Understanding the components of profitability and productivity change at the micro level

Wiech, Bernd Andreas; Kourouklis, Athanassios; Johnston, James

Published in:
International Journal of Productivity and Performance Management

DOI:
10.1108/IJPPM-10-2018-0366

Published: 08/06/2020

Document Version
Peer reviewed version

Citation for published version (APA):
Wiech, B. A., Kourouklis, A., & Johnston, J. (2020). Understanding the components of profitability and productivity change at the micro level. *International Journal of Productivity and Performance Management*, *69*(5), 1061-1079. https://doi.org/10.1108/IJPPM-10-2018-0366

International Journal of Productivity and Performance Management

Understanding the components of profitability and productivity change at the micro level

Journal:	*International Journal of Productivity and Performance Management*
Manuscript ID	IJPPM-10-2018-0366.R2
Manuscript Type:	Standard Paper
Keywords:	Performance measurement, Profitability, Productivity, Total Factor Productivity, Output Mix

Understanding the components of profitability and productivity change at the micro level

Purpose - This paper presents a refined framework providing clarity in terms of the components of profitability and productivity change from the perspective of the firm level.

Design/methodology/approach - The literature is analysed with a scoping study and a systematic literature review. Productivity measurement approaches are compared using data at the product level.

Findings - The definition of total factor productivity (TFP) in the literature negatively affects the accuracy of profitability and productivity measurement. In the usual case of a dynamic output mix, TFP change encompasses biasing output mix effects relating to profitability, but not to productivity change. Therefore, this paper defines changes of a ratio of output quantities to input quantities not as TFP change, but as *quantitative profitability (QP) change*. A framework is proposed decomposing profitability change into price recovery and quantitative profitability change, whereas the latter comprises of valid productivity change (encompassing technological, technical efficiency, and productivity-related scale effects) and output mix change (encompassing proportion, quality, output switching, and profitability-related scale effects).

Research limitations/implications - Future research should include literature from the industrial organisation field of economics. The presented framework should be transferred to the standard production function framework used in economics.

Practical implications - The paper can help preventing faulty decision-making or distrust due to the use of biased profitability or productivity indicators. TFP-based productivity indicators are unsuitable for most firms. To measure productivity meaningfully, firms should use adequate approaches (e.g. SI- or ATFP-based ones).

Originality/value – The paper contributes to a more accurate performance measurement approach, as researchers and practitioners better understand the components of profitability and productivity change.

Keywords: Performance Measurement, Profitability, Productivity, Total Factor Productivity, Output Mix

1 Introduction

Productivity is an important determinant of a company's performance. Productivity, defined as the ratio of outputs to inputs, appears to be simple. However, measurements of productivity based on the commonly used definition of Total Factor Productivity (TFP) can lead to considerable biases. The literature commonly defines TFP as the ratio of the quantity of outputs to the quantity of inputs (e.g. O'Donnell, 2012).[1] Changes of TFP in turn (as shown in Figure 1) can be explained as the combined result of technological change, technical efficiency change, input mix change, output mix change, and scale change (e.g. Balk, 2010, p. 248).[2]

Accordingly, as Figure 1 shows, changes in profitability, that are not attributable to changes in TFP, are caused by changes in the price of outputs and inputs. This view or paradigm is commonly held in economics (e.g. O'Donnell, 2012, p. 255), but also in management science and engineering (e.g. Bernolak, 1997, p. 208; Tangen, 2005, p. 39).

However, concurrently, the literature identifies particularly the component of output mix change as a bias of TFP change, which seems to contradict the definition above. Banker et al. (1989, p. 543) gets to the heart of the issue by saying:

> *[…] because the APC measure[3] assumes a constant product mix between periods, it can signal productivity improvements when there have been no productivity improvements in the use of labour, material, or overheads. False productivity improvements can be signalled merely by changes in the mix of output.*

Another example is provided by Bernard et al. (2009, p. 681) who recognise that output mix change in the form of output switching 'is an important and hitherto largely neglected source of bias in productivity measurement'. Hence, it can be concluded that the conventional approach of TFP *only* yields valid measurements of productivity change in two limiting cases:

1. There is only one output, or
2. In a multiple output case, the output mix is static over time.

The first case is rare in practice. In fact, 'very few firms produce single homogeneous products' (Kathuria et al., 2014, p. 33). Only companies such as water utilities have one homogeneous output. On the contrary, the vast majority of firms have multiple outputs that form the output or product mix. The second is equally improbable, because output mixes are always likely to be more or less dynamic and not static over time. In fact, Bernard et al., 2010, p. 82) conclude that output mix change happens with 'surprising intensity and frequency'. Eighty-nine percent (89%) of all US manufacturing output 'is produced by firms that change their mix of products across census years' (ibid.), whereas the study only focusses on one of four sources of output mix change (output switching; see Section 4.2). Hence, in practice, the TFP approach to the quantification of productivity assuming a single output or static product mix, will lead to biased productivity estimates.

Verma (1992) identified output mix change as a factor that led to 'anomalies' in the productivity measurement system of a company and as one of the reasons why management did not accept it. To this day, there is a risk of mistrust of measurement results and – even worse – decision-making based on biased profitability or productivity indicators. Unfortunately, researchers and practitioners applying productivity measurement methods are often not aware that, in practice, TFP change is not synonymous with valid productivity change. The absence of differentiation between (valid) productivity change and TFP change in the productivity literature reinforces the problem. For example, Balk (2003, p. 6) states that

> *[…] productivity change, is nothing but the "real" component of profitability change. Put otherwise, if there were no effect of prices then productivity change would coincide with profitability change.*

This statement suggests that TFP change is equivalent with valid productivity change. Hence, it is not surprising that, for instance, Mohanty and Rajput (1988, p. 77) say that the 'product mix may raise productivity'. In this case, output mix changes included in TFP-based productivity measurement methods are erroneously interpreted as valid productivity change. In fact, productivity itself is not affected by a changing output mix, but only profitability, as will be shown later. It may be the case that TFP change is often interpreted as valid productivity change, merely because the expression includes the term "productivity". It is not obvious that it would only be valid in the case of a single output or static output mix. Given that most companies have dynamic output mixes, there is a risk that researchers and practitioners will measure productivity change in invalid ways. Since output mix changes are included by *definition*, measured changes will be overestimated, if interpreted as valid productivity changes. Consequently, the impact of productivity change on changes in profitability will also be overestimated.

The central aim of this paper is to encourage confidence in performance measurements in companies, as well as preventing faulty decision-making due to the use of biased profitability or productivity indicators. A subsidiary aim is to identify measurement approaches, which are suitable for accurate productivity measurement at the micro level. For this purpose, a refined framework of profitability and (valid) productivity change is developed and empirically tested. It defines changes in the ratio of output quantities to input quantities not as TFP change (as done in the literature), but as quantitative profitability change. More specifically, this paper aims to analyse the concepts of profitability, productivity, and output mix change in terms of their components and to propose a refined framework that includes valid definitions of the three concepts. The proposed framework is empirically validated by showing the extent of bias of TFP-based productivity indicators due to output mix effects and second, the extent of bias to changes in profitability using plant level manufacturing data.

The following Section 2 presents the results of the literature review and Section 3 sets out the methodological approach adopted in the study. Section 4 in turn introduces the concept of quantitative profitability change and presents the proposed framework together with the results of the empirical validation. Finally, Section 4 concludes upon the main findings of the study.

2 Literature Review

As a first step towards the development of a refined framework, this section presents a critical evaluation of cross-disciplinary perspectives on the definition and validity of TFP and productivity change, of the concept of profitability change, and of available measurement methods.

2.1 On the Validity of TFP Change – a critical Evaluation

It seems to be surprising that TFP, a concept derived from the production function, which is the common definition of productivity, has such a limited validity. Certainly, one explanation is that the concept stems from economics, where the focus is on the macro level (above firm level) and an assumption such as 'a single good produced' lacks realism and is not sustainable (Baily and Solow, 2001, p. 159). In the case of practical applications, such simplifying assumptions need to be relaxed. The theory of productivity and its measurement seem to represent such a case.

Another comprehensible reason, for the restricted validity of TFP change, is that it is used to account for the unexplained residual or error term in growth equations recognized early on as a 'measure of our ignorance' (Abramovitz,1956, p. 11; Solow, 1957). However, over the decades, based on modern microeconomic theory, the residual was explained and decomposed into components. Hence, 'in reality, there are a number of other factors contributing to [total factor!][4] productivity change, such as efficiency change, scale effects, and input- or output-mix change' (Balk, 2003, p. 17). These different components automatically were accepted as being parts of TFP, although they represent not only (valid) productivity change, but also other components of higher-level profitability change (i.e. scale, input mix, and output mix change in Balk's [ibid.] decomposition above).

Finally, a third reason for the restricted validity might be that TFP is indeed correctly defined as an absolute measure (first order). This approach is valid for comparing or benchmarking productivities at a single point of time, but not particularly useful for monitoring productivity change over time (second order), where factors, such as output mix change, can bias the measurements.

2.2 What is valid Productivity Change?

This subsection analyses how valid productivity change relates to TFP change and the higher-level concept of profitability change.

2.2.1 Top-down Approach

Figure 1 shows Grifell-Tatjé's and Lovell's (1999) framework of profitability change, which is representative for the modern microeconomic decomposition (e.g. O'Donnell, 2010). By comparing the components of valid productivity change and TFP change, it is evident that an approach to the analysis of profitability change that fails to control for the impact of changes in input and output mixes, and scale on (TFP-based) productivity, will result in biased estimates of productivity change itself and its contribution to profitability change.

[Figure 1]

A similar decomposition of profitability change, from the domain of management, is presented by Banker et al. (1993; 1996). Assuming that changes in capacity utilisation can be considered as scale change, input mix change is the only component that differentiates the two frameworks. This inconsistency is addressed again later (Subsection 4.3).

2.2.2 Bottom-up Approach

Another perspective on productivity can arise by considering the internal and the external environment of an organisation (Neely et al., 2005, p. 1248). While profitability is a measure of performance influenced by both the external and internal environment of a company, productivity measures show the efficiency of the *transformation process* (Misterek et al., 1992, p. 30) described as 'internal efficiency' (Hannula, 2002, p. 57). This internal focus makes productivity a valuable performance indicator, as it relates to competitive sustainability. Such a perspective also allows evaluating, whether a phenomenon, such as output mix change, relates to profitability or productivity change, depending on its impact on the transformation process.

2.3 Productivity Measurement Approaches from the Perspective of Validity

The purpose of this subsection is to critically evaluate existing approaches to productivity measurement in terms of their ability to measure valid productivity change, as defined in the previous subsection.

2.3.1 Classic TFP Approach

Over the past decades, many productivity measurement methods based on the classic TFP approach have emerged from disciplines, such as economics, management science and engineering. Table 1 includes a selection of authors that present and/or apply productivity measurement methods based on this approach.

[Table 1]

From a measurement point of view, the issues with the validity of TFP change discussed earlier are summarised in equations 1 to 3. The expression in equation 1 represents valid productivity, although it includes multiple outputs. This is because it relates to a single period. Measuring productivity change (comparison over time) can be based on the TFP index shown in equation 2. Unfortunately, this expression only equates to actual productivity change (VPI), if the output mix is identical in both time periods and therefore, $\sum_j O_{jc}$ of the current period is identical to $\sum_j O_{jb}$ of the base period. This limiting case is uncommon in practice and is the cause of the inconsistent use of theory in practice.

The dynamic nature of the output mix is captured by equation 3, which measures not only changes of productivity, but also other biasing (quantitative) changes relating only to profitability change (e.g. output mix change). Hence, obtaining valid productivities across measurement periods requires biasing output mix effects be removed.

$$TFP = \frac{\sum_j O_j \times V_j}{\sum_n \sum_j I_{jn} \times V_n} \qquad (1)$$

where:
O_J = *Quantity of output type J of measurement period*
V_j = *Fixed or deflated monetary value per unit of output j; j = 1, …, J*
I_{jn} = *Quantity of input factor n consumed for output j of measurement period; n = 1, …, N*
V_n = *Fixed or deflated monetary value per unit of input factor n*

$$\frac{\frac{\sum_j O_{jc} \times V_j}{\sum_n I_{nc} \times V_n}}{\frac{\sum_j O_{jb} \times V_j}{\sum_n I_{nb} \times V_n}} = TFPI = VPI \qquad (2)$$

where:
$\sum_j O_{jc} = \sum_j O_{jb}$
TFPI = Total Factor Productivity Index
VPI = Valid Productivity Index

$$\frac{\frac{\sum_j O_{jc} \times V_j}{\sum_n I_{nc} \times V_n}}{\frac{\sum_j O_{jb} \times V_j}{\sum_n I_{nb} \times V_n}} = TFPI \neq VPI \qquad (3)$$

where:
$\sum_j O_{jc} \neq \sum_j O_{jb}$

2.3.2 Modern TFP Approach

Using the classic TFP approach found in macroeconomics as their starting point, economic theorists have worked to develop a microeconomic approach to the measurement of productivity. It is part of a research programme that 'continues to emerge' (Van Beveren, 2012, p. 99) and that has at its root the idea of the efficient frontier of the production function of a technology, which envelops data and represents "best practice" (Mahadevan, 2003, p. 372).

Applying this approach to monitor productivity in a single firm (micro level) would be complicated, as it would require a large number of observations in order to ensure statistical robustness (Banker and Natarajan, 2011; Coelli et al., 2005, p. 313). Moreover, although the modern TFP approach allows for the decomposition of measurement results into different components (see Figure 1) and is adequate to measure valid productivity change, at the micro level, a new production frontier would have to be estimated for each measurement period to measure the important component of 'technological change'. Therefore, the modern TFP approach is mostly used either at the macro level or, if at the micro level, in terms of productivity benchmarking (e.g. Asaftei, 2008).

2.3.3 SI Approach

Another approach to the measurement of productivity that emerged from management science and engineering and is also utilised by service organisations (e.g. Sahay, 2005) is the SI (Standard Input) approach. This approach substitutes the output mix of a certain period with the input requirements (e.g. Mahadevan, 2003, p. 370). Productivity can be measured as a ratio of standard input factor quantities (representing the output) to the actual input factor quantities consumed to produce the output. Such standard quantities are usually available from management accounting (Banker et al., 1989) or engineering (Roll and Sachish, 1981) in the form of input standards used for cost estimation. Instead of standard values, it is also possible to use target, maximum, or minimum values.

Equation 5 illustrates that the quantity of a specific output type O_J is equivalent to the product of its quantity and the input factor quantities IR_{nJ} required per output unit. The different input factors are unified by multiplying the result with fixed input factor prices V_n. As a result, the output quantity is equivalent to the standard input value required to produce the output (I_J^S). In other words, the output is transformed into the corresponding input value.

$$O_J \equiv O_J \times \sum_n IR_{nJ} \times V_n \equiv I_J^S \qquad (5)$$

where:

IR_{nJ} = Input factor quantity required to produce a unit of output type J related to input factor n (input requirement)
I_J^S = Standard input of output type J

Based on the relationship in Equation 5, Equation 6 demonstrates that a ratio of the quantity of outputs to the quantity of inputs (TFP; first term) can be transformed to a ratio of standard inputs (former outputs) to actual inputs (third term) representing SI-based total productivity.

$$P^{SI} \text{ or } TFP = \frac{\sum_j O_j \times V_j}{\sum_n \sum_j I_{jn} \times V_n} \equiv \frac{\sum_n \sum_j O_j \times IR_{jn} \times V_n}{\sum_n \sum_j I_{jn} \times V_n} \equiv \frac{\sum_n \sum_j I_{jn}^S \times V_n}{\sum_n \sum_j I_{jn} \times V_n} \quad (6)$$

where:
P^{SI} = SI-based total productivity
IR_{jn} = Input factor quantity required to produce a unit of output j related to input factor n (input requirement)

Unlike the classic TFP approach, this method does not necessarily need a reference period to become meaningful, which is why output mix change cannot affect the measurements. For this reason, the SI approach is considered suitable for measuring valid productivity change.

2.3.4 ATFP Approach

In the domain of engineering, a productivity measurement approach was developed based on the concept of standard outputs (see Table 1). This paper designates it as the ATFP (Adjusted Total Factor Productivity) approach. It directly builds on the TFP approach and adjusts the input quantities consumed by a heterogeneous product mix in a period, to a defined standard output. The approach was implemented by Krafcik (1988), where such adjustments eliminated quality differences across production plants. The ATFP approach can be also applied for productivity monitoring in a single plant or firm.

Equation 7 shows the ATFP-based total productivity ratio. The ATFP approach is based on the question of how much input would have been used, if the output had been the standard output and it is comparable to the use of equivalence numbers in management accounting. It requires comparable input factors and outputs to apply the adjustments. Thus, its application may be restricted to the plant or shop floor level, if a company produces significantly different outputs (e.g. cars and motorcycles).

$$P^{ATFP} = \frac{\sum_j O_j \times V_j}{\sum_n \sum_j I_{jn}^{adj} \times V_n} \quad (7)$$

where:
P^{ATFP} = ATFP-based total productivity
I_{jn}^{adj} = Quantity of input factor n of product or job j adjusted to defined standard output

The ATFP approach is able to eliminate biasing output mix effects from a classic TFP-based productivity indicator. Just like the SI approach, productivity change is exhibited as a residual including technological and technical efficiency change. However, it allows for exhibiting the single output mix effects that have been eliminated. The ATFP approach is considered as suitable for measuring valid productivity change at the micro level.

3 Methodology[5]

The overall methodological approach for this study is depicted schematically in Figure 2. As ‘productivity research is such a scattered and wide-ranging field that it is even difficult to define’ (Käpylä et al., 2010, p. 608), a two-stage literature review was conducted to analyse the productivity literature.

[Figure 2]

First, as recommended by Tranfield et al. (2003), a scoping study utilising Arksey’s and O’Malley’s (2005) five-stage framework was undertaken. Cross-disciplinary and alternative perspectives on productivity measurement were captured by analysing studies from the domains of economics, management science, and engineering. Table 2 gives an overview of the keywords used and the number of search results obtained from the databases. In total, 1,613 search results were checked as to their titles and abstracts. Additionally, articles from the reference lists of relevant articles from the database search were selected, if they were linked to relevant text passages.

[Table 2]

This process yielded 127 relevant sources (journal papers, work studies, books, and doctoral theses), which were reviewed at the full text level. A spreadsheet was used to record general and specific information in the selected articles, such as type of article, year of publication, methodology, purpose of study, and important results. Finally, the articles were classified by their relevance and research focus and commented on.

After the scoping study, a systematic literature review, that has become increasingly popular outside the medical science discipline (Petticrew, 2001, p. 98), was executed. In this context, the recommendations of Tranfield et al. (2003) were followed on how to apply the principles of systematic literature reviews to management science. For the keyword search, a period from 1965 to 2015 was chosen. According to Sumanth (1984, p. 99), Kendrick and Creamer (1965) were the first ones who dealt exclusively with productivity measurement at the firm level, which is why 1965 was chosen as starting point. The systematic literature review yielded 40 relevant articles and together with the results of the scoping study (127 relevant articles), 167 articles in total were fully reviewed.

The outcome of the systematic literature review was the formulation of a set of well-defined review questions.

1st Review Question: Is there a valid definition of productivity?

2nd Review Question: What kinds of biases affect TFP-based productivity measurement?

3rd Review Question: What is output mix change?

4th Review Question: What kinds of productivity measurement methods are available for valid productivity measurement?

The approach described above allowed a critical analysis and evaluation of perspectives on three concepts (productivity, profitability and output mix change) and a review of productivity measurement methods. Exploration of these concepts contributed to the synthesis of a proposed framework for a more accurate description of profitability and productivity change.

The utility of the proposed framework was tested through empirical evaluation. The objective of the empirical investigation was to compare different productivity measurement approaches in terms of validity. For this purpose, disaggregated data at the product or order level were analysed from two production processes at a web offset printing company over a period of two years. The units of analysis were selected due to the intensity of output mix change. Web offset printing represents a typical make-to-order production process that has a highly dynamic output mix due to customer requirements. Therefore, it was considered as appropriate to compare different productivity measurement approaches at the micro level. Detailed and reliable data were fully available from operating databases and machine data acquisition systems.

4 Development of a new analytical Framework

As prerequisites for the framework, this section first introduces quantitative profitability change as a new concept and presents a decomposition of output mix change. Then, the concepts of quantitative profitability and productivity change are decomposed and analysed at the micro level. Finally, a refined framework is presented explaining profitability and valid productivity change and their subcomponents at different levels.

4.1 Introducing the Concept of Quantitative Profitability Change

As was shown earlier in this paper, in practice, the common TFP approach exhibits biased measurements of productivity. For this reason, this paper introduces the new concept of *quantitative profitability change (QP change)* as an alternative expression for what is measured by TFP-based measurement approaches. The new designation is appropriate and preferable to TFP change, as it highlights the importance of all *quantity-related* changes in profitability change excluding price changes. By referring to Figure 1, the misleading expression 'TFP change' is substituted by 'quantitative profitability change'. This substitution is included in the framework in Figure 4 at the second level.

Equation 8 explains the concept of quantitative profitability change from a mathematical point of view. As already explained in Equation 3 (Subsection 2.3.1), the change measured by a TFP index (TFPI) is unequal to (valid) productivity change (VPI). In contrast, it actually measures an index of quantitative profitability change (QPI). If prices in Equation 8 were not fixed or deflated, but dynamic, the expression would measure profitability change.

$$\frac{\frac{\sum_j O_{jc} \times V_j}{\sum_n I_{nc} \times V_n}}{\frac{\sum_j O_{jb} \times V_j}{\sum_n I_{nb} \times V_n}} = TFPI \neq VPI = QPI \qquad (8)$$

where:
$\sum_j O_{jc} \neq \sum_j O_{jb}$
QPI = Quantitative Profitability Index

4.2 Decomposing Output Mix Change

The analysis of the literature revealed that the output mix of a transformation process may change in several ways. As a result, output mix change can be defined as the combined result of *quality change*, *output switching*, *scale change*, and *proportion change* in the mix of outputs. The framework in Table 3 summarises this finding.

[Table 3]

In the following two sections, the framework is integrated in a superordinated one.

4.3 Analysing the Components of Quantitative Profitability and Productivity Change

So far, the focus of the analysis has been on output mix change as an independent component of QP or TFP change and as a bias of TFP-based productivity measurement. However, the microeconomic framework shown in Figure 1 also defines input mix change and scale change as independent components. In order to analyse all three components, Figure 3 shows the refined model of a transformation process including multiple inputs and outputs, as can be found in management science or engineering (Stewart, 1983, p. 747; Kurosawa, 1991, p. 74). This approach is comparable with the production function approach found in economics. Other than the models found in the literature, the one presented here does not refer to a specific period, but to the changes between two periods assuming a dynamic output mix. From a micro-level perspective, the model explains changes in the input mix, transformation process, and output mix and whether the changes affect productivity or other components of quantitative profitability. For this purpose, the model integrates the decomposition of output mix change from the previous section.

[Figure 3]

Basically, the model illustrates that, on the one hand, quantity changes in the input mix can be caused by changes in the output mix affecting input requirements (coloured in orange). These changes are caused by quality change, output switching, and proportion change. They relate to quantitative profitability change, but not to productivity change. Secondly, there are also input quantity changes caused by changes of the transformation process (coloured in green). These changes in turn relate to productivity change. The following subsections discuss in detail the different components causing changes in the input mix.

4.3.1 Quality Change, Proportion Change, and Output Switching

The orange-coloured type of input mix change is caused by quality change, output switching, or proportion change occurring in the output mix. The variable input factors need to reflect those changes, as is illustrated by the orange linking line on the top. In other words, output mix change causes input mix change. An index of the quantity of outputs to the quantity of inputs (QPI or

TFPI) measures such output mix-related changes of the input mix in terms of a quality, output switching, or proportion effect. Those effects do relate to quantitative profitability change, but not to productivity change. The failure to include such changes in a productivity indicator leads to errors in the estimation of productivity change, as well as in the contribution of productivity change to profitability change.

As regards the impact of quality change, small changes in material may not be relevant, but continuous incremental changes (e.g. of a car) could vastly change the quality and thus the input requirements of a product and consequently cause input mix change. The quality effect does not affect productivity, because the input mix change is not caused by a change in the transformation process that stems from changes in efficiency or technology. Whether a phenomenon such as quality change is related to profitability or productivity change, depends on whether it directly affects the transformation process or not (see Subsection 2.2.2). For example, an improvement of car quality over time that requires more input factor quantities should be considered a deterioration of quantitative profitability (possibly compensated by price changes) and not a deterioration of productivity.

A *proportion effect* occurs, if, in the product mix, the proportion of products changes and affects the input mix. If, in a measurement period, a specific product has a higher proportion in the product mix and the productivity of the product is more or less than average productivity, a TFP-based indicator will measure a proportion effect. This effect does not relate to productivity, since it is independent of a change of the transformation process. Otherwise, merely producing a higher proportion of a simple product having a better ratio of output to input quantities compared to other products, would be considered as an improvement in productivity. Proportion change relates to quantitative profitability, but not to productivity change.

Whether the addition or removal of a product to or from a product suite (output switching) adds to or lowers the profitability of a suite of products depends on whether the profitability of the added or removed product is more or less than the average profitability of the existing suite. The same seems to apply for productivity. Abolhassani et al. (2018) claim that launching a new product and each model type proliferation increase the hours per vehicle of automotive production plants and interpret this as a decrease of the (labour) productivity. However, an added or removed product may have an inherent profitability, but no inherent productivity. It has inherent input requirements though, which affect the input mix in terms of an *output switching effect* not relating to productivity (see Section 1). Similar to proportion change, just replacing a product by a less complex one causing less material waste, for instance, should not be considered as an improvement of productivity. This is because the change of material waste is not caused by an improvement of the transformation process (which in turn has an inherent productivity). Otherwise, productivity could be improved by just replacing complex products by simple products. In fact, productivity will only change, if the inherent input requirements of a newly added product (which may be relatively low compared to other products) can be reduced over time by a more efficient transformation process.

4.3.2 Technological Change and Technical Efficiency Change

Having discussed changes of the input mix that do not relate to productivity change, the focus is now on the second type of input mix change related to productivity change (green box in input mix). Such a change of quantities in the input mix change may be said to occur, if a transformation process consumes more or fewer input factors for a given output mix (holding volumes and composition in terms of qualities, proportion, and types of products constant). This can be due to technological change or technical efficiency change (green boxes in transformation process). In a ratio of the quantity of outputs to the quantity of inputs (QP or TFP), only such changes in the input mix relate to productivity change. A *technological effect* usually occurs, when a new (more productive) production line replaces an old one and enables the production of (more complex and less complex) products more effectively and efficiently (e.g. less material waste). In turn, a *technical efficiency effect* occurs, if, for example, the rejection rate is reduced following implementation of Six Sigma methods.

4.3.3 Scale Change

Scale change represents the fourth possible component of change in the output mix and has an indirect and hybrid character. It may result in two different effects – only a profitability- or additionally a productivity-related one. In the case of the well-known profitability-related scale effect, the scale change relates to fixed (not variable) input factors (orange-coloured part of box). Hence, it does not affect the input mix, which is why the orange linking line has no arrow. For example, assume that a production line produces an increased output quantity due to higher capacity utilisation. This means that fixed input factor consumptions (usually valued monetarily as fixed costs) are distributed across a higher quantity of output. That is, the fixed costs per unit of output will fall. Consequently, a ratio of the quantity of outputs to the quantity of inputs (QP or TFP) will measure an improvement. In contrast to a profitability indicator, a productivity indicator should not exhibit this effect. This is because the effect has no relationship to an improvement or deterioration of the transformation process itself.

Secondly, there is also a *productivity-related scale effect*. It occurs, if scale change in the output mix (green-coloured part of box) affects the technical efficiency of the transformation process, which in turn affects the input mix as a *mediating variable*. If the volume of the output mix changes (e.g. more production jobs), then the *non-fixed* or variable input factors will change correspondingly. As long as this change is proportional, a ratio of the quantity of outputs to the quantity of inputs (QP or TFP) will measure no change. However, if the input factors change disproportionately, the ratio will exhibit productivity change. For example, if there is very high capacity utilisation, the maintenance of production equipment is often neglected or the production staff can be overworked, leading to lower levels of productivity (in terms of technical efficiency change). In contrast, if capacity utilisation is low, the production time of jobs might lengthen and productivity fall. In those cases, the scale change affects the technical efficiency of the transformation process, which in turn affects the input mix. This phenomenon is called productivity-related scale effect in this research. In the literature, no framework or productivity measurement approach was found describing or exhibiting this effect.

As mentioned in the beginning of this section, modern microeconomic decompositions of profitability change (Figure 1) exhibit scale change as an independent component besides output mix change. However, the model in Figure 3 implies that, at the micro level, scale change rather represents a subordinated component of output mix change. Carlsson (1981, p. 347) corroborates this finding by stating that half of his ‘measured productivity growth at the firm level consists of changes in output mix caused by […] increased utilization of scale economies’.

4.3.4 Input Mix Change as independent Component

Except from the two types of input mix change explained in Subsections 4.3.1 and 4.3.2 (orange and green box in input mix), at the micro level, no other kind of input mix change was identified affecting the ratio of the quantity of outputs to the quantity of inputs of a transformation process.

Hence, in contrast to the literature (see Subsection 2.2.1), there seems to be no independent input mix effect. Input mix change rather seems to have the characteristic of a *mediating variable* (between output mix change and QP/TFP change or between changes of transformation process and productivity change).

As regards this finding, there might be a need for further research in economics. There are a number of empirical studies decomposing TFP/QP change based on modern microeconomic theory including the components of output mix change and input mix change (e.g. Grifell-Tatjé and Lovell, 1999; Asaftei, 2008). However, as no explanation was found for an independent component of input mix change, it might be that the same thing is measured twice. That is, measuring output mix change and the same again in terms of output mix-related input mix change (first type). Besides, measuring productivity change (technological, technical efficiency, or productivity-related scale effect) and the same again in terms of the related input mix quantity change (second type).

4.4 Refined Framework of Profitability and valid Productivity Change

Based on the results of the previous subsections, Figure 4 presents a refined framework decomposing profitability change and valid productivity change. At the second level, profitability can be decomposed into the components of price recovery and quantitative profitability change (designated as TFP change in the literature). Holding prices constant (input and output), any changes in profitability will be the result of changes in quantitative profitability (see Subsection 4.1).

[Figure 4]

At the third level, quantitative profitability change is decomposed into technical efficiency change, technological change, and output mix change. Compared to the microeconomic framework presented in Subsection 2.2.1, there is no input mix change and scale change. As regards the former, it was argued that there is no *independent* component of input mix change and it is therefore omitted. In turn scale change represents a *subcomponent* of output mix change at the fourth level of the framework as discussed in Subsection 4.3.3.

The fourth level decomposes output mix change into the four subcomponents of scale change, quality change, proportion change, and output switching. In addition, price recovery is disaggregated into input price change and output price change.

Finally, the fifth level allows for distinguishing valid productivity change (sixth level) from the components solely related to profitability change. For this purpose, the different changes from the fourth level are expressed in terms of the *effects* they have. This is because scale change, as a subcomponent of output mix change, may cause productivity-related and non-productivity-related effects (see previous subsection). Consequently, there are effects impacting productivity and quantitative profitability (technological, technical efficiency, and productivity-related scale effect) and effects that merely affect profitability (quality, proportion, output switching, input price, output price, and profitability-related scale effect).

The framework implies that, in contrast to the microeconomic framework, at the micro level, besides of technical efficiency and technological change, also scale change in the form of a *productivity-related scale effect* may contribute to valid productivity change. Productivity indicators are supposed to measure only those effects, which contrasts with TFP-based ones including all effects except from the price effects.

5 Empirical Comparison of Productivity Measurement Approaches

This subsection compares classic TFP-based productivity measurements with SI- and ATFP-based ones at the shop floor level. The empirical work allows us to capture the extent of bias in TFP-based productivity indicators due to output mix effects and estimates of the contribution of productivity change to changes in profitability change.

5.1 Background of the empirical Investigation

In order to measure productivities, it was decided to focus on partial productivity instead of measuring total productivity. At the micro level, partial productivity ratios are often used due to their high practicality (Hannula, 2002, p. 57; e.g. labour hours per car). A problem of total productivity is the potential aggregation bias caused by the monetary valuation of the different input factors included (e.g. Kendrick and Creamer, 1965, p. 25). Besides, the need of input standards (Subsection 2.3) required a deep data analysis and thus, a focus on one input factor was preferred. For this purpose, the input factor “paper” was selected representing the highest proportion of input costs in the investigated firm.

Instead of measuring productivity conventionally, by relating the total paper consumption to the output produced (print run), the *paper waste ratio* was measured. This ratio represents a widespread partial productivity indicator in the printing industry. Paper waste is the difference between the volume of a print job or print run (= output measure) and the total paper consumption (= input measure). Hence, only the scrap material is used as input measure. By relating the paper waste (numerator) to the print volume of a print job (denominator), the paper waste ratio provides a TFP-based productivity indicator. The paper waste ratio was measured for consecutive samples of 30 consecutively produced print jobs across two years, which were comparable to months. The constant samples provided ideal data for statistical analysis.

For two of the three productivity measurement approaches investigated, input standards were required (SI and ATFP approaches; Subsection 2.3). Such standards allow for estimating the input required for a print job, depending on the production process used and the specification of the job to be produced (output). In this work, standards were required for the input factor of paper for each of the two units of analysis. Chenery’s (1949) concept of *engineering production functions* proved to be an adequate theoretical foundation for the determination of relationships between inputs and outputs at a much disaggregated level. Derived from the engineering production function, the input quantity can be expressed as engineering *input function*, which is equivalent with an input standard. Such functions were developed empirically for four paper waste types (set-up waste, plate change waste, imprint change waste, and breakdown waste). In order to check the validity of the paper waste standards, residuals (difference between actual paper waste and estimated standard paper waste of print jobs) were analysed and checked, if they are normally distributed.

5.2 Productivity Measurement Results

Figures 5 and 6 show empirical partial productivity measurements (paper waste ratios) based on the TFP, SI, and ATFP approaches of two production processes (designated as M-1 and M-2) over a period of two years.[6] The TFP-based (black line) and ATFP-based measurements (blue line) yield a paper waste ratio as percentages, while the SI approach (green line) yields a ratio without a unit. An increase in the ratios corresponds to a decrease in productivity. While the SI- and ATFP-based measurements exhibit valid productivity change, the TFP-based ones include biasing output mix effects. The two units of analysis show significantly different measurement results between the TFP-based productivities and the SI- or ATFP-based productivities due to output mix effects. The TFP paper waste ratio of M-1 tends to increase over the two years and thus suggests deterioration in productivity. In fact, the ATFP- and SI-based measurements reveal an opposite productivity trend – particularly during the second year (samples 10 to 16), whereas both follow a similar trend. These results clearly show how deceptive TFP-based productivity measurements can be. Remarkably, the TFP-based paper waste ratio is not only the one used by the investigated company, but is widespread in the printing industry. The same applies for the commonly used productivity indicator in the automotive industry (hours per vehicle), to which the results can be generalised.

M-2 in turn is subject to continuous significant productivity deterioration over the two years investigated, with the ATFP and SI paper waste ratios following a similar trend. In contrast, the TFP-based measurements are subject to strong fluctuations due to biasing output mix effects.

[Figure 5]

[Figure 6]

Table 4 shows that, in case of M-1, the classic TFP paper waste ratio increases by 0.7% between the two years investigated. In case of M-2, it is an increase of 3.4%. The difference between the TFP-based productivity changes and the valid ATFP-based ones (-0.6% and 1.6%) yields a total biasing total output mix effect of 1.3% for M-1 and 1.8% for M-2. Hence, expressed as a percentage, 68% of the TFP-based productivity change of M-1 is subject to biasing output mix effects. In case of M-2, it is 53%. This also means that 68% or 53% of the measured change is erroneously interpreted as productivity change contributing to profitability change, if relied on the TFP-based indicator. Note that the empirical measurements include profitability-related scale effects and quality effects, but no proportion or output switching effect.[7] Hence, at the plant level, the percentage of the biasing total output mix effect might be even higher.

[Table 4]

6 Conclusion

The following quotation from a recent productivity study dealing with the fishing industry highlights the ongoing problem of TFP-based productivity measurement and the need for a new approach:

If the influence of changing biomass [= output mix change; note by author] on productivity change cannot be separated from the productivity change metric, the productivity metric will be "biased". Instead of using the term "biased", the terms "biomass unadjusted" (BU) or "biomass adjusted" (BA) productivity are used. (Färe et al., 2015)

In this case, it is recognised that a TFP-based productivity indicator is biased by a changing output mix comprising of fishes. The authors use the auxiliary terms "biomass unadjusted" and "biomass adjusted" productivity to overcome the conflict. The framework presented in this study would allow them to speak of "quantitative profitability" (QP) instead of "biomass unadjusted productivity" and simply of "productivity" instead of "biomass adjusted productivity". Since, in practice, TFP change does not equate to actual productivity change, this paper defines changes in the ratio of the quantity of outputs to the quantity of inputs not as TFP change (as done in the literature), but as *quantitative profitability change.* This is because the ratio actually measures all *quantity-related* components of profitability change excluding price changes.

The concept of QP change is part of a refined decomposition of profitability and valid productivity change from the perspective of the micro level. QP itself can be decomposed into technological, technical efficiency, and output mix change. In contrast to the literature, scale change is not considered as an independent component of QP change (former TFP change), but as a subcomponent of output mix change (comprising of scale change, quality change, proportion change, and output switching).

The framework and the empirical investigation prove that TFP-based productivity indicators are unsuitable for the clear majority of companies. This is because they only measure valid productivity change, when there is a single output or a static output mix. Otherwise, the indicators are significantly biased. Therefore, this study suggests that companies would benefit from the use of the SI and ATFP approaches, as these are able to measure valid productivity change. Alternatively, companies should rather decide not to measure productivity indicators, such as the paper waste ratio in the printing or the hours per vehicle in the automotive industry or should interpret them correctly as QP indicators. Relying on TFP-based indicators would also lead to erroneous interpretations of the contribution of productivity change to changes in profitability.

Another important finding is that (compared to decompositions from microeconomics) *no independent component of input mix change* could be identified. Furthermore, it was found that the component of scale change may cause either productivity or only higher-level profitability change. While the *profitability-related scale effect* is well-known in the literature, no framework or productivity measurement approach was found describing or exhibiting the *productivity-related scale effect*.

This paper can help reducing the risk of flawed decision-making by researchers and practitioners or distrust due to biased profitability or productivity indicators. Having a clear distinction between the components of valid productivity and (quantitative) profitability change consistently in the literature, would improve the understanding of productivity and profitability, prevent confusion (related to TFP), and help researchers and practitioners to measure the two concepts more accurately.

The focus of this paper is the micro level. Thus, it omits literature from the industrial organisation field of economics, where a long literature has wrestled with questions of productivity measurement (e.g. Syverson, 2011; Olley and Pakes, 1992). This is a large and influential literature that will universally suffer from the limitations outlined in this paper, potentially confounding various productivity and profitability concepts. Hence, there is a need for future research to include that literature as per its key motives, such as understanding the relationship between plant- (or firm-) level productivity and subsequent growth and survival from a macroeconomic perspective. Another challenge for future research in economics is to transfer the presented framework to the standard production function framework, which basically assumes only one output per plant. This may involve showing specifically how it is insufficient and how it can be expanded to accommodate the key points presented here. Further need for research relates to the concept of input mix change, which, in economics, is considered an independent component of TFP change. As mentioned above, no explanation was found for this assumption from the bottom-up perspective of this research.

While the empirical investigation of this research focused on partial productivities at the shop floor level, it would be very interesting to see empirical applications at the plant or firm level decomposing profitability and total productivity validly as proposed in this research. It is natural to ask whether there is an approach that is able to decompose profitability into *all* of its components at the micro level. Currently, only the modern microeconomic TFP approach seems to be able to do that. Meanwhile, such research seems possible due to the availability of different data types at a much disaggregated level (Big Data). Likewise, this prerequisite should enable practitioners implementing accurate performance measurement based on the presented decomposition of profitability and valid productivity change.

References

Abolhassani, A., Harner, J., Jaridi, M. and Gopalakrishnan, B. (2018), "Productivity enhancement strategies in North American automotive industry", International Journal of Production Research, Vol. 56 No. 4, pp. 1414-1431.

Abramovitz, M. (1956), "Resource and output trends in the United States since 1870", National Bureau of Economic Research, pp. 1–23.

Arksey, H. and O'Malley L., (2005), "Scoping studies: towards a methodological framework", International Journal of Social Research Methodology, Vol. 8 No. 1, pp. 19–32.

Asaftei, G. (2008), "The contribution of product mix versus efficiency and technical change in US banking", Journal of Banking & Finance, Vol. 32 No. 11, pp. 2336–2345.

Balk, B.M. (2003), "The residual: On monitoring and benchmarking firms, industries, and economies with respect to productivity", Journal of Productivity Analysis, Vol. 20 No. 1, pp. 5–47.

Balk, B.M. (2010), "An assumption-free framework for measuring productivity change", Review of Income and Wealth, Vol. 56 No. 1, pp. 224–256.

Baily, M.N. and Solow, R.M. (2001), "International productivity comparisons built from the firm level", The Journal of Economic Perspectives, Vol. 15 No. 3, pp. 151–172.

Banker, R.D. and Natarajan, R. (2011), "Statistical tests based on DEA efficiency scores", in Cooper, W.W. and Seiford, L.M., Zhu, J. (Eds), Handbook on Data Envelopment Analysis, International Series in Operations Research & Management Science, Springer Science + Business Media, pp. 273-295.

Banker, R.D., Datar, S.M. and Kaplan, R.S. (1989), "Productivity measurement and management accounting", Journal of Accounting, Auditing & Finance, Vol. 4 No. 4, pp. 529–554.

Banker, R.D., Chang, H.-H. and Majumdar, S.K. (1993), "Analyzing the underlying dimensions of firm profitability", Managerial and Decision Economics, Vol. 14 No. 1, pp. 25–36.

Banker, R.D., Chang and H.-H., Majumdar, S.K. (1996), "A framework for analyzing changes in strategic performance", Strategic Management Journal, Vol. 17 No. 9, pp. 693–712.

Bennett, A., Hui, J. and Silver, M.S. (1987), “A framework for productivity analysis at the organisational level: Method and an applied case“, Engineering Costs and Production Economics, Vol. 12 No. 1-4, pp. 401–411.

Bernard, A.B., Redding, S.J. and Schott, P.K. (2010), “Multiple-product firms and product switching“, American Economic Review, Vol. 100 No. 1, pp. 70–97.

Bernard, A.B., Redding, S.J. and Schott, P.K. (2009), “Products and productivity“, The Scandinavian Journal of Economics, Vol. 111 No. 4, pp. 681–709.

Bernolak, I. (1997), “Effective measurement and successful elements of company productivity: the basis of competitiveness and world prosperity“, International Journal of Production Economics, Vol. 52 No. 1-2, pp. 203–213.

Carlsson, B. (1981), “The content of productivity growth in Swedish manufacturing“, Research Policy, Vol. 10 No. 4, 336–355.

Chenery, H.B. (1949), “Engineering Production Functions“, The Quarterly Journal of Economics, Vol. 63 No. 4, pp. 507 –531.

Coelli, T.J., Rao, D.S.P., O’Donnell, C.J. and Battese, G.E. (2005), An introduction to efficiency and productivity analysis, Springer, New York, NY.

Diewert, W.E. (1992), “The measurement of productivity*“, Bulletin of Economic Research, Vol. 44 No. 3, pp. 163–198.

1. Färe, R., Grosskopf, S. and Walden, J. (2015), “Productivity change and fleet restructuring after transition to individual transferable quota management“, Marine Policy, 62, pp. 318-325.

Grifell-Tatjé, E. and Lovell, C.A.K. (1999), “Profits and productivity“, Management Science, Vol. 45 No. 9, pp. 1177–1193.

Hannula, M., (2002) “Total productivity measurement based on partial productivity ratios“, International Journal of Production Economics, Vol. 78 No. 1, pp. 57–67.

Kathuria V., Raj R.S.N. and Sen K. (2014), Productivity in Indian Manufacturing: Measurements, Methods and Analysis, Routledge, New Delhi.

Käpylä, J., Jääskeläinen, A. and Lönnqvist, A. (2010), “Identifying future challenges for productivity research: evidence from Finland“, International Journal of Productivity and Performance Management, Vol. 59 No. 7, pp. 607–623.

Kendrick, J.W. and Creamer, D.B. (1965), Measuring Company Productivity: Handbook with Case Studies, Studies in Business Economics, National Industrial Conference Board, New York, NY.

Krafcik, J.F. (1988), Comparative Analysis of Performance Indicators at World Auto Assembly Plants, Master Thesis, Sloan School of Management, Cambridge, MA.

Kurosawa, K. (1991), Productivity Measurement and Management at the Company Level: The Japanese Experience, Advances in Industrial Engineering, Elsevier, Amsterdam, Oxford, New York, Tokyo.

Mahadevan, R. (2003), “To measure or not to measure total factor productivity growth?“, Oxford Development Studies, Vol. 31 No. 3, pp. 365–378.

Miller, D.M. (1984), “Profitability = productivity + price recovery“, Harvard Business Review, Vol. 62 No. 3, pp. 145–153.

Misterek, S.D.A., Dooley, K.J. and Anderson, J.C. (1992), “Productivity as a performance measure“, International Journal of Operations & Production Management, Vol. 12 No. 1, pp. 29–45.

Mohanty, R.P. and Rajput, I. (1988), “Productivity measurement in a manufacturing company“, International Journal of Operations & Production Management, Vol. 8 No. 4, pp. 65–78.
Neely, A., Gregory, M. and Platts, K. (2005), “Performance measurement system design: a literature review and research agenda“, International Journal of Operations & Production Management, Vol. 25 No. 12, pp. 1228–1263.
O’Donnell, C. (2012), “An aggregate quantity framework for measuring and decomposing productivity change“, Journal of Productivity Analysis, Vol. 38 No. 3, pp. 255–272.
Olley, G. S. and Pakes, A. (1992), “The dynamics of productivity in the telecommunications equipment industry“, National Bureau of Economic Research, No. w3977.
Petticrew, M. (2001), “Systematic reviews from astronomy to zoology: myths and misconceptions“, British Medical Journal, Vol. 322 No. 7278, pp. 98–101.
Roll, Y. and Sachish, A. (1981), “Productivity measurement at the plant level“, Omega, Vol. 9 No. 1, pp. 37–42.
Sahay, B.S. (2005), “Multi-factor productivity measurement model for service organisation“, International Journal of Productivity and Performance Management, Vol. 54 No. 1, pp. 7–22.
Solow, R. M. (1957), “Technical change and the aggregate production function“, The review of Economics and Statistics, Vol. 39 No. 3, pp. 312-320.
Stewart, W.T. (1983), “Multiple input productivity measurement of production systems“, International Journal of Production Research, Vol. 21 No. 5, pp. 745–753.
Sumanth, D.J. (1984), Productivity Engineering and Management: Productivity Measurement, Evaluation, Planning and Improvement in Manufacturing and Service Organizations, McGraw-Hill, New York, NY.
Syverson, C. (2011), “What determines productivity? “, Journal of Economic literature, Vol. 49 No. 2, pp. 326-65.
Tangen, S. (2005), “Demystifying productivity and performance“, International Journal of Productivity and Performance Management, Vol. 54 No. 1, pp. 34–46.
Tranfield, D., Denyer, D. and Smart, P. (2003), “Towards a methodology for developing evidence-informed management knowledge by means of systematic review“, British Journal of Management, Vol. 14 No. 3, pp. 207–222.
Van Beveren, I. (2012), “Total factor productivity estimation: a practical review“, Journal of Economic Surveys, Vol. 26 No. 1, pp. 98–128.
Verma, K. (1992), “Total-factor productivity measurement, pertinent or passé?”, in Bruns, W.J. (Ed.), Performance Measurement, Evaluation, and Incentives, Series in Accounting and Control, Harvard Business School Press, pp. 279–300.

[1] In economics, TFP is defined relative to a theorized production function. A common assumption is that output Y is given by Y=A*K^a*L^b*M^c, whereas “A” represents TFP. This paper spans over the domains of economics, management science, and engineering and its focus is the firm level. Therefore, a more practical and generic approach is used (e.g. like Banker et al., 1993).
[2] Balk (2010a, p. 248) additionally mentions the component ‘chance’ meaning random variation by this. In this paper, the focus is on accuracy as regards validity and not reliability.
[3] The APC measure is a productivity measurement method based on the TFP approach.
[4] Squared bracket included by author to distinguish from valid productivity change.

[5] The methodology of the underlying research project had a focus on the concept of productivity. During the investigation, the findings and results required to include the closely related higher-level concept of profitability.
[6] Note that the measurements do not include the phenomenon of random variation. For this reason, some of the measured productivity changes may be not significant.
[7] The output switching and proportion effect did not occur at the shop floor level, but only at the aggregated plant level.

Table 1: Productivity measurement approaches

Productivity Measurement Approach	Domain	Selection of Associated Literature
Classic TFP Approach	Management, Engineering, Economics	Hannula (2002), Diewert (1992), Mohanty and Rajput (1988), Miller (1984), Sumanth (1984), Kendrick and Creamer (1965)
Modern TFP Approach	Economics	O'Donnell (2012), Balk (2010), Lovell (2003), Grifell-Tatjé and Lovell (1999), Caves et al. (1982)
SI Approach	Management, Engineering	Sahay (2005), Banker et al. (1996), Banker et al. (1993), Banker et al. (1989), Stewart (1983), Roll and Sachish (1981)
ATFP Approach	Engineering	Krafcik (1988), Bennett et al. (1987)

Table 2: Databases, search results, and keywords of scoping study

Databases	Number of Sources	Keywords Searched in Title
Springerlink	324	productivity measurement, efficiency measurement, productivity analysis, productivity estimation, productivity measure, estimating productivity
Science Direct	322	
JSTOR	293	
Wiley Online Library	198	
Taylor & Francis	155	
Emerald	84	
Inderscience	32	
EBSCO	22 (not all keywords included)	
SAGE	21 (not all keywords included)	
EconBiz	89	Produktivitätsmessung, Messung Produktivität, Gesamtproduktivität, Unternehmensproduktivität
PRIMO (Online Library University of Mannheim)	61	
KIT-Katalog (Online Library University of Karlsruhe)	12	

Table 3: Framework of output mix change defined as the combined result of quality change, output switching, scale change, and proportion change

	Output Mix Change			
Components	**Quality Change**	**Output Switching**	**Scale Change**	**Proportion Change**
Description	Change of the quality of products	Adding and/or deletion of products	Change of the volume of products	Change of shares of products in the output mix
References	e.g. Misterek et al., 1992, p. 36	e.g. Bernard et al., 2009, p. 681	e.g. Mahadevan, 2003, p. 371	e.g. Misterek et al., 1992, p. 39

Table 4: Productivity change and output mix change between the two years investigated

Unit of analysis	Productivity change TFP	Productivity change ATFP	Biasing total output mix effect	Proportion of biasing total output mix effect
M-1	0.7%	-0.6%	1.3%	68%
M-2	3.4%	1.6%	1.8%	53%

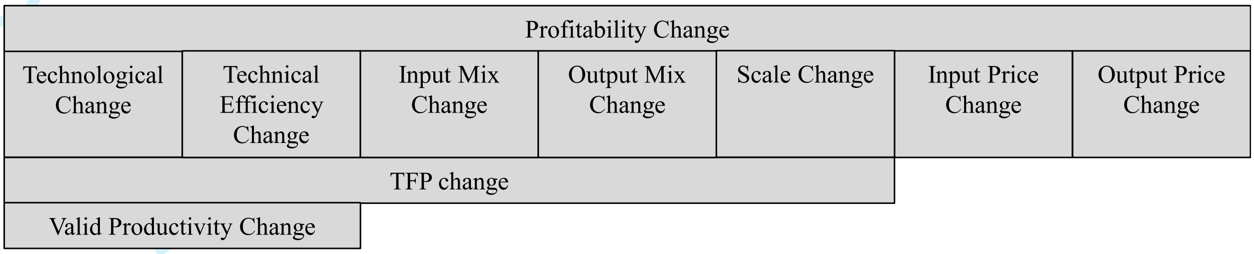

Figure 1: Microeconomic framework of the components of profitability change, TFP-change, and valid productivity change (adapted from Grifell-Tatjé and Lovell [1999])

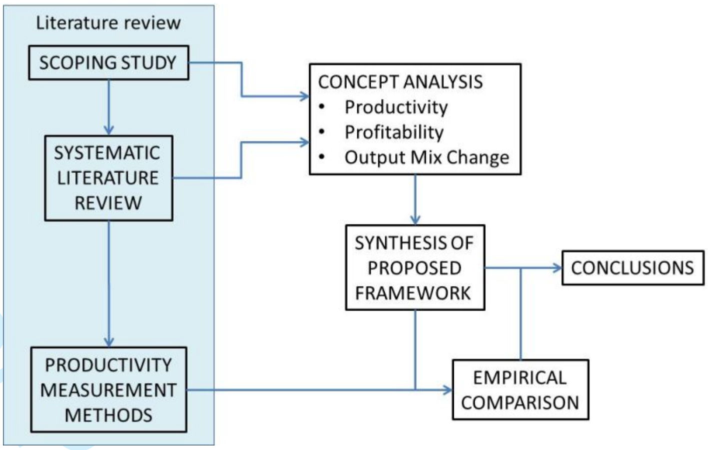

Figure 2: Research design

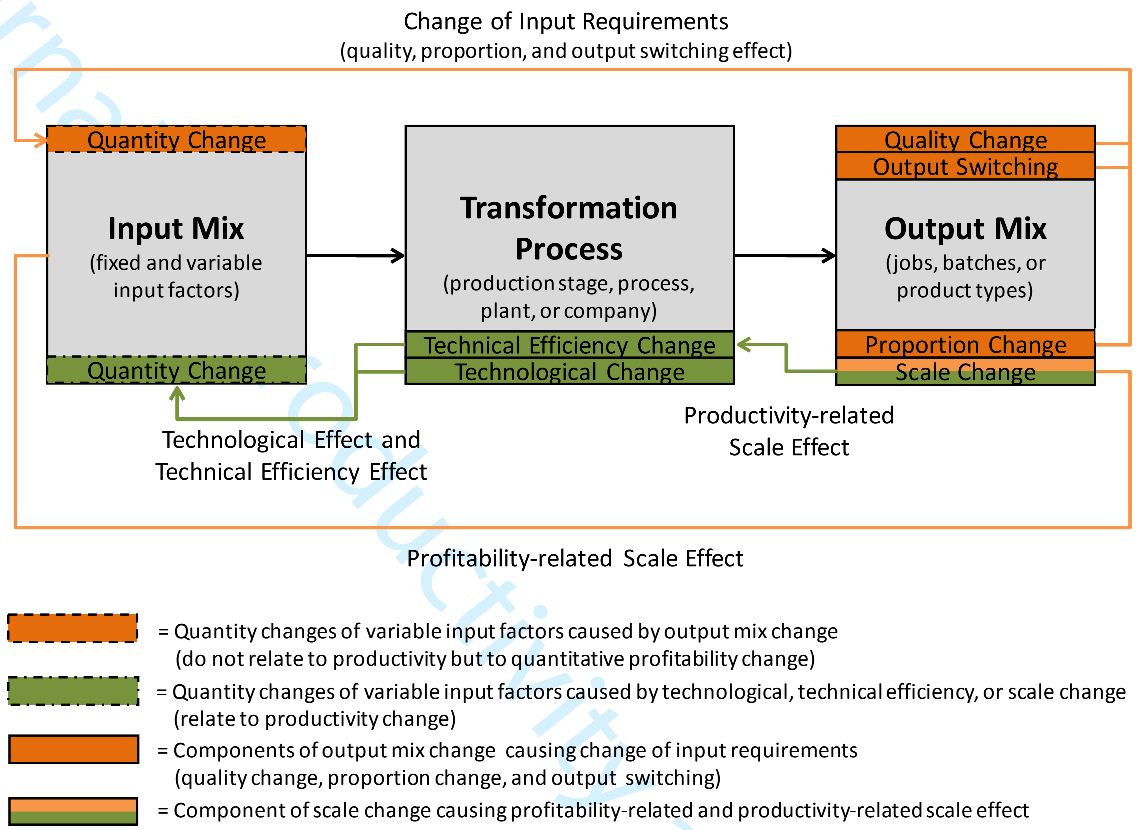

Figure 3: Refined model of a transformation process distinguishing components of valid productivity change (green boxes) and components, which do not relate to valid productivity change, but to higher-level quantitative profitability change (orange boxes). The sum of all changes and corresponding effects represents QP or TFP change.

Profitability Change								
Quantitative Profitability Change (former TFP change)							Price Recovery	
Technological Change	Technical Efficiency Change	Output Mix Change					Price Recovery	
Technological Change	Technical Efficiency Change	Scale Change		Quality Change	Proportion Change	Output Switching	Input Price Change	Output Price Change
Technological Effect	Technical Efficiency Effect	Productivity-related Scale Effect	Profitability-related Scale Effect	Quality Effect	Proportion Effect	Output Switching Effect	Input Price Effect	Output Price Effect
Valid Productivity Change								

Figure 4: Refined framework decomposing profitability change and valid productivity change

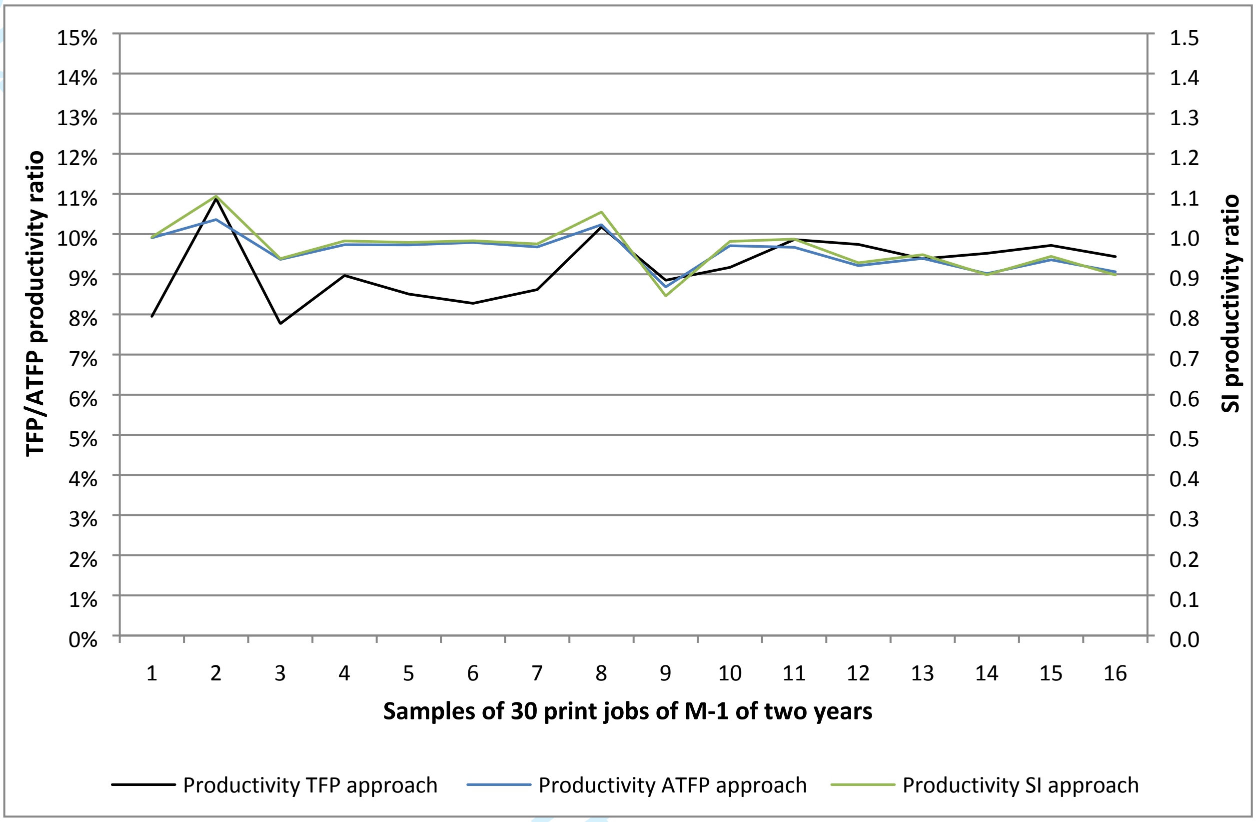

Figure 5: Partial productivity ratios of unit of analysis M-1based on the classic TFP, ATFP, and SI measurement approaches

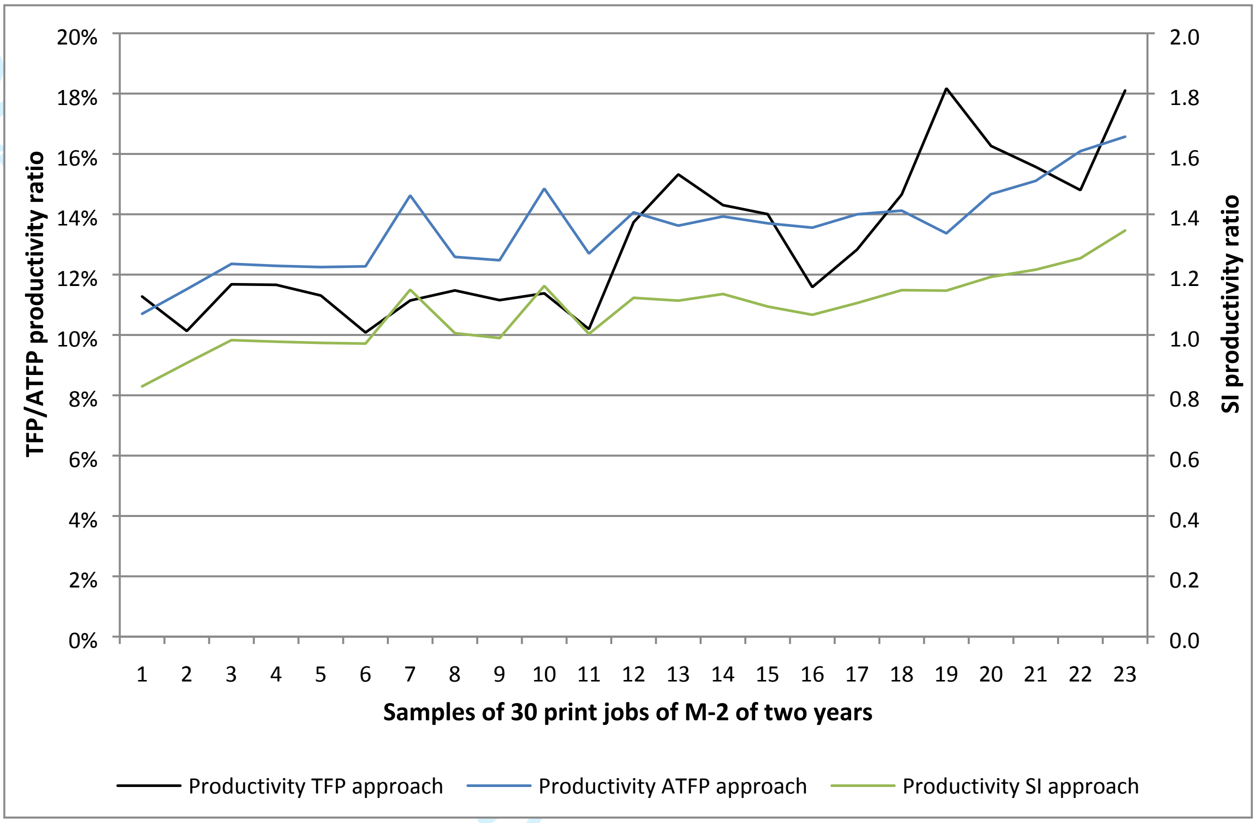

Figure 6: Partial productivity ratios of unit of analysis M-2 based on the classic TFP, ATFP, and SI measurement approaches