merged.

[29] Merging is the same as in Raknerud and Rønningen (2004).

Table 4.1: SIC94 code and description of industries in the manufacturing sector

SIC94 Code (NACE)	Description
15-16	15 - Manufacture of food products. 16 - Manufacture of tobacco products.
17-18	17 - Manufacture of textiles. 18 - Manufacture of wearing apparel; Dressing and dyeing of fur.
19*	19 - Tanning and dressing of leather; Manufacture of luggage, handbags, saddlery, harness and footwear.
20	20 - Manufacture of wood and products of wood and cork, except furniture; Manufacture of articles of straw and plaiting materials.
21	21 - Manufacture of pulp, paper and paper products.
22	22 - Publishing, printing and reproduction of recorded media.
23*	23 - Manufacture of coke, refined petroleum products and nuclear fuel.
24	24 - Manufacture of chemicals and chemical products.
25	25 - Manufacture of rubber and plastic products.
26	26 - Manufacture of other non-metallic mineral products.
27	27 - Manufacture of basic metals.
28	28 - Manufacture of fabricated metal products, except machinery and equipment.
29	29 - Manufacture of machinery and equipment.
30-33	30 - Manufacture of office machinery and computers. 31 - Manufacture of electrical machinery and apparatus. 32 - Manufacture of radio, television and communication equipment and apparatus. 33 - Manufacture of medical, precision and optical instruments, watches and clocks.
34-35	34 - Manufacture of motor vehicles, trailers and semi-trailers. 35 - Manufacture of other transport equipment.
36-37	36 - Manufacture of furniture. 37 - Recycling.

Source: Official Statistics of Norway, Standard Industrial Classification, Statistics Norway (1997).

* Not included in the analysis because of the very small number of observations.

The development of productivity growth during the period 1993 – 2002 in the industries of the manufacturing sector in Norway as in table 4.1 is presented in the next section.

Productivity growth (1993-2002) in the Norwegian manufacturing sector measured with the Thörnqvist index

We have initially measured productivity growth in the industries in table 4.1 in terms of total factor productivity growth (TFP_g) as well as labor productivity growth (AL_g) applying the the Thörnqvist index. By manipulating Eq 4-1 one can re-write it using the natural log of output per man-hour worked or labor productivity (*O/L*) and log of capital per man-hour worked or capital intensity (*K/L*).

Eq 0-4: $\ln TFP^{j}(t) = \ln \frac{O^{j}(t)}{L^{j}(t)} - [\overline{\alpha} * \ln \frac{K^{j}(t)}{L^{j}(t)}]$

Another way of looking at Eq 4-4 is to consider labor productivity decomposed into total factor productivity and capital intensity (discounted by factor elasticity), which enter additively into the computation of labor productivity. The measure of labor productivity growth for the whole industry is obtained as the difference of the natural log *O/L* level for the industry in time *t* with the natural log *O/L* level for the industry in time (*t-1*) as in Eq 4-5.

Eq 0-5: $AL_g = \ln \frac{O(t)}{L(t)} - \ln \frac{O(t-1)}{L(t-1)}$

The same weights used as in the calculation of natural log *TFP* are also used to obtain a weighted arithmetic average for natural log *O/L* (or a weighted geometric average for *O/L*) for the industry as in Eq 4-6. As noted earlier, the choice of the weights is done to take into account firms' size differences with the aim of giving more weight to larger firms.

Eq 0-6: $\ln \frac{O(t)}{L(t)} = \sum_j \frac{L^{j}(t)}{\sum_j L^{j}(t)} * \ln \frac{O^{j}(t)}{L^{j}(t)}$

This looks similar to the calculation of output and inputs in the construction of the hypothetical unit of the trans-log multilateral index (Eq 1-12 and Eq 13), but with the use of weighed rather than simple geometric average we are taking into account firms' size as well. As noted earlier, the idea in doing this is to make the larger firms count more in the aggregate average estimates. The reason behind this is because we believe that, at least in terms of the volumes, larger firms would be the main drives of industry's productivity performance.

Measures of KL_g for the industry are obtained similarly:

Eq 0-7: $KL_g = \ln \frac{K(t)}{L(t)} - \ln \frac{K(t-1)}{L(t-1)}$

Eq 0-8: $\ln \frac{K(t)}{L(t)} = \sum_j \frac{L^{j}(t)}{\sum_j L^{j}(t)} * \ln \frac{K^{j}(t)}{L^{j}(t)}$

After obtaining TFP_g, AL_g, and KL_g for each year, we have obtained (simple arithmetic) average estimates over 1993 – 2002 and the results for the industries in table 4.1 are in table 4.2.

Table 4.2: Average labor productivity (AL_g), total factor productivity (TFP_g), and capital intensity (KL_g) growths in Norwegian manufacturing sector during 1993-2002

SIC94 Code: Short description	Average labor productivity growth (%)	Average total factor productivity growth (%)	Average capital intensity growth (%)
15-16: Food and Tobacco	3.0	1.4	5.8
17-18: Textile and Wearing	2.8	1.3	8.1
20: Wood (except Furniture) and Straw	2.7	1.9	3.7
21: Pulp and Paper	3.2	1.2	7.3
22: Publishing, Printing and Recorded Media	2.2	1.0	5.1
24: Chemicals	0.3	-1.9	7.5
25: Rubber and Plastic	2.2	1.1	4.5
26: Other Non-metallic mineral	1.0	-0.3	4.9
27: Basic metals	2.8	0.9	7.4
28: Fabricated metal	3.2	2.2	5.4
29: Machinery and equipment	2.7	1.9	4.1
30-33: Office, Electrical, Tele-communication, Medical	1.0	0.6	3.0
34-35: Motor vehicles and Other transport	1.8	1.0	5.2
36-37: Furniture and Recycling	2.5	1.2	5.6
All industries	2.2	1.0	5.5

The estimates for all industries (estimates of industries divided by the number of industries) in the last row show that on average labor productivity in the manufacturing sector in Norway during 1993-2002 has increased by 2.2% and total factor productivity has increased by 1.0%. This implies that the overall contribution of capital intensity to labor productivity growth is 1.2% (2.2-1.0). Capital intensity for all industries has increased by 5.5%. On average, about half of the labor productivity growth is due to total productivity growth and the other half due to the (discounted by capital elasticity) capital intensity growth. Except a few industries, such pattern seems to be the same for each industry. It is also seen that capital intensity is more volatile than both labor and total factor productivity growth.

The lowest labor productivity growth is in the industry of chemicals and chemical products (code 24), merely 0.3%, which is the industry that has also experienced the sharpest decline by 1.9% in total productivity growth. The reason for this industry to have a slightly positive growth in labor productivity is the large increase in capital investments, as shown by the second largest growth by 7.5% of capital intensity. Another industry that has experienced negative total productivity growth is the manufacturing of non-metallic mineral products (code 26), where the decline is by 0.3%. This industry and those with codes 30-33 have the second lowest growth of labor productivity (only 1.0%).

The highest growth of capital intensity is in the manufacturing of textiles and wearing apparel (codes 17 and 18) reaching 8.1%. However, this high growth in capital intensity is not associated with the highest growth in labor productivity and a reason is the modest growth by 1.3% in total factor productivity. The highest labor productivity growth has been in the manufacturing of pulp, paper and paper products (code 21) and of fabricated mineral products (code 28) reaching 3.2%. Even though both have reached the maximum labor productivity growth, the effects of total factor productivity and capital intensity differ widely between these two industries. In the manufacturing of pulp, paper and paper products, labor productivity growth is driven by capital intensity growth, which has grown by 7.3% while total factor productivity by just 1.2%. Quite opposite is the case with manufacturing of fabricated mineral products where capital intensity has grown by 5.4% but total factor productivity by 2.2%.

The differences between these two industries illustrate the importance of relying on more than one estimate of productivity growth, for example, if only the measure of labor productivity growth would have been reported, as discussed in section 2 (see table 2.1), one could conclude that productivity in both industries has grown equally. However, as seen from table 4.2, although this is true for labor productivity alone, it is not true for total factor productivity (and capital intensity).

Apart from the manufacturing of textiles and wearing apparel, another industry that is notable for its large growth in capital intensity is the manufacturing of basic metals (code 27) where capital intensity has grown by 7.4%. Its total factor productivity growth is about the same as the average for all industries, labor productivity is higher than for all industries.

In addition to the industry averages for the whole period, it would be interesting to look at the development of TFP_g, AL_g, and KL_g in each industry over time. To see this, we draw the graph for the estimated growths of labor productivity, total factor productivity and capital intensity in each industry over 1992 – 2002. These graphs are in appendix 1. From figures A1.1 to A1.14 in appendix 1, it is seen that labor productivity and total factor productivity growths in each industry follow more or less the same patterns, while the development of capital intensity growth is more different.

Overall, in each industry, the growths of labor productivity and total factor productivity experience changes more or less of the same magnitude over time. However, Changes in the capital intensity are not only much more different in magnitude, but sometimes they move in opposite directions with the changes in labor or total factor productivity. For example, in figure A1.1 for 1998, in figure A1.2 for 1994, 1995, 1998 and 2002, in figure A1.3 for 1994 and 1997, etc. Except different patterns between labor and total factor productivity on one hand and capital intensity on the other hand in each industry, figures A1.1 to A1.10 show also differences between industries. For example, for labor and total productivity growths, there are no big swings in figures A1.6, A1.12 (until 2000) and A1.14 (until 1998) there are no relatively big swings as in other cases. For capital intensity, differences between industries are much larger. The upshot of the graphs is that apart from the differences of estimates of average productivity growth from table 4.2, there are also differences in the dynamics of the development of productivity estimates over time.

After discussing these results obtained from the Thörnqvist index, we now address the question raised earlier on whether these estimates are much different from estimates obtained from a simpler methodology that keeps the factor elasticity constant over the whole period. We call this methodology Overall Average (OA), because its constant factor elasticity in period t, $\alpha^{OA}(t)$, is computed as:

$$\alpha^{OA}(t) = \frac{\sum_{t=1993}^{2002} \sum_j \alpha^j(t)}{\sum_{t=1993}^{2002} N(t)}$$

As seen, this constant factor elasticity is obtained by dividing the sum of factor elasticities of all firms (computed based on the cost minimization principal as before) during the whole period by the number of all firms (over 1993-2002). The upper script '*OA*' is to note that this factor elasticity is computed as an overall average. With such factor elasticities for each industry, we have computed total factor productivity growths in the same way as with the Thörnqvist index. First, we compute the natural log of *TFP* for each firm (Eq 4-1), but instead of using factor elasticity estimates $\overline{\alpha}_t$ in each year we now use the constant α^{OA}. Productivity growth for the industry with the OA methodology is measured as in Eq 4-2 again.

A comparison of these two methodologies is made by looking at the estimates of the means for the whole period and the correlation coefficient of the estimates of total factor productivity growth[30] over 1993 – 2002 in each industry obtained with each methodology. The results are shown in table 4.3.

[30] Since labor productivity and factor intensity are not dependent on factor elasticity, they are the same for both methodologies. What remains to check is total factor productivity growth.

Table 4.3: Averages (%) and correlation of total factor productivity growth estimates based on the Thörnqvist based index and Overall Average methodology

SIC94 Code	Average of *TFP* growth estimates		Correlation coefficient of *TFP* growth estimates
	The Thörnqvist index	Overall Average	
15-16	1.4	1.4	0.99940
17-18	1.3	1.3	0.99922
20	1.9	1.9	0.99996
21	1.2	1.1	0.99928
22	1.0	1.0	1.0000
24	-1.9	-1.8	0.99098
25	1.1	1.1	0.99998
26	-0.3	-0.3	0.99994
27	0.9	1.1	0.99968
28	2.2	2.2	0.99971
29	1.9	2.0	0.99945
30-33	0.6	0.6	0.99998
34-35	1.0	0.9	0.99978
36-37	1.2	1.2	0.99830
All industries	1.0	1.0	---

Results in table 4.3 show that the two methodologies produce almost equal estimates of total factor productivity growth averages for the whole period where only in five cases are they different by not more than 0.1% absolute difference. In addition, these two methodologies are almost equal over the years of the period because of the very high correlation coefficients in all industries with the smallest correlation coefficient 0.99098. The implication for productivity estimates is that the assumption of constant factor elasticities over the whole period does hold. This result suggests that one can safely use simpler computations for estimating productivity growth instead of those required by index numbers.

While the Thörnqvist based and the Overall Average methodologies are both based on the index numbers approach and compute productivity growth using the growth accounting technique, maybe it may not come as a surprise that they produce almost equal results. If their results would be different from each other, the only implication is that the assumption of having constant factor elasticities over the whole period of time does not hold. In order to investigate the robustness of different methods of measuring productivity growth, it would be more interesting to compare methods that are based on different estimation approaches rather than estimates based on different methodologies based on the same approach. As we mentioned in section 2.2, the conclusions reached on the robustness of productivity estimates with different methods are yet unclear (according to Van Biesebroeck, 2003, 2004).

In trying to provide some further explanations about the differences of estimates obtained from different methods of measurement, we investigate the robustness of two types of methods, the Thörnqvist index (with the results shown above) and a parametric approach (discussed in the next section). We do this by firstly looking at the differences of the means for the whole period, but also by looking at the correlation coefficient of the estimates over time (similar to how Van Biesebroeck, 2003, 2004, makes the comparisons).

However, before introducing the parametric method that we apply in order to compare its results with the results from the Thörnqvist index method, it should be noted that both of the methods that we apply assume 0 inefficiency.[31] At first, it might seem that this analysis is based on one more restriction in this respect as compared for example to the DEA method and Malmquist firm specific index or the parametric methods that allow inefficiency (discussed in section 2.2). However, we posit that although the existence of such a restriction is relevant for an analysis that measures and compares productivity at the firm-level, it cannot be equally relevant for measurements at an aggregate level, as is our case with the industry-level.

Our reasoning for this position is based on the fact that we treat each firm/production unit as one observation to compute our estimates for the productivity at the aggregate level and as such firms' productivity values are, of course, expected to differ across these observations. Interpreting such differences as measures of the relative productivity that come from two sources, efficiency and technical change, and subsequently analyzing them individually does not relate to putting an extra restriction to an analysis of productivity at the industry level. What this actually means is rather that one can consider our average aggregate productivity estimates as to have been obtained under the efficiency as well as under the inefficiency assumption depending on how one would make use of these results for further firm or industry level analysis in addressing the issue of (in)efficiency. This issue of efficiency is addressed in a further work in progress with the datasets explained in section 4.1.2 and others at the Statistics Norway, though its main aim is in finding out any relationships between productivity growth and exchange rates.

[31] This point was brought forth by Finn Førsund.

In the following section we discuss the robustness of our two methods.

Robustness of two methods of measuring productivity growth

We compare the estimates of total factor productivity growth of the previous section, obtained with the Thörnqvist index method (index numbers method), with a Cobb-Douglas parametric approach. From Eq 2-13, maintaining a constant returns-to-scale production function, such a Cobb-Douglas method based on the parametric approach would look like in Eq 4-9.

Eq 0-9: $\ln O^j(t) = \beta_0 + \alpha * \ln K^j(t) + (1-\alpha) * \ln L^j(t) + \ln TFP^j(t) + u^j(t)$,

where the natural log *TFP* for each firm in year *t* is estimated as the residual.

However, as noted in section 2.2, when trying to estimate the parameters with the parametric method, one problem that we identified was misspecification (what others usually call endogeneity). In order to avoid this problem we adapt Eq 4-9 such that to estimate instead productivity levels for the industry rather than for each firm (as residual). In doing this we deal with three problems simultaneously. First, we specify the model “correctly” by accounting for productivity. Second, we do not run into the problem of the estimation impossibilities by attempting to obtain a larger number of estimates than the number of observations available. Third, this would also mitigate what others usually argue as one of the sources of what they call endogeneity (as discussed in section 2.2, the argument was that since firms, among others, know their own level of productivity, they would choose *K* and *L* according to this knowledge also). Although this may be true, firms are not expected to have the same knowledge about the whole industry's productivity level. As a result, the choices of *K* and *L* that firms make are not likely to be dependent on industry’s productivity level as much as on own firm’s productivity level. Hence, accounting for productivity at the industry level, we believe, would help mitigate problems caused by the inter-relationships of *K* and *L* with productivity (which when accounting for productivity actually looks more like “multi-collinearity” rather than “endogeneity”).

We obtain estimates of productivity level by including into Eq 4-9 dummy variables, *D(t)*, for each year which is equal to 1 in year *t* and 0 in other years. The parameters for *D(t)* capture the orthogonal effect of natural log productivity levels of all the observations in year *t*, that is they estimate the average log industry’s productivity level in year *t*. Each parameter of the year dummy variable *D(t)* is interpreted as the productivity level of the industry for that year. We carry out our estimations after rearranging Eq 4-9 as:

Eq 0-10: $\ln\frac{O^j(t)}{L^j(t)} = \sum_{t=93}^{02}\beta(t)*D(t) + \alpha*\ln\frac{K^j(t)}{L^j(t)} + u^j(t)$,

where parameters of the year dummies, $\beta(t)$, from 1993 (93) to 2002 (02) are equal to the log natural of productivity levels for the whole industry and α is the factor elasticity.

Estimates of productivity growth for the industry are obtained by taking the difference of the $\beta(t)$'s, keeping year 1993 as the base year. For *t=94* to *t=02*, measures of productivity growth are obtained as:

$TFP_g^{OLS} = \hat{\beta}(t)^{OLS} - \hat{\beta}(t-1)^{OLS}$,

where TFP_g^{OLS} denotes *TFP* growth estimated with ordinary least squares (OLS) and the hat over β is for estimated.

As noted, although Eq 4-10 is constructed to help avoid the problems stated earlier, when trying to estimate the parameters of Eq 4-10 by OLS, two more problems are still present. The first one is related to heterogeneity, which according to the experience at the Statistics Norway is also entangled with the measurement errors of obtaining figures for the value added (*O*), and the second to autocorrelation. We have dealt with these two problems by further transforming Eq 4-10.

About heterogeneity (entangled with measurement errors in *O*), from experience with the data at the Statistics Norway, it is expected that smaller firms are more likely to have larger standard errors than larger firms. If this is the case, one would expect to find larger values of the error term in Eq 4-10 for the smaller firms than for the larger ones. In order to see this, we first ran OLS for each industry. After this, we obtained the estimated error terms for each firm, took the square of these estimated error terms, and then made a scatter plot of them against *L*, which is our indicative variable of the firm's size. These scatter plots are shown in appendix 2. The pattern of these scatter plots in each industry confirms that the smaller firms have larger standard errors than the larger firms. Based on the pattern of scatter plots, we remedy the problem of heterogeneity by constructing a weighted version of Eq 4-10. The weights are found by evaluating two likely models that would fit the relationship seen from the scatter plots in all of the figures in appendix 2. The model that fits better is chosen to construct the weights.

The models that are compared in choosing the one that fits better in the relationships seen in the scatter plots in appendix 2 are given in Eq 4-11 and Eq 4-12.

Model 1 (M1):

Eq 0-11: $w_1^j(t) = E[u^j(t)]^2 = X1 * \exp[Y1 * L^j(t)] + Z1$

Model 2 (M2):

Eq 0-12: $w_2^j(t) = E[u^j(t)]^2 = X2 * [L^j(t)]^{Y2} + Z2$

The left hand side notation, *w*, is chosen to refer to the weights used in the following, *E* is for expected value and 'exp' denotes exponential. *X1*, *Y1*, *Z1* are unknown parameters for model 1 and *X2*, *Y2*, *Z2* are unknown parameters for model 2. These parameters were estimated using non-linear regression with the squared OLS residuals from Eq 4-10 as the dependent variable. With the use of these models, Eq 4-10 is transformed into a weighted linear regression:

Eq 0-13:
$$\frac{1}{\sqrt{w_i^j(t)}} \ln\frac{O^j(t)}{L^j(t)} = \sum_{t=93}^{02} \beta(t) * \frac{D(t)}{\sqrt{w_i^j(t)}} + \alpha * \frac{1}{\sqrt{w_i^j(t)}} \ln\frac{K^j(t)}{L^j(t)} + \frac{1}{\sqrt{w_i^j(t)}} u^j(t) =$$
$$= [\ln\frac{O^j(t)}{L^j(t)}]^W = \sum_{t=93}^{02} \beta(t) * [D(t)]^W + \alpha * [\ln\frac{K^j(t)}{L^j(t)}]^W + [u^j(t)]^W ,$$

where *i=1* or *2*, depending on which of the models fits better, and the upper script *W* denotes weighted.

After estimating models 1 and 2 with non-linear least squares (NLS) we have chosen the one that has the highest log-likelihood (or equivalently the lowest residual sum of squares). Results for these two statistics after running NLS on both models are given in table 4.4.

Table 4.4: Log-likelihood and residual sum of squares of models 1 and 2

SIC94 Code	**Log-likelihood**		**Residual Sum of Squares**	
	Model 1	**Model 2**	**Model 1**	**Model 2**
15-16	-8178.87	-8282.72	4561.49073	4706.31045
17-18	-1628.64	-1588.72	571.343481	550.609378
20	-3275.93	-3203.19	1111.61955	1077.56389
21	-430.024	-429.767	148.406416	148.277061
22	-10607.5	-10480.3	4491.18661	4387.02304
24	-1358.56	-1358.06	1511.6502	1509.68922
25	-1809.77	-1805.81	710.80951	708.021008
26	-2795.04	-2774.94	1420.48257	1397.16717
27	-581.637	-581.5	219.373103	219.285118
28	-5080.28	-5001.55	1751.68783	1712.63537
29	-7212.85	-7167.32	4158.47971	4092.92758

30-33	-6721.06	-6719.51	8130.81649	8124.04437
34-35	-3975.01	-3975.43	1714.54793	1714.90888
36-37	-3875.3	-3873.71	1754.12415	1752.62331

From table 4.4, it is seen that the fits for both models are close in all industries. However, model 2 fits a bit better except for two cases, industries with codes 15-16 and 34-35. Hence, for these two industries, the estimated weights used to construct the variables are: $\hat{w}_1^j(t) = \hat{X}1 * \exp[\hat{Y}1 * L^j(t)] + \hat{Z}1$, whereas for all others the estimated weights are:

$\hat{w}_2^j(t) = \hat{X}2 * [L^j(t)]^{\hat{Y}2} + \hat{Z}2$, where the hat denotes as before estimated.

From the shape of the scatter plots in appendix 2, parameters *Y1* and *Y2* have negative signs and others positive. This means that the use of models 1 and 2 not only helps avoid the problem caused by heteroscedasticity problem, but also the weights enter into Eq 4-13 in a way that give more weight to larger firms than to smaller ones. This implies that the total factor productivity level estimated by the $\beta(t)$'s is obtained by giving more weights to larger firms. This, in turn, makes the estimation with this procedure akin to the estimation of industry's productivity level with the Thörnqvist index, which was obtained as a weighted average with the larger firms having more weight.

After removing the problem of heterogeneity with the construction of the weighted linear model as in Eq 4-13, the other problem to be removed is autocorrelation. With time series data this problem is expected to be present. We check this by looking at the residuals after running the OLS on Eq 4-13 or the weighted least squares (WLS) on Eq 4-10. The scatter plots of these residuals indicate the presence of a positive auto-correlation in all industries. We remedy this problem with the following two-step procedure.

First, the disturbance terms of Eq 4-13 are considered to be correlated with the lagged disturbance terms as in the following:

$$[u^j(t)]^W = \rho * [u^j(t-1)]^W + \varepsilon^j(t)$$

We found ρ to be significant for each industry and in most of the cases around 0.55.

Second, after estimating ρ, Eq 4-13 is transformed using this estimate as in Eq 4-14:

Eq 0-14:
$$[\ln\frac{O^j(t)}{L^j(t)}]^W - \rho*[\ln\frac{O^j(t-1)}{L^j(t-1)}]^W =$$
$$= \sum_{t=94}^{02}\beta(t)*\{[D(t)]^W - \rho*[D(t-1)]^W\} + \alpha*\{[\ln\frac{K^j(t)}{L^j(t)}]^W - \rho*[\ln\frac{K^j(t-1)}{L^j(t-1)}]^W\} + \varepsilon^j(t)$$

When estimating the parameters in Eq 4-14 one cannot obtain an estimate for $\beta(93)$ because observations for year 1993 are not valid. In order to estimate all the $\beta(t)$'s we include observations for 1993 after transforming them using the so called Prais-Winsten transformation. This transformation is done using this relationship:

$$\sqrt{1-\rho^2}[\ln\frac{O^j(93)}{L^j(93)}]^W = \beta(93)*\sqrt{1-\rho^2}[D(93)]^W + \alpha*\sqrt{1-\rho^2}[\ln\frac{K^j(93)}{L^j(93)}]^W + \sqrt{1-\rho^2}[u^j(t)]^W$$

Finally, after remedying these problems caused by heterogeneity and autocorrelation, total factor productivity growth is estimated as:

Eq 0-15: $TFP_g^{PM} = \hat{\beta}(t)^{PM} - \hat{\beta}(t-1)^{PM}$,

where 'PM' means parametric method to distinguish it from the estimates when using OLS on Eq 4-10.

After running the regressions as in Eq 4-14 for each industry together with observations for 1993, we first obtained the estimates of total factor productivity growth in each year from Eq 4-15 and with these estimates calculated the average *TFP* growth over the whole period. We compare the results from the Thörnqvist index and the Parametric Method by looking for each industry at the average *TFP* growth estimates over the whole period, their deviations (absolute value of their differences) and the correlation coefficient of *TFP* growth estimates over the years (1993 – 2002) as shown in table 4.5.

Table 4.5: Averages (%) over the whole period, deviations and correlation of *TFP* growth estimates over the years based on Thörnqvist Index (TI) and Parametric Method (PM)

SIC94 Code	Average of *TFP* estimates		Deviation	Correlation
	Thörnqvist Index	Parametric Method	|TI - PM|	
15-16	1.4	0.4	1.0	0.87769
17-18	1.3	0.1	1.2	0.82051
20	1.9	2.2	0.3	0.75609
21	1.2	0.6	0.6	0.61808*
22	1.0	-0.4	1.4	0.99330
24	-1.9	-0.7	1.2	0.55430

25	1.1	-0.1	1.2	0.67328
26	-0.3	0.0	0.3	0.14416*
27	0.9	-0.1	1.0	0.78491
28	2.2	1.0	1.2	0.63318
29	1.9	0.0	1.9	0.79799
30-33	0.6	0.4	0.2	0.34137*
34-35	1.0	1.3	0.3	0.62757
36-37	1.2	0.0	1.2	0.86477
All industries	1.0	0.3	0.7	---

* Only in three cases (codes 21, 26 and 30-33), the correlation coefficient between estimates from TI and PM was lower than the correlation coefficient between the estimates from TI and OLS (as in Eq 4-10).

Table 4.5 reveals some interesting results. First, *TFP* growth of the manufacturing sector (all industries) in Norway over 1993 – 2002 is much lower (about 1/3-rd) according to the estimation based on the parametric method (0.3%) than the Thörnqvist index (1.0%). Second, a low (high) degree of correlation of estimates over the years between the two methods does not necessarily imply high (low) deviation (absolute difference) between the averages over the whole period. In particular, although the degree of correlation for the manufacturing of other non-metallic mineral products (code 26) is lowest, the absolute value of the difference of averages over the whole period is second lowest (0.3). The lowest deviation is in fact where the degree of correlation is second lowest (for code 30-33). Also, where the degree of correlation is highest, the deviation is second highest (for code 22). The largest deviation is seen in the manufacturing of machinery and equipment (code 29), where the degree of correlation between the two methods is quite high (about 0.80). In all industries except two (codes 20 and 34-35) averages over the whole period based on the parametric method are all closer to 0 as compared to averages based on the Thörnqvist index.

From these results, we could conclude that even when the differences between the *TFP* growth estimates over time from the two methods are not large, there are important differences in the estimates of the average values for the whole period. As for the degree of correlation alone, it is higher than 0.9 (almost 1) in only one case and higher than 0.8 in three cases. As seen, the correlation coefficient varies widely across industries, which leads to investigating the following hypothesis:

‘There are differences in the estimates obtained from different methods, though maybe not very much so because of the methods[32] themselves, but possibly because of some industry features that make these methods’ productivity estimates differ to varying degrees.’

The exploration of this hypothesis would open up a new chapter in the study of comparing productivity growth because it requires first identifying the industry-specific factors and then investigating their effect on the differences in estimates obtained from each method. Although the investigation of the effect of these factors is a new topic and would require much in-depth research, we examine here the effect of a specific industry-related candidate factor. This is the factor elasticity of each industry or the capital elasticity in our models. We look at the effect of the differences in the estimates of factor elasticities obtained from the two methods we have considered on the degree of correlation of these methods. Estimates of our only factor elasticity (α) are in table 4.6.

Table 4.6: Estimates of factor elasticity (α) from each method

SIC94 Code	**Estimated of factor elasticity (α)**				
	The Thörnqvist based index *	**Overall Average**	**OLS**	**PM1****	**PM2*****
15-16	0.257789	0.259747	0.349241	0.340400	--
17-18	0.183786	0.185603	0.289685	--	0.275654
20	0.203539	0.205559	0.277969	--	0.226593
21	0.282576	0.281763	0.326267	--	0.399783
22	0.230416	0.231629	0.335433	--	0.306711
24	0.274259	0.278324	0.393780	--	0.415325
25	0.248781	0.250333	0.336524	--	0.314024
26	0.258479	0.255379	0.371853	--	0.333093
27	0.230877	0.234080	0.264718	--	0.285463
28	0.182873	0.184650	0.289056	--	0.227226
29	0.179625	0.183119	0.311710	--	0.237074
30-33	0.165009	0.164683	0.285998	--	0.271373
34-35	0.153083	0.156929	0.236960	0.251441	--
36-37	0.215720	0.220597	0.320297	--	0.262436

[32] At least for the Thörnqvist index and the parametric method we have considered.

* - A common α for the industry for the Thörnqvist based index is obtained as the average of elasticities over the whole period. ** - PM1 stands for parametric method using weights from model 1. *** - PM2 stands for parametric method using weights from model 2.

Table 4.6 shows that while the estimates from the Thörnqvist index and Overall Average are almost equal (as one might expect), there are more notable differences between the estimates from the OLS and PM (with model 1 or 2 for the weights). One more interesting observation is that the estimates from both parametric methods are larger than the estimates from both Thörnqvist index and Overall Average methodologies in all industries. This might be a clear indication that the choice of the method might have important implications for factor elasticity estimates. Although which estimate from these methods is preferred might not be so obvious, we are inclined towards having some preference for the estimates from the parametric method. The reason is because of the extra condition imposed when obtaining factor elasticity estimates with the Thörnqvist index, namely that firms minimize costs (from section 4.1.1).

Since by assumption each industry (or group) has its own factor elasticities, we look at the effect of the deviations of the estimates of factor elasticities on the degree of correlation of *TFP* growth estimates. We do this by the following simple regression:

Eq 0-16: $R_i = C + \Phi * [\alpha(PM)_i - \alpha(TI)_i] + v_i$,

where *R* denotes correlation of coefficient between estimates of *TFP* growth from the two methods (last column in table 4.5), *C* is a constant, $\alpha(PM)$ means α computed with Parametric Method, $\alpha(TI)$ means α computed with the Thörnqvist Index and *i* is for industry.
The analysis done so far allows us to have only 14 cross-section observations. Despite the small number of observations, we try to get an idea on whether the effect of differences in α is significant by estimating regression 4-16 with the results given in table 4.7.

Table 4.7: Regression results for the effect of differences in α.

Parameter	**Estimated value**	**Std.Error**	**t-value**	**t-prob**
C	0.853328	0.1587	5.38	0.000
Φ	-2.27767	1.912	-1.19	0.257
Some statistics				
R^2	0.105759		**RSS**	0.579626564
var(R_i)	0.0462984		**F(1,12) =**	1.419 [0.257]

From table 4.7, it is seen that the estimated parameter of factor elasticity (α) although does have a negative sign, it does not have a significant effect on the correlation coefficients. This result and low value of R^2 imply that there are factors which are more important in explaining the differences in the estimates of total factor productivity growth.

After discussing these empirical findings, the concluding remarks are presented next.

Concluding remarks

To end this document, we provide some concluding remarks which are in the form of conclusions reached from our findings alone and in combination with the findings from the other studies which we discussed as well as proposals for follow-up research.

A useful starting point for every study on productivity is that index based measures of productivity levels in money terms are not possible to obtain when using base year prices. When using current year prices, such measures of productivity levels are possible to obtain, but may not be so useful because market mechanisms will tend to equalize productivity across industries. However, measures of productivity growth are still useful and production units can be compared in a meaningful way with each other based on the estimates for growth.

Measurement is an important aspect in studies of productivity. For example, based on differences in measurement, different studies have reached different conclusions on the size of contribution of productivity growth in the manufacturing sector to the rapid output growth in the newly industrialized countries in East Asia after the Second World War. Because of differences in measurements, different studies have also reached different conclusions on the size of contribution of the information and communication technologies (ICT-s) to the bouncing back of productivity growth estimates to high rates, which are seen since the mid 1990s. Despite the differing conclusions about the size of the contribution of ICT-s, studies agree that in general ICT-s seem to have contributed positively to the output growth and in particular the use of ICT has contributed considerably to the labor productivity growth.

With the use of growth accounting techniques, based on an application of the Thörnqvist Index method in the Norwegian manufacturing sector from 1993 to 2002, it is concluded that overall labor productivity has increased by 2.2%, total factor productivity by 1.0%, and capital intensity by 5.5%. These average estimates hide a great deal of diversity among industries. Based on the Thörnqvist Index based estimates only 2 out of 14 industries (or groupings) experienced negative total factor productivity growth and all of them experienced positive labor productivity growth over 1993 – 2002. When looking at the dynamics of the estimates based on the Thörnqvist Index, it is observed that the magnitude and patterns of the development of labor productivity and total factor productivity growths in each industry are similar. However, the magnitude and patterns of the development of capital intensity growth are more different.

Estimates of total factor productivity growth based on another (index based) methodology, Overall Average, which assumes constant factor elasticities over the whole period, are practically the same with those obtained from the Thörnqvist Index. For this reason, as far as the index based method is concerned, one can safely use instead this methodology because of simpler computations needed.

The results on the robustness of the estimates from the Thörnqvist Index (or similarly the Overall Average methodology) and a Cobb-Douglas based Parametric Method with data from the manufacturing sector in Norway help shed some light on whether methods matter. One important and interesting finding is that the correlation of the estimates from the two methods that we have considered seems to be dependent on industry-related factors. Another interesting finding is that the parametric method estimates of the elasticity of capital are larger than the estimates of the index numbers method in all industries. Considering capital elasticity as an industry-related factor, we look at the effect of the differences in the estimates of capital elasticity on the degree of correlation of the estimates of total factor productivity growth from the two methods. We do not find any significant effect of the differences in the estimates of capital elasticity on the degree of correlation of the two methods.

Based on the findings in this document, we think that four directions of future follow-up research would further improve these findings. First, a rather obvious extension would be to relax the constant return-to-scale assumption, based on which we have obtained our estimates from both the Thörnqvist Index and the Cobb-Douglas based Parametric Method, as well as consider other inputs and outputs apart from capital and labor and value added, as we have done here. Second, another extension would be to obtain estimates from other methods as well, for example, the data envelopment analysis and the Malmquist firm specific index and see how the correlations of the estimates of total factor productivity growth from all these different methods differ across industries. Third, it would be interesting to obtain productivity estimates not only from the Cobb-Douglas based parametric method but based on other forms of specifications as well. Fourth, it would also be interesting to examine other industry-related factors apart from capital intensity, as we have done here, which would presumably affect estimates obtained from different methods. An example is to study the role and impact of (the use of) the information and communication technologies, which are recently considered as to have an important impact on output and productivity growth. Since the use of these technologies is considered to incorporate a range of other non-technological issues as well, the implications of the deployment of such technologies for productivity measurements based on different methods might by an area of investigation that is worth deserving attention.

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Development of labor productivity, total factor productivity and capital intensity growths from 1993 to 2002 in manufacturing sector in Norway

Explanation of variables and notation:

VAL_{gr} - value added per man-hour worked or labor productivity growth (straight line). $TFP_{gr}TI$ - total factor productivity growth computed with the Thörnqvist index (dashed line). KL_{gr} - capital per man-hour worked or capital intensity growth (dotted line).

Figure A1.1: Manufacturing of food and tobacco products (Codes 15 - 16)

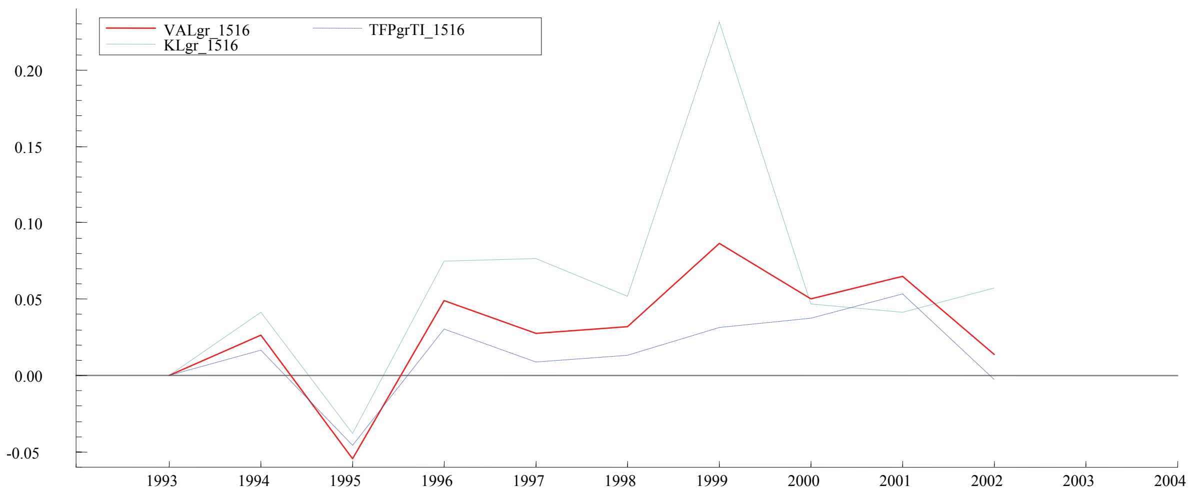


Figure A1.2: Manufacturing of textiles and wearing apparel (Codes 17 - 18)

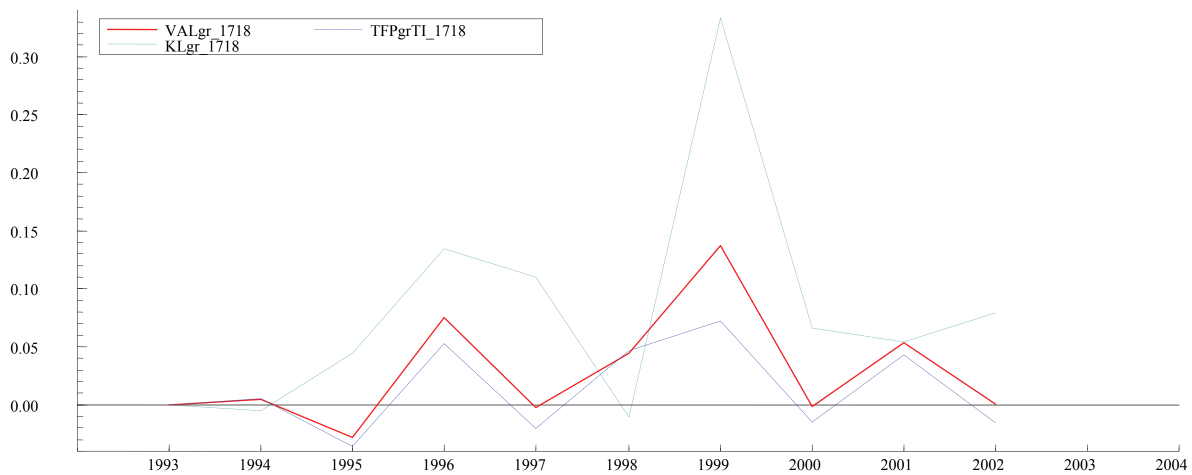


Figure A1.3: Manufacturing of wood and products of wood (Code 20)

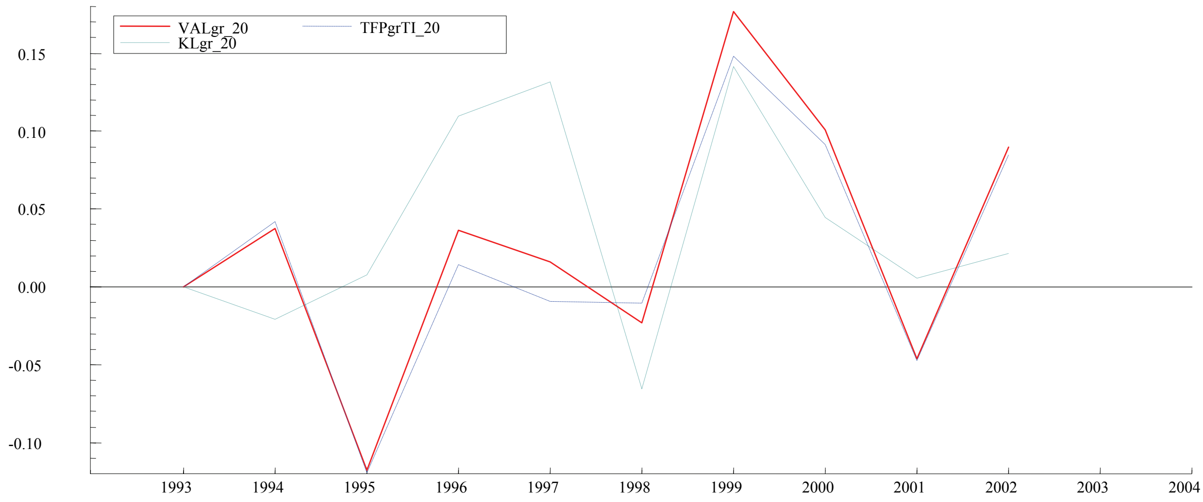


Figure A1.4: Manufacturing of pulp, paper and paper products (Code 21)

Figure A1.5: Publishing, printing and reproduction of recorded media (Code 22)

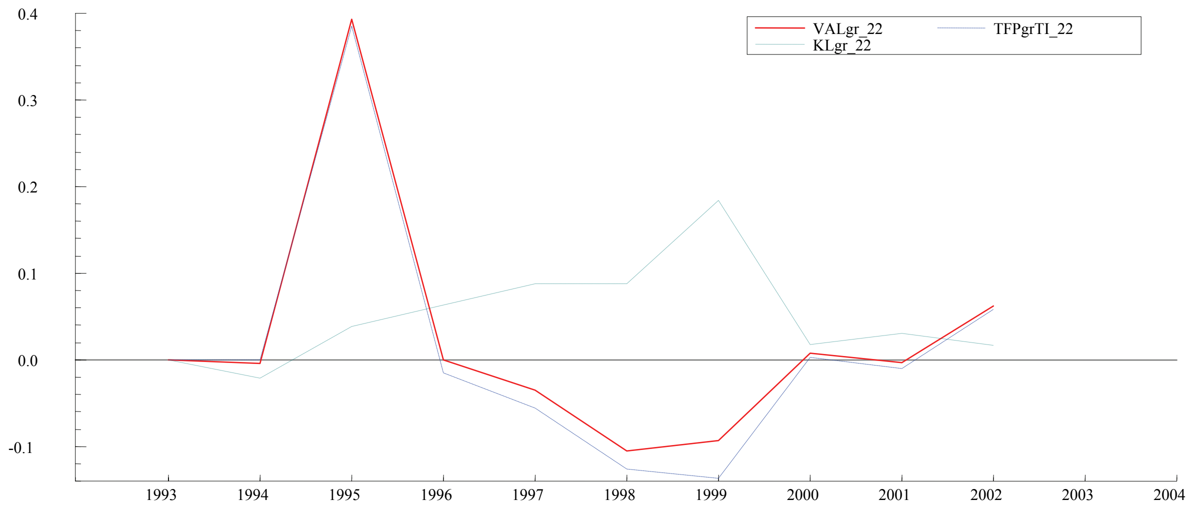


Figure A1.6: Manufacturing of chemicals and chemical products (Code 24)

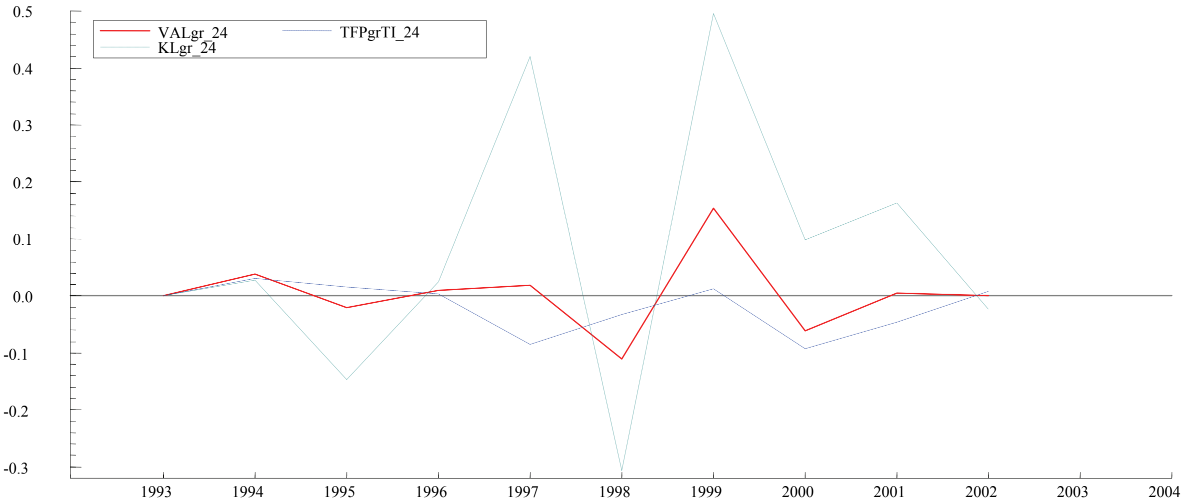


Figure A1.7: Manufacturing of rubber and plastic products (Code 25)

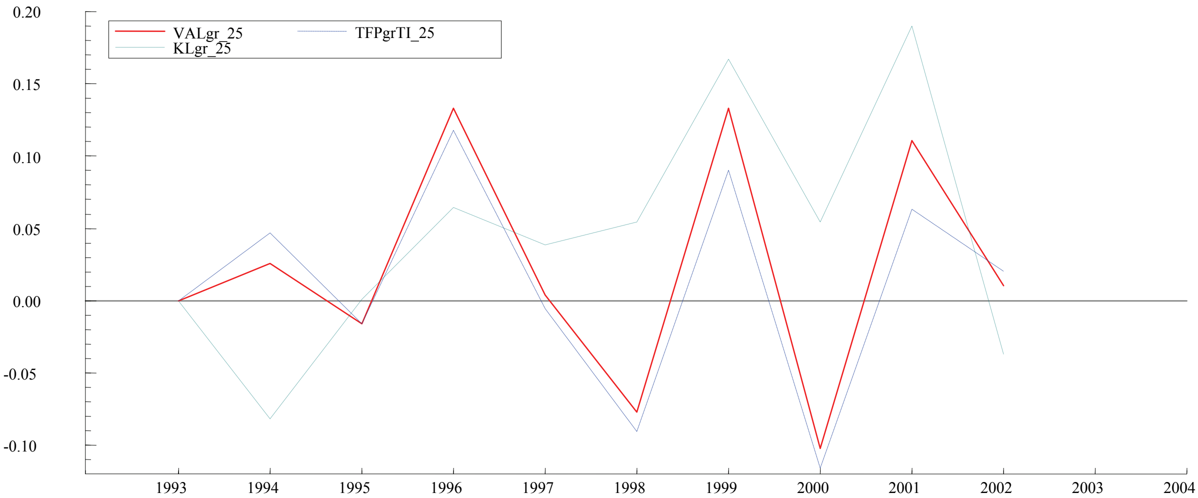


Figure A1.8: Manufacturing of other non-metallic products (Code 26)

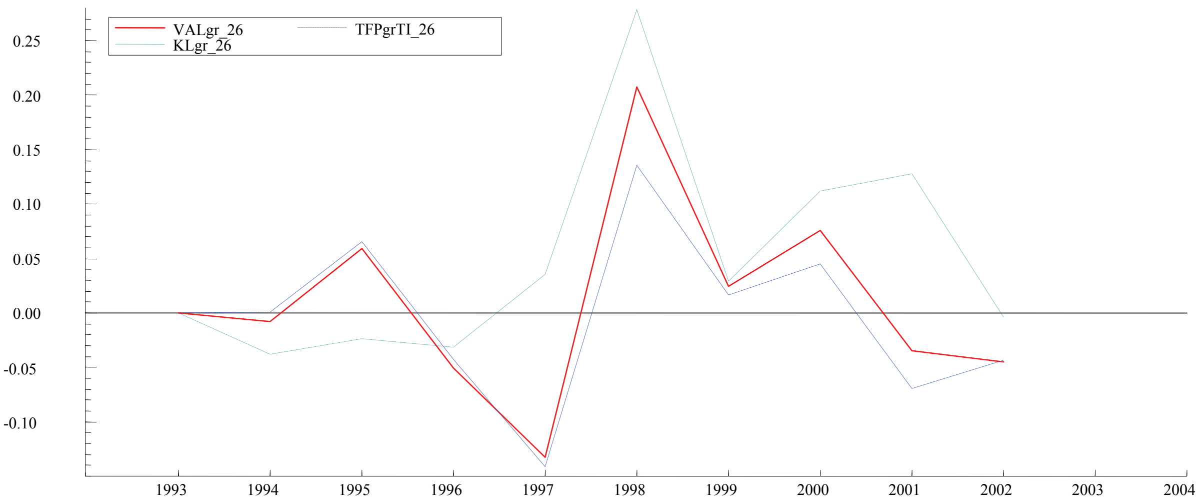


Figure A1.9: Manufacturing of basic metals (Code 27)

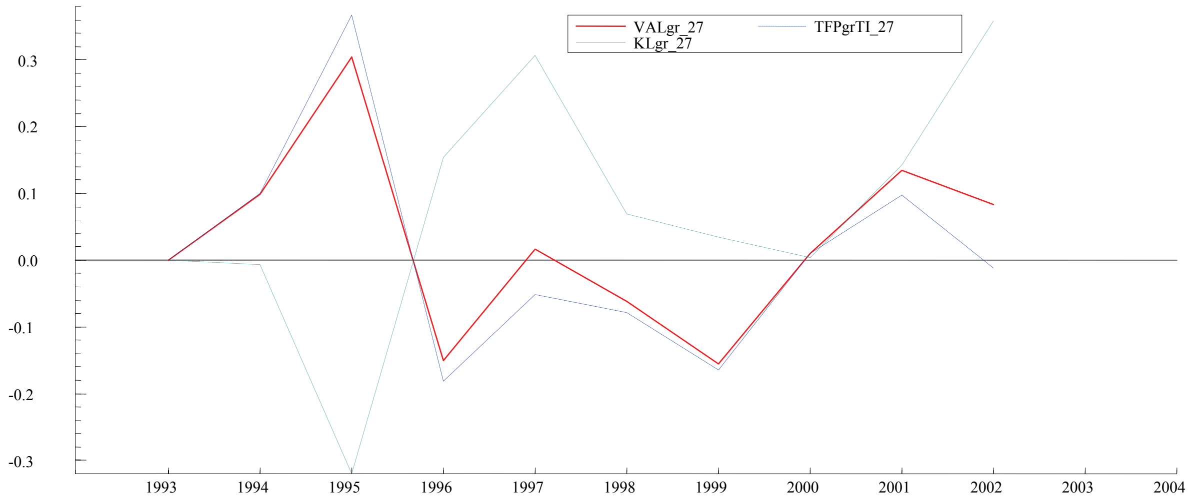


Figure A1.10: Manufacturing of fabricated metal products (Code 28)

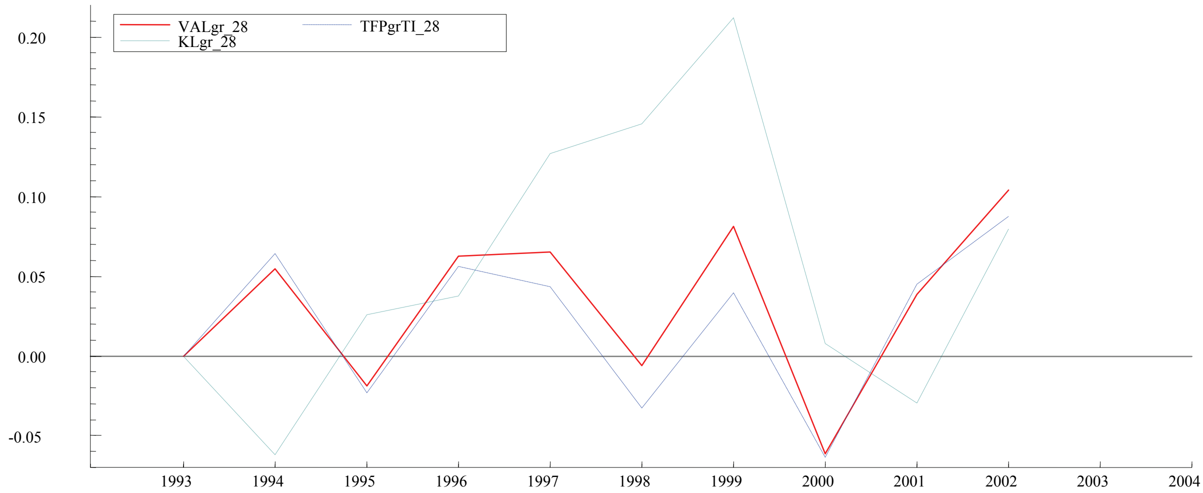


Figure A1.11: Manufacturing of machinery and equipment (Code 29)

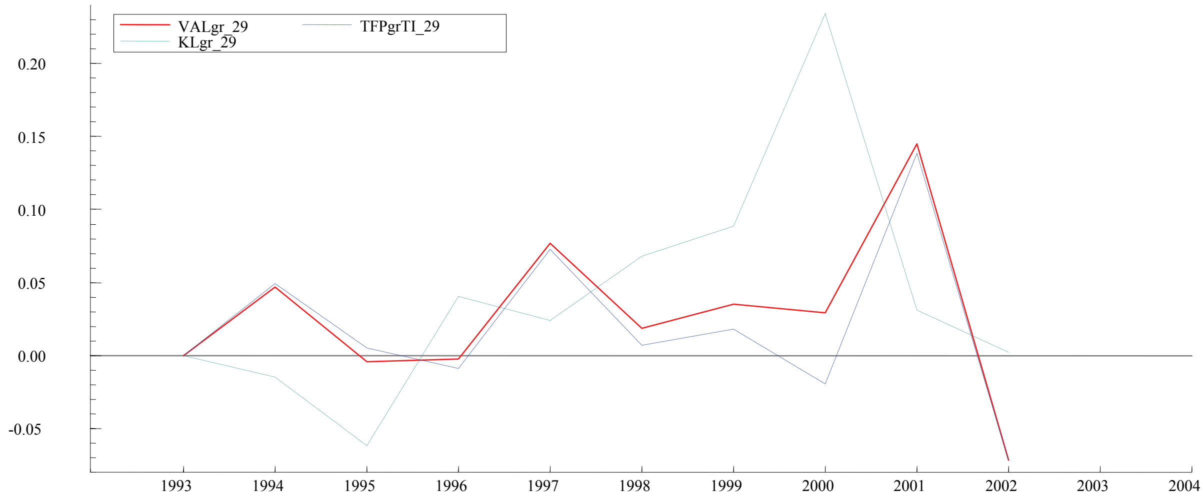


Figure A1.12: Manufacturing of office machinery and equipment, electrical machinery, radio, television, medical, precision and optical instruments, watches and clocks (Codes 30 - 33)

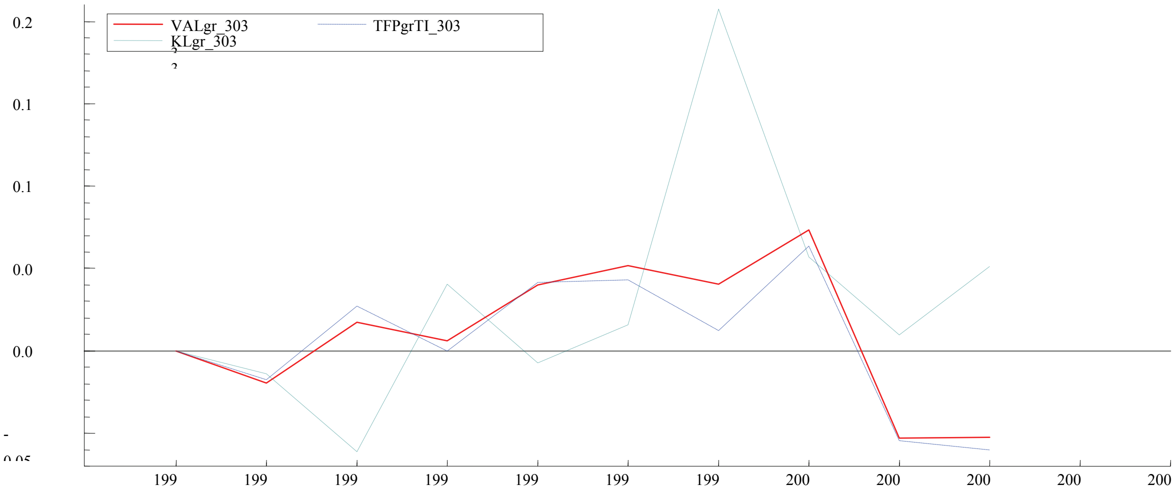


Figure A1.13: Manufacturing of motor vehicles, trailers and other transport equipment (Codes 34- 35)

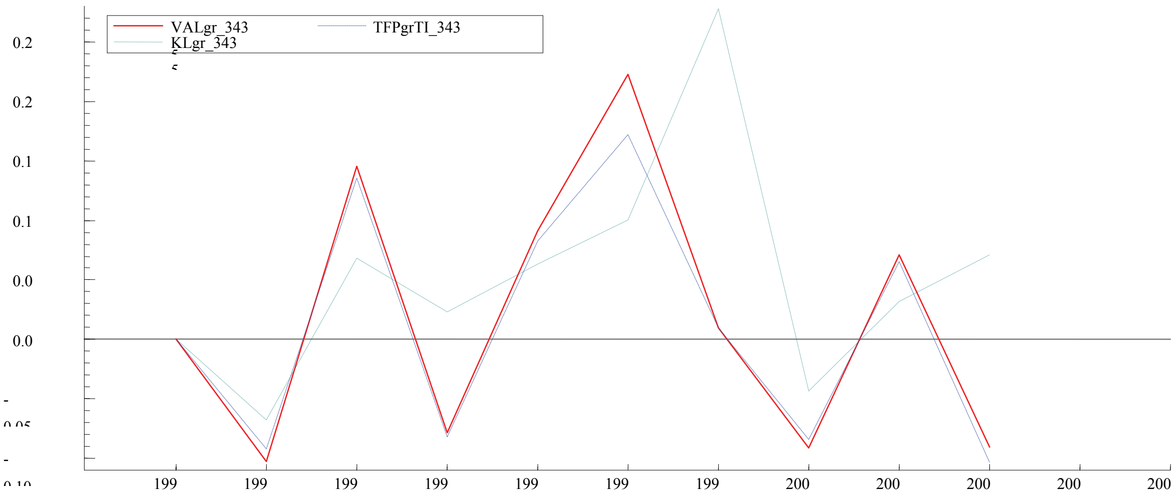
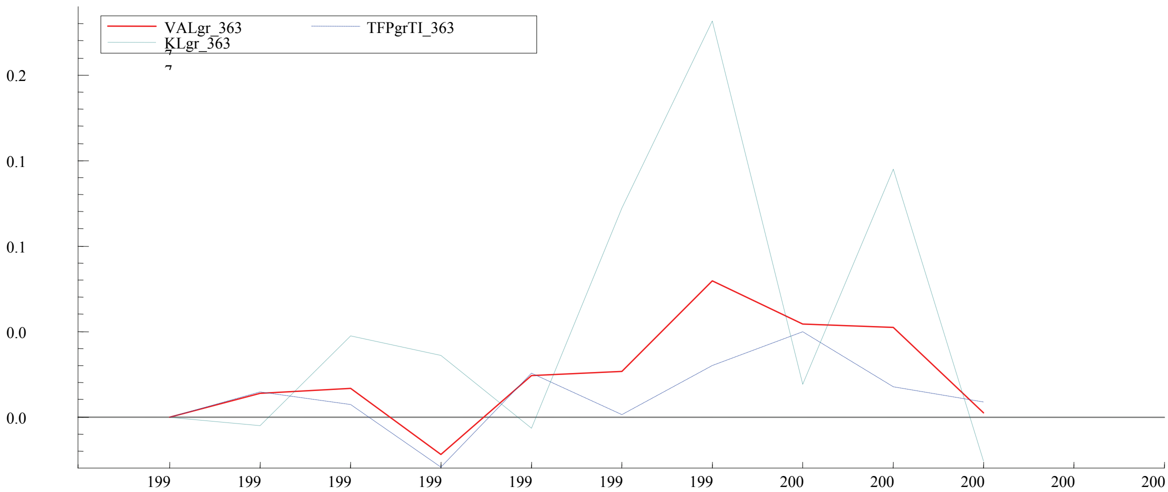


Figure A1.14: Manufacturing of furniture and recycling (Codes 36 - 37)

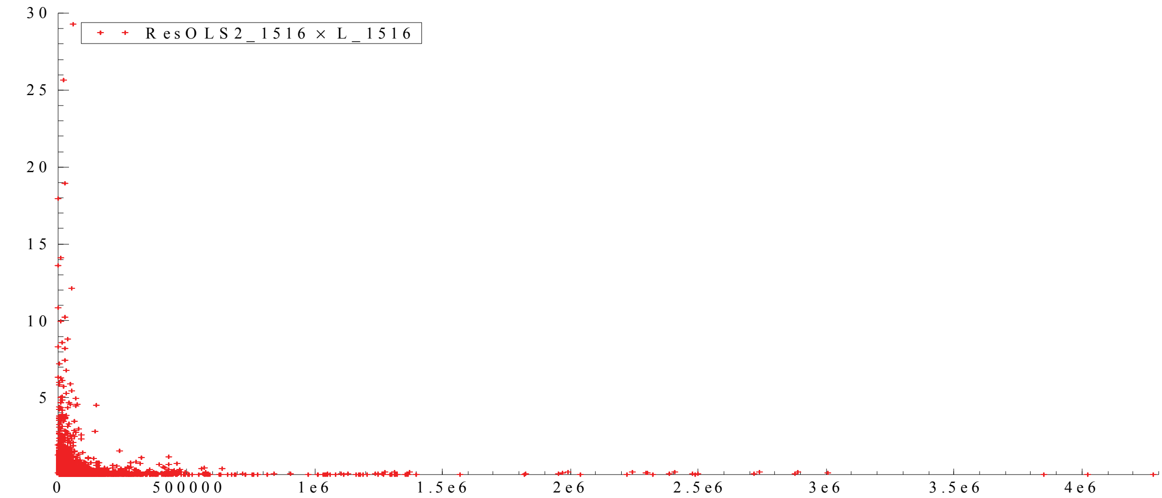


Relationship between estimated error terms with OLS and man-hours worked

Explanation of variables and notation:

ResOLS2 – squared residuals obtained from running OLS for Eq 4-10 with values on the vertical axis. *L* - man-hours worked with values on the horizontal axis.

Figure A2.1: Manufacturing of food and tobacco products (Codes 15 - 16)



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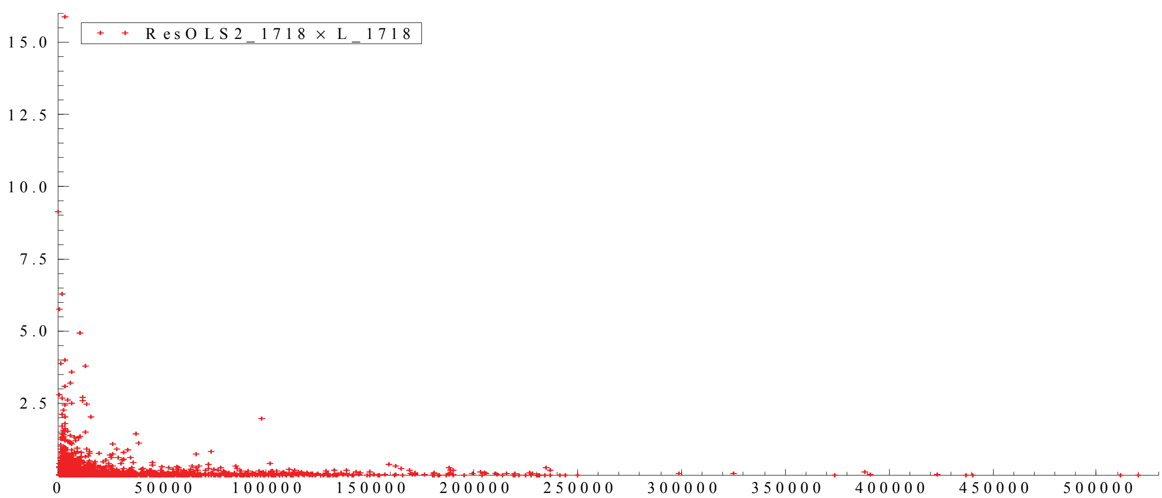

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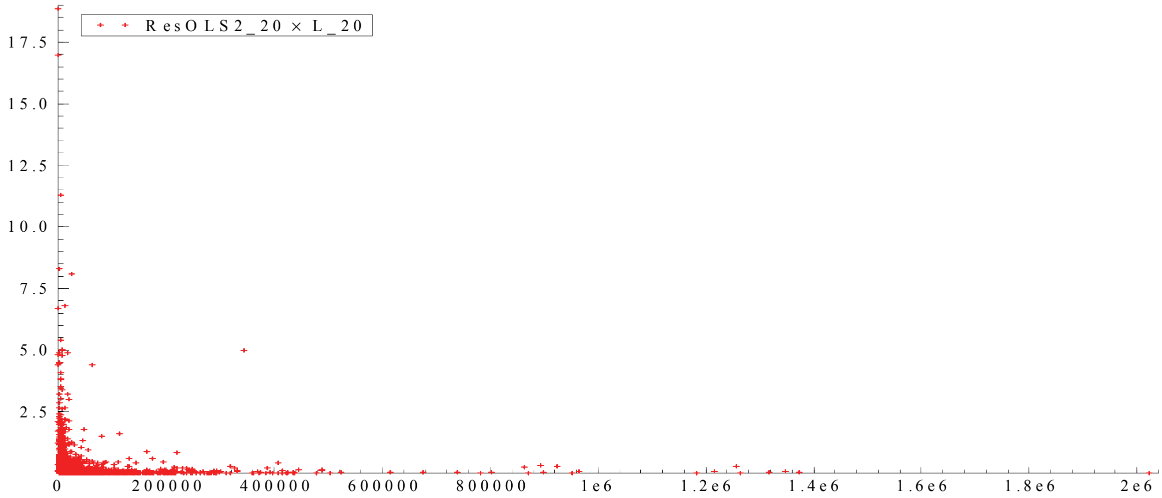

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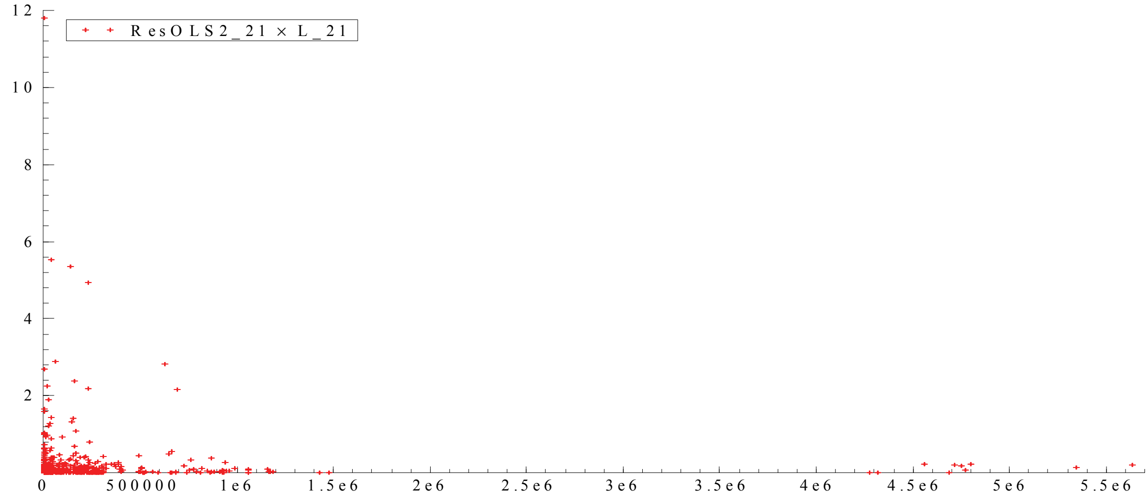
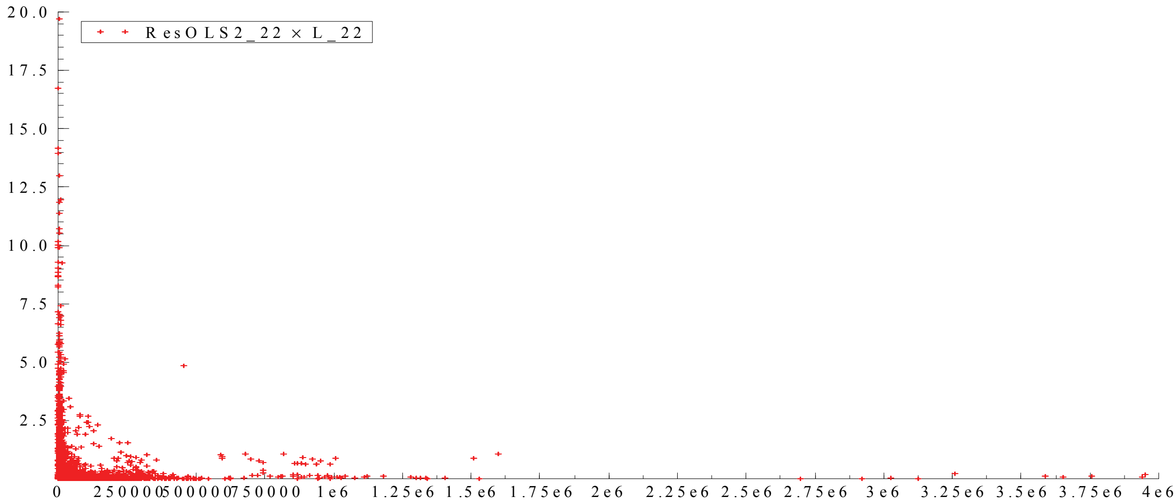


Figure A2.5: Publishing, printing and reproduction of recorded media (Code 22)



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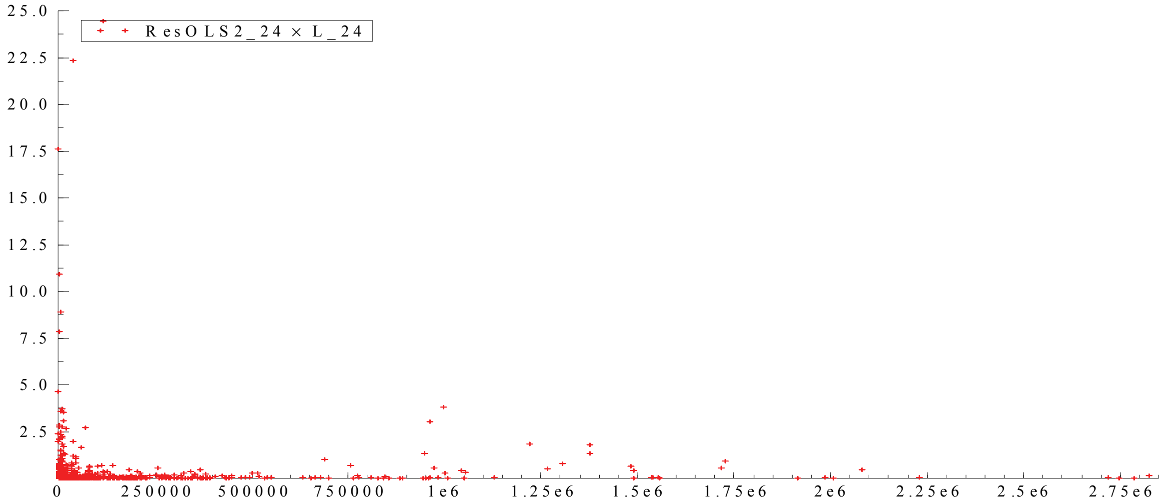

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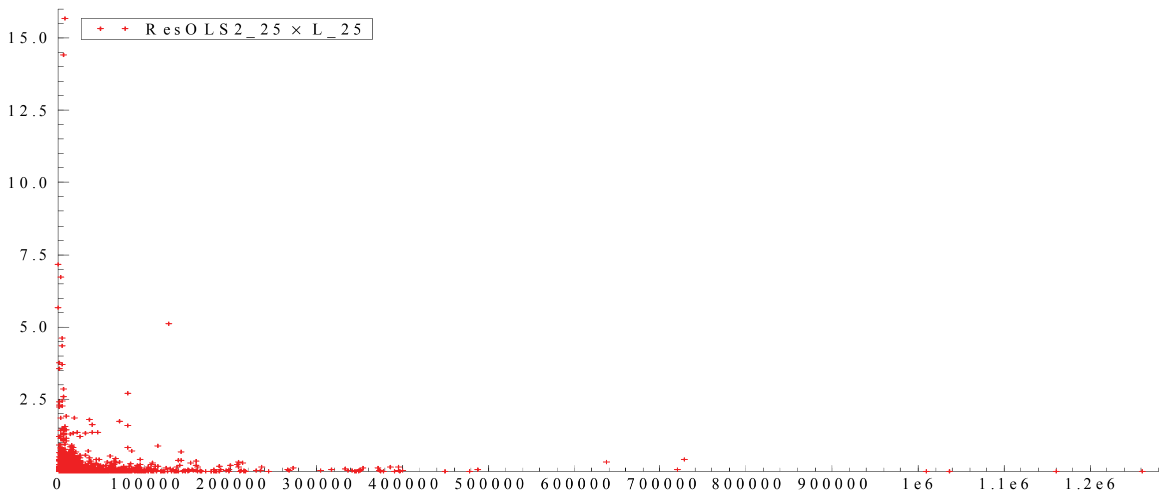
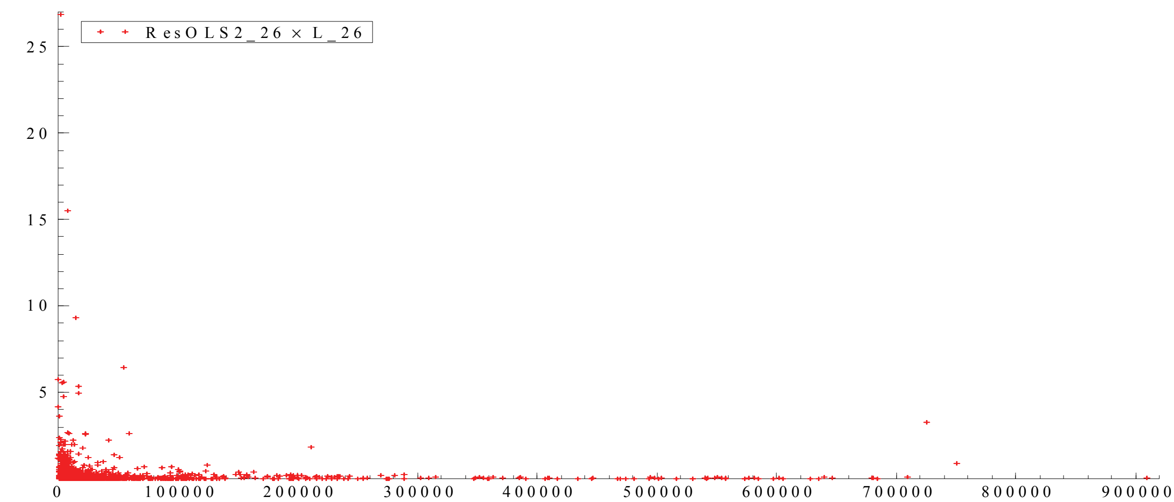


Figure A2.8: Manufacturing of other non-metallic products (Code 26)



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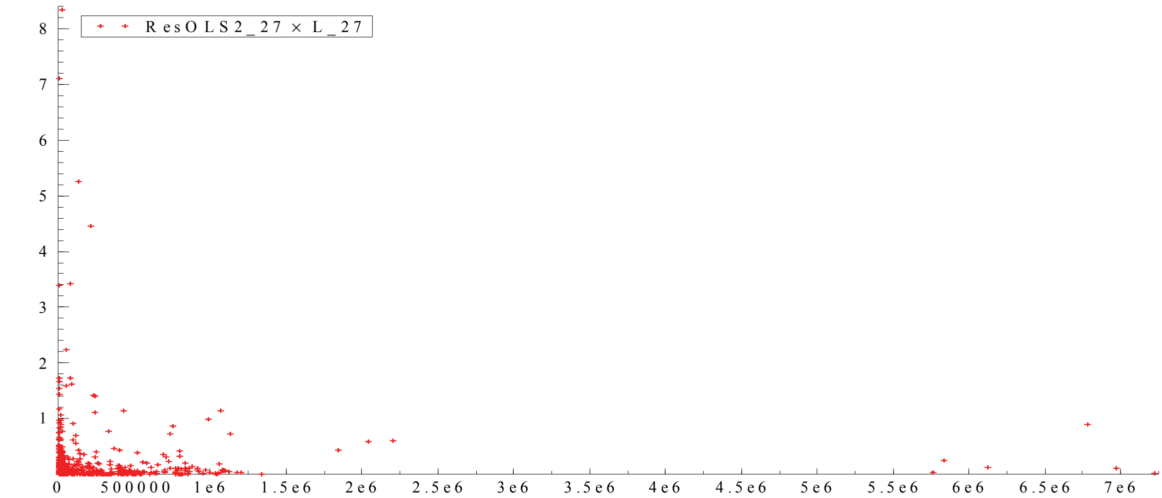

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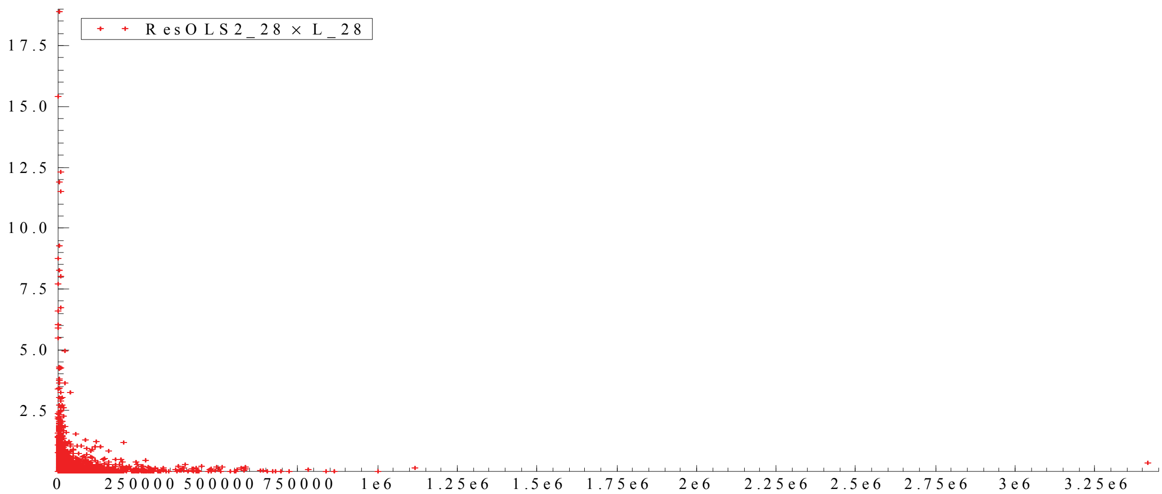

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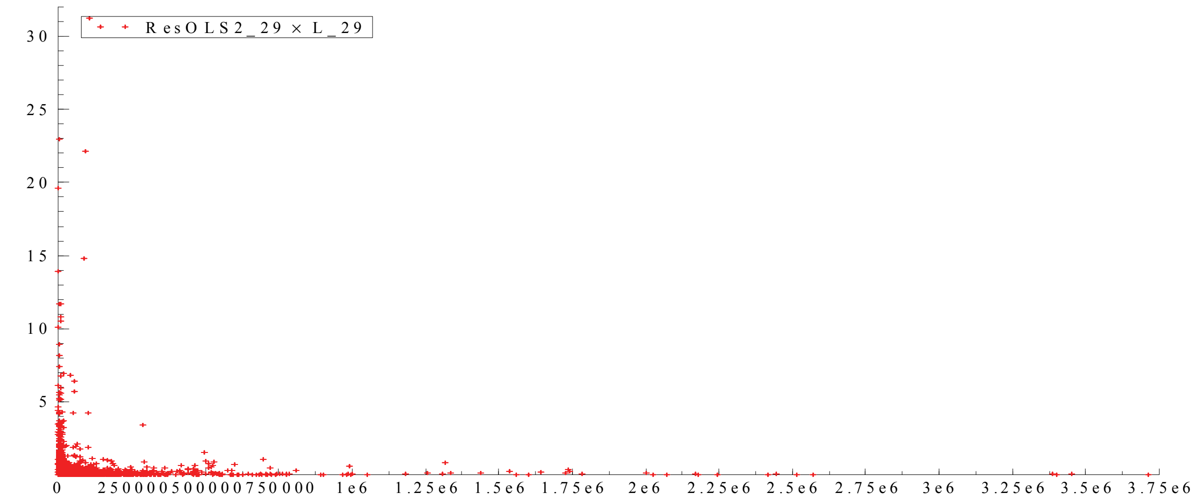

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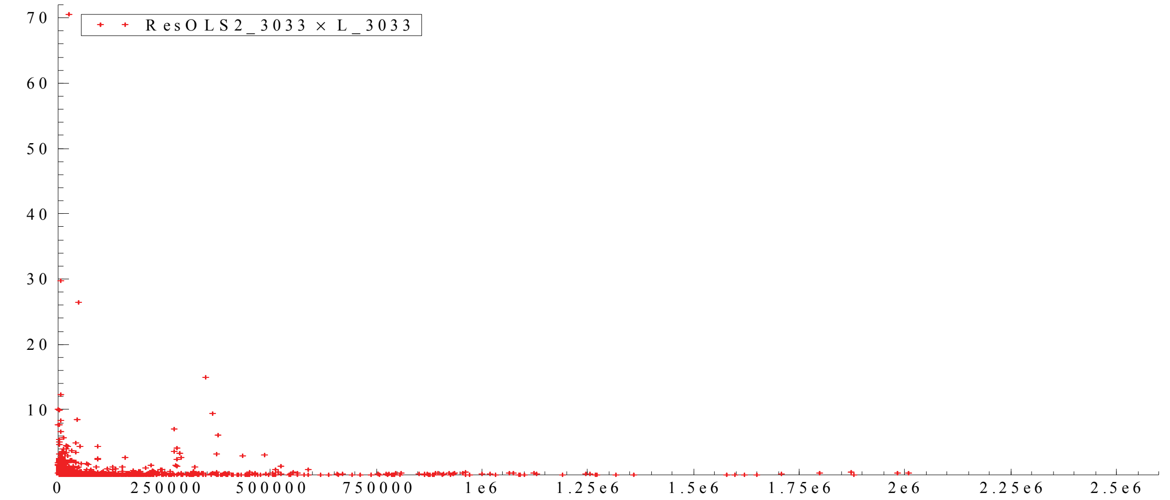

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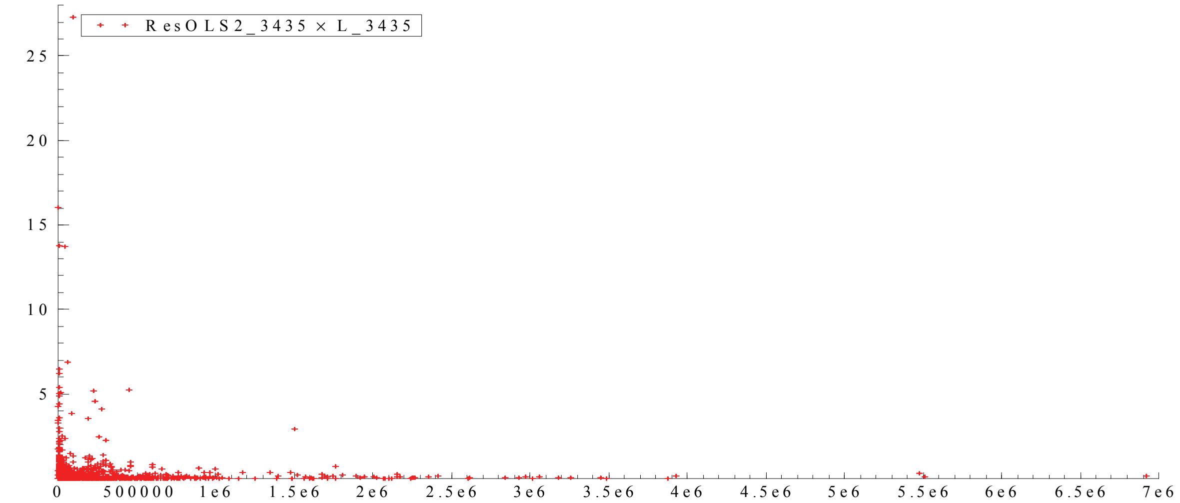

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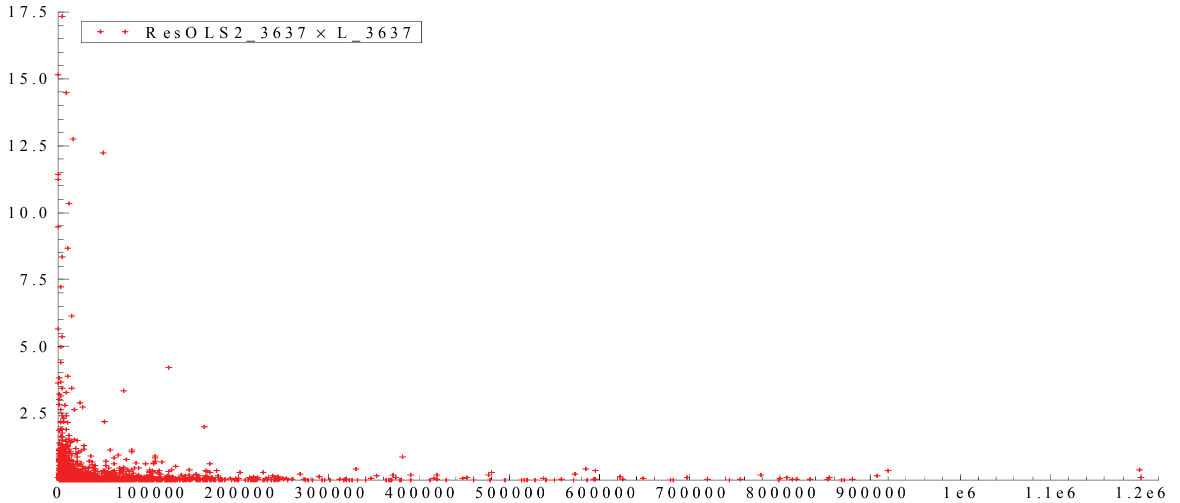

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