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Abstract:
The Norwegian productivity puzzle is rooted in three seemingly contradictory "facts": First, Norway is one of the most productive OECD countries. Second, Norway has experienced high growth in productivity. Third, Norway has a relatively low level of R&D intensity. In this article, I show that the first premise of the puzzle is probably false. Explicitly, I demonstrate that labour productivity in Norway is not particularly high when using production purchasing power parities instead of expenditure purchasing power parities to measure mainland GDP in a common currency. The gap between the two measures is traced back to the use of market exchange rates as proxies for relative net export prices in the calculation of expenditure PPPs. In addition, I show that the high growth rate in productivity can be explained by an empirical growth model that takes both R&D capital, human capital and the distance to the technological frontier into account. Based on these results, there is no reason to claim that the development of productivity in Norway represents a puzzle.

Keywords: Economic growth, Productivity, Index numbers, Aggregation, Price level.

JEL classification: C43, E01, E31, O47, O57.

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Sammendrag

Det norske produktivitetsparadokset har sitt opphav i tre tilsynelatende motstridende observasjoner: For det første er Norge et av de mest produktive OECD-landene. For det andre har det vært en høy vekst i produktiviteten og for det tredje er FoU investeringer relativt lave i Norge. I denne artikkelen sannsynliggjør jeg at den første observasjonen er misvisende. Mer eksplisitt analyserer jeg utviklingen i kjøpekraftsparitetene som ligger til grunn for produktivitetssammenligninger på tvers av land. Disse blir sammenlignet med kjøpekraftspariteter laget for industrispesifikke produktivitetsanalyser gjennom EU KLEMS-prosjektet. Forskjellen mellom de to målene spores tilbake til OECDs bruk av valutakurser som kjøpekraftspariteter for relative netto eksportpriser. I en situasjon hvor landene som sammenlignes har ulik næringsstruktur og hvor bytteforholdet øker, slik Norge opplevde fra slutten av 1990 tallet, vil en prisstigning på eksportvarer feilaktig kunne gi seg utslag i høyere *målt* produktivitet. Ved å bruke kjøpekraftspariteter med basisår i 1997, før Norges bytteforholdsgevinster akselererte, måles produktiviteten i Norge til om lag å være på høyde med nivået i Sverige og Frankrike i 2005, men 7 og 3 prosent lavere sammenlignet med henholdsvis USA og Tyskland. I tillegg viser jeg at den høye vekstraten kan forklares med en empirisk modell som tar hensyn til utviklingen i både FoU kapital, humankapital og avstanden til teknologifronten. Basert på disse resultatene er det ingen grunn til å hevde at produktivitetsutviklingen i Norge har vært paradoksal.

1 Introduction

In standard economic textbooks on economic growth, such as Acemoglu (2009, p. 12), Jones and Vollrath (2013, p. 278), Weil (2013, p. 186) or Ros (2013, p. 410), we can read about measures indicating that Norway enjoys one of the highest levels of productivity in the world. Some of these measures, such as those provided by OECD, Penn World Table (Heston et al. 2012, Feenstra et al. 2013) and The Total Economy Database (The Conference Board 2014), are based on gross domestic product (GDP) for the whole economy and include petroleum extraction. Since much of petroleum extraction is the collection of economic rent, these measures overestimate the true level of productivity. That said, the level of productivity in Norway is still reported to be higher than in other countries when controlling for the petroleum extraction industry. For example, Statistics Norway reported the level of productivity to be between 20 and 30 per cent higher than in Denmark, Sweden, Finland, Germany and France in 2010, see Statistics Norway (2013, p. 46). Also, OECD reported the Norwegian GDP per worker in the mainland economy to be about 10 to 20 percent higher than in the abovementioned countries in 2005 (OECD 2007a, Figure 1.1.B, p. 19).

Such high productivity levels seem puzzling when compared with the relatively low aggregate level of R&D investments in Norway. As stated in the opening lines of OECDs Economic Survey: "There is a puzzle about Norway. How did it succeed in reaching one of the highest living standards among OECD countries from a relatively poor ranking in 1970?"(OECD 2007a, p. 18). It is not only the level of living standards, or productivity, that is high, but also the growth in productivity has been high in Norway. According to OECD "the Norwegian puzzle is that despite weak innovation inputs and even weaker outputs, Norwegian per capita incomes are very high by international comparison, even excluding petroleum earnings. Furthermore, the level and growth rate of total factor productivity – TFP – has been respectable by international comparison" (2007a, p. 125). Moreover, it is stated that "Productivity is high, real growth rates have been respectable, overall TFP growth is better than in many countries with higher R&D spending, and industry has by and large managed to survive a changing world and a strong exchange rate."(OECD 2007a, p. 129).

The purpose of this paper is twofold. The first aim is to analyse if the *level* of productivity in Norway is really as high as reported statistics suggest. I find that using Purchasing Power Parities (PPP) with a recent base year can significantly overestimate the level of productivity in Norway. The reason is that net exports is deflated directly in the calculation of overall expenditure PPPs (Eurostat and OECD 2012, Section 12.39). However, the contributions from exports and imports should be deflated separately since net exports can take upon both positive and negative values. Using export and import price indices relative to the US, I show that a separate deflation of exports and imports can account for most of the difference between constant and current PPPs between 1997 and 2010. When using PPPs with a base year in 1997, i.e., before the surge in Norway's terms of trade began, the productivity level in Norway is on par with the levels in Sweden and France in 2005, but around 7 and 3 percent lower than in the USA and Germany, respectively.

The second aim of the paper is to analyse if there is a puzzle underlying the relatively high productivity *growth* in Norway beginning in the mid 1990s. To analyse if the high growth rate represents a puzzle, I estimate a model that takes into account the level of human capital, R&D capital stock and the distance to the technological frontier by means of panel data techniques. The functional form of the model represents a hybrid between the models in Griffith et al. (2004), Cameron et al. (2005) and Coe et al. (2009). If there really is a puzzle about productivity in Norway one would expect the unexplained growth in productivity to be significantly higher in Norway compared with other countries. I show that unexplained productivity growth between 1995 and 2005 is quite evenly distributed across countries. For Norway the result is clearly within one standard deviation from the mean unexplained rate of TFP growth across countries. Thus, based on these results there is no reason to claim that the development of productivity in Norway represents a puzzle.

The rest of the paper is organised as follows. Related literature regarding both the level and growth in productivity in Norway is discussed in Section 2. In Section 3, the level of productivity in Norway is analysed, with a particular focus on the construction of PPPs. In Section 4, productivity growth in Norway from 1995 to 2005 is analysed. In this section, I outline the econometric framework and the main results are presented. The last section concludes.

2 Related Literature

The Norwegian productivity puzzle, sometimes also referred to as the Norwegian paradox, has spurred research trying to explain it. With this puzzle in mind, Grønning et al. (2008), Fagerberg et al. (2009) and Asheim (2012) point to different aspects of the Norwegian national system of innovation. In contrast, Castellacci (2008) claims that the source of the paradox lies not with innovative activities, but it has rather to do with the sectoral composition of the economy.

Several international studies analysing productivity use total GDP which includes the petroleum industry. Recently Feenstra et al. (2009) propose a new method to measure real GDP from the production side by modifying real GDP from the expenditure side to include differences in terms of trade between countries. Madsen et al. (2010) use aggregate data for Norway and show that R&D intensity, the interaction with distance to the frontier, educational attainment-based absorptive capacity, and technology gap positively influence TFP growth.

By focusing at the industry level the problems related to measuring productivity in the petroleum sector can be avoided. Griffith et al. (2004) analyse productivity across 15 manufacturing industries in a panel of OECD countries from the beginning of the 1970s to 1990. To convert value added in domestic currency to US dollars they use an economy wide PPP. However, since relative prices can vary greatly between countries and industries, using a common PPP across all industries could distort the estimate of the technological frontier. To account for this Griffith et al. (2004) also use disaggregated industry specific PPPs for 7 of the OECD countries in their sample, but not for Norway. For those countries where industry specific PPP data were not available they adjust the whole economy PPP by the average ratio across countries of the industry-specific to the whole economy PPP in a particular industry.

The studies by Griffith et al. (2004), Kneller (2005) and Kneller and Stevens (2006) were conducted using data on a limited set of manufacturing industries and the sample ended before the acceleration of Norway's productivity growth began. More recent data are needed to analyse the underlying causes of this surge in measured productivity growth.

Within the EU KLEMS project there has been extensive research efforts to provide production PPPs at the industry level. Inklaar and Timmer (2013) outline the procedure needed to adjust PPPs for final domestic demand to output PPPs and Inklaar and Timmer (2008) provide detailed information about the Productivity Level Database at the Groningen Growth and Development Centre. Unfortunately, data for Norway are currently not included in the Productivity Level Database. However, Timmer et al. (2006) did provide production PPPs at the industry level for the benchmark year 1997 also for Norway. These output PPPs are a mixture of adjusted expenditure PPPs and production PPPs where the weighting between the two methods is based on the quality and availability of data. The results from the present study are based on the production PPPs provided by Timmer et al. (2006).

3 Comparing the level of productivity across countries

In this section I analyse if the *level* of productivity in Norway, measured as GDP per hour worked, is really as high as reported statistics suggest. The analysis will focus on the choice of PPPs used to measure GDP in a common currency.

There are different concepts of PPPs that can be applied, for example current or constant PPPs. Current PPPs at time t refers to PPPs generated from a price survey at time t. In contrast, the term constant PPPs at time t refers to the PPPs from a price survey at a particular base year and then extrapolated to time t using relative temporal price indices between countries. When comparing productivity across countries over time it is constant PPPs that should be used since they capture volume changes only, whereas current PPPs capture both volume and price changes.

Since the level of productivity refers to the ratio of output to inputs in real terms, a PPP that yields the ratio of real value added (Y_{jt}/Y_{kt}) between country j and k at time t is preferred. To illustrate, let $P_{jt}Y_{jt}$ be value added measured in current prices in country j. If data on value added in current prices in both countries are available, the use of a purchasing power parity that represents the price ratio of value added between country j and k, $PPP_{jkt} = P_{jt}/P_{kt}$, yields the desired result

$$\frac{(P_{jt}Y_{jt})}{(PPP_{jkt})\,(P_{kt}Y_{kt})} = \left(\frac{Y_{jt}}{Y_{kt}}\right). \tag{1}$$

This expression illustrates that PPPs are not only price deflators, but also currency converters if value added in country j and k is measured in different currencies. Equation 1 also shows why an exchange rate is not suitable for comparisons of productivity: since an exchange rate fluctuates due to for example investors' sentiments, government intervention and capital flows between countries, there is no reason why an exchange rate should equal the price ratio of value added between the two countries at all time periods.

The measured level of productivity is directly impacted by the choice of PPPs when applying Equation 1. It is therefore important which PPP that is used for productivity analysis. In the following I will compare the PPPs provided by the Eurostat-OECD PPP Programme and a set of PPPs provided by Timmer et al. (2006). The purpose of the Eurostat-OECD PPP Programme is to create PPPs for value added across countries. Theoretically, they can be constructed from either the production or the expenditure side. Due to data availability they are constructed from the expenditure side and cover consumption, investment and net exports for the whole economy. These PPPs are suitable if the purpose is to study aggregate productivity. However, if the purpose is to analyse productivity at the industry level or to control for the impact from the petroleum industry, production PPPs at the industry level are required (Eurostat and OECD 2012, Section 1.2.2). Timmer et al. (2006) have made available a dataset with PPPs for industry output that includes Norway. It is constructed from both PPPs based on producer prices and on adjusted PPPs based on purchasers' prices. To derive an output price from a domestic expenditure prices they make adjustments for margins and taxes, international trade prices and an adjustment for intermediate consumption. They provide PPPs at a two digit industry level. To get PPPs at a more aggregate level, I follow their work and apply the Èltetö-Köves-Szulc (EKS) method to aggregate PPPs across industries and countries in the base year 1997.[1] The EKS method is also used to aggregate PPPs by OECD and Eurostat (2012). To calculate the PPPs from Timmer et al. (2006) for other years than the base year I extend the PPPs from the base year using the relative price index for value added between countries. More explicitly, for a given base year

[1]See the appendix, Section 6.1 for details regarding the computation of the EKS index.

$t = b$, the PPP between country j and country k, for all time periods t, is calculated as

$$PPP_{jkt} = PPP_{jkb} \frac{(P_{jt}/P_{jb})}{(P_{kt}/P_{kb})}. \tag{2}$$

where (P_{jt}/P_{jb}) and (P_{kt}/P_{kb}) is the temporal price indices for value added in country j and k, respectively. This way of constructing PPPs is often referred to as "constant PPPs" and it preserves the domestic volume growth rates when applying Equation 1 over time. Relative productivity is thus measured with respect to a constant base year b.

Figure 1 compares the expenditure PPP from OECD and the aggregated PPPs based on Timmer et al. (2006), both for all industries and when excluding the petroleum and computer industries.[2] The current expenditure PPP from OECD is converted to basic prices by multiplying with the relative ratio of GDP measured at basic and purchasers' prices between Norway and USA.[3] In 1997, the production PPP for all industries and the production PPP for all industries except petroleum and computers are 10.2 per cent and 6.8 per cent higher than the PPP from OECD, when measured by NOK/USD. Using the PPPs from Timmer et al. (2006) would thus lead to a lower measured relative level of productivity for Norway. Before 1995 there is a close correspondence between the PPPs provided by OECD and the PPPs based on Timmer et al. (2006). The reason why there is so little discrepancy between these series is due to how OECD has calculated the PPPs. Prior to 1995, PPPs for all countries have been backdated using the relative rates of inflation between countries as measured by their implicit price deflators for GDP.[4] The series labeled current PPPs by OECD thus represent constant PPPs prior to 1995. After 1998 there is a widening gap between the different measures of PPPs.

There are several potential explanations for the large gap between constant and current PPPs. It could be due to differences across countries in creating price indices and different frameworks in the creation of national accounts and in the creation of PPPs. For example, there are differences in how countries adjust for quality changes in the construction of price indices. Since the U.S. Bureau of Economic Analysis uses hedonic methods extensively to account for quality changes, the price changes in the U.S. GDP deflator will

[2] Isic Rev. 4 codes d05t09 (Mining and quarrying) and d26 (Computer, electronic and optical products). Mining and quarrying has been excluded since much of the value added from this industry is the collection of economic rent. To study relative productivity levels, the portion of an industry's value added being economic rent should be excluded. Excluding the computer, electronic and optical products industry does not change the overall picture much, but this industry has been excluded since for some countries, the growth in value added has been extremely high. It is therefore possible that differences in productivity for this industry are mainly caused by differences across countries in dividing the current price estimate into a price index and a constant price estimate. For example, the value added deflator in Sweden went from 52.7 in 1993 to 1 in 2005. From estimates based on the US intermediate input price deflators from semiconductors and microprocessors, Edquist (2005) concludes that the productivity growth of the Swedish Radio, television and communication equipment industry during the 1990s is an artefact.

[3] The PPP from OECD in basic prices NOK/USD is calculated as $PPP^B = PPP^P \left(\frac{GDP^B_{NOR}/GDP^P_{NOR}}{GDP^B_{USA}/GDP^P_{USA}}\right)$, where GDP is the value of gross domestic product and the superscripts P and B refer to purchasers' and basic prices, respectively.

[4] See www.oecd.org/std/ppp/faq.

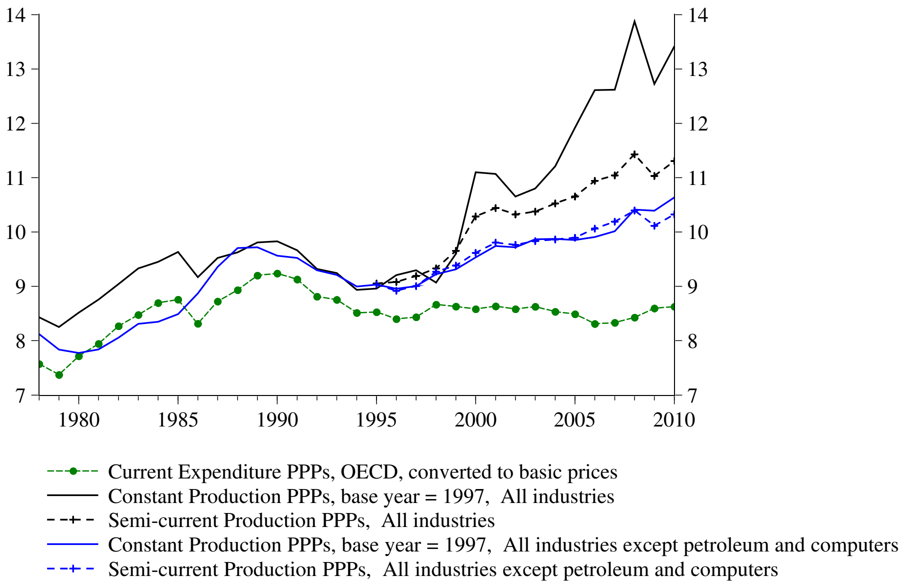


Figure 1 – Expenditure and production PPPs measured in basic prices, NOK/USD. Sources: OECD and Timmer et al. (2006), author's calculations. Constant Production PPPs are generated by first applying the EKS index at the lower industry level to create an aggregate PPP and then using Equation 2 to create a time series at the aggregate level. In contrast, the Semi-current Production PPPs are generated by first using Equation 2 to create time series for PPPs at the lower industry level, and then aggregate using the EKS index. The current expenditure PPP from OECD is converted to basic prices by multiplying with the relative ratio of GDP measured at basic and purchasers' prices between Norway and USA.

be lower than in countries not taking into account quality changes, all other things equal (McCarthy 2013), potentially causing a gap between extrapolated PPPs and current PPPs relative to the U.S. In the following, I will consider two other explanations for the large and widening gap: the so called "Tableau effect" and the treatment of net exports in the creation aggregate PPPs.

3.1 The Tableau effect

A potential reason for the widening gap is the difference in weighting schemes applied when constructing current and constant PPPs. If there are large differences in industry structure over time, the PPPs based on data in 2005 will potentially differ from the PPPs calculated in 1997 and extrapolated to 2005 using Equation 2. To illustrate, consider the following example: There are two goods and two countries, and the price of the two goods is the same in both countries at all time periods. Thus, the current PPP equals unity in all time periods. Further, assume that country j almost only produces one of the goods, say petroleum, and that the price of this good has increased by 5 per cent since the base year. As country j almost only produces petroleum, the aggregate price index is approximately equal to P_{jt}/P_{jb}= 1.05. Symmetrically, assume that the other good is almost only produced in country k and that the price is unchanged across time periods:

P_{kt}/P_{kb}= 1. In contrast to the spatial price index which yields a PPP equal to unity at time t, the constant PPP one gets from applying Equation 2 equals 1.05. The problem arises since current PPPs are based on common weights whereas constant PPPs are based on national weights. While current PPPs measure the aggregate relative price of the same goods in different countries, the constant PPPs are also influenced by price changes of the goods that countries produce relatively much or little of. This example illustrates how the choice of currency converter for productivity analysis typically depends on the base year chosen, a well known result dubbed the "tableau effect" by Summers and Heston (1991, p. 340). Unfortunately, it is not possible to measure the size of the tableau effect directly since current production PPP data are not available. However, it is possible to construct a semi-current production PPP from a two digit industry level using the data from Timmer et al. (2006). As pointed out above, the construction of constant PPPs was done in two steps: first applying the EKS index at the lower industry level and then using Equation 2 to create a time series at the aggregate level. In contrast, the semi-current production PPPs is generated by first using Equation 2 to create time series for PPPs at the lower industry level, and then aggregate using the EKS index. Any price structure shift at the lower industry level is then accounted for.

Figure 1 shows semi-current production PPPs for both all industries and all industries except petroleum and computers measured in Norwegian Kroner per US dollars. The deviation between the constant and semi-current PPPs for all industries is large, reflecting the sizeable increase in the petroleum price after 2000. In contrast, for most of the years the deviations between the constant and semi-current PPPs when subtracting the petroleum and computers industries are within 1 per cent. The change in price structure between industries at the two-digit level is therefore not able to explain the difference between constant and semi-current PPPs. This robustness check points to a different explanation for the increasing discrepancy between the constant production PPPs and the current expenditure PPPs after 2000.

3.2 The nominal exchange rate as a proxy for relative net exports prices

Another explanation for the widening gap between constant and current PPPs relates to how net exports is treated in the construction of current expenditure PPPs. The contribution from net exports to the total PPP is based on the assumption that market exchange rates can be used to value net exports (Eurostat and OECD 2012, Section 12.39). To be precise, the contribution from net exports (NX) is calculated as

$$1/2\left(s_{jt}^{NX}+s_{kt}^{NX}\right)\ln(PPP_{jkt}^{NX}) \tag{3}$$

where $s^{NX}=\frac{P^X X-P^M M}{PY}$ represents the share of net exports in GDP measured in current prices and where the official exchange rate is used to proxy relative net export prices PPP_{jkt}^{NX}. Using exchange rates to proxy relative net export prices is a strong assumption since the construction of a net export price index does not have the consistency in aggregation property.[5] When import and export prices have different growth rates, the aggregate net export price index may show little correspondence with how terms of trade develop. The reason is that net exports can take upon both positive and negative values. As pointed out by Diewert (2005, p. 12): "...normal index number theory fails spectacularly as a value aggregate approaches zero". It is only in the extreme case where relative import and export prices between countries both follow the exchange rate that the procedure used to create official PPPs is valid. To illustrate, consider the Törnqvist PPP index for net exports between countries j and k

$$\ln(PPP_{jkt}^{NX}) = 1/2\left(\tilde{s}_{jt}^{X} + \tilde{s}_{kt}^{X}\right)\ln(PPP_{jkt}^{X}) - 1/2\left(\tilde{s}_{jt}^{M} + \tilde{s}_{kt}^{M}\right)\ln(PPP_{jkt}^{M}), \tag{4}$$

where the superscripts X and M refer to exports and imports, respectively, and where $\tilde{s}^X$ and $\tilde{s}^M$ represents the export and import share of net exports measured in current prices, i.e., $\tilde{s}^X = \frac{P^X X}{P^X X - P^M M}$ and $\tilde{s}^M = \frac{P^M M}{P^X X - P^M M}$, respectively. To calculate the total impact from net export prices to PPP_{jkt} for GDP, the index (Equation 4) must be weighted with the mean share of net exports in GDP between the two countries. Accordingly, inserting Equation 4 into Equation 3 yields

$$\begin{aligned} 1/2\left(s_{jt}^{NX} + s_{kt}^{NX}\right)\ln(PPP_{jkt}^{NX}) = {} & 1/4\left(s_{jt}^{NX} + s_{kt}^{NX}\right)\left(\tilde{s}_{jt}^{X} + \tilde{s}_{kt}^{X}\right)\ln(PPP_{jkt}^{X}) \\ & - 1/4\left(s_{jt}^{NX} + s_{kt}^{NX}\right)\left(\tilde{s}_{jt}^{M} + \tilde{s}_{kt}^{M}\right)\ln(PPP_{jkt}^{M}). \end{aligned} \tag{5}$$

In contrast to the seminal result from Diewert (1978), where it was shown that the Törnqvist index is approximately consistent in aggregation, the two-step procedure in Equation 5 is not consistent in aggregation. While the value aggregates in Diewert (1978) were of the same sign, the net export figure in Equation 5 can take on both positive and negative values, possibly yielding very different results compared with a one-step procedure, see also IMF et al. (2009, p. 468). Ideally, if data on relative export and import prices between countries are available, the contribution from net exports should be calculated as the separate sum of contributions from exports and imports

$$1/2\left(s_{jt}^{X} + s_{kt}^{X}\right)\ln(PPP_{jkt}^{X}) - 1/2\left(s_{jt}^{M} + s_{kt}^{M}\right)\ln(PPP_{jkt}^{M}), \tag{6}$$

[5] An index is *consistent in aggregation* when "the index for some aggregate has the same value whether it is calculated directly in a single operation, without distinguishing its components, or it is calculated in two or more steps by first calculating separate indices, or sub-indices, for its components, or subcomponents, and then aggregating them, the same formula being used at each step" (OECD 2007b, p. 136).

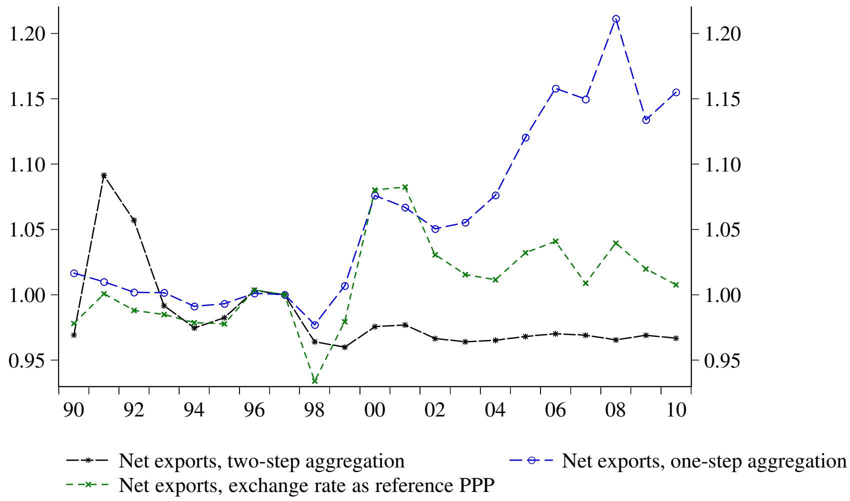


Figure 2 – Contribution to changes in bilateral PPPs between Norway and USA. Source: OECD, author's calculations. Relative export and import price indices between the USA and Norway are used in Equation 5 and Equation 6 to calculate *Net exports, two-step aggregation* and *Net exports, one-step aggregation* respectively. The series *Net exports, exchange rate as reference PPP* is calculated as $1/2(s^{NX}_{NOR} + s^{NX}_{USA})\ln(EX_{NOR,USA})$, where EX is the official exchange rate between Norway and USA. All series are normalised to unity in 1997.

where s^X and s^M represents the export and import shares of GDP measured in current prices, i.e., $s^X = \frac{P^X X}{PY}$ and $s^M = \frac{P^M M}{PY}$, respectively. There is no particular reason why the calculation from the one-step procedure (Equation 6) should equal the two-step aggregation procedure (Equation 5) since the weights in the two expressions can be very different. Only if $PPP^X_{jkt} = PPP^M_{jkt}$ will the two methods be equal irrespective of the weights. If the exchange rate perfectly reflects the relative price of both exports and imports, the procedure used by Eurostat and OECD to aggregate PPPs is therefore valid. However, if the exchange rate does not perfectly reflect the relative price of both exports and imports, the two methods can yield very different results. To illustrate, compare the export weights $1/2\left(s^X_{jt} + s^X_{kt}\right)$ with the weights from the two-step procedure $1/4\left(s^{NX}_{jt} + s^{NX}_{kt}\right)\left(\tilde{s}^X_{jt} + \tilde{s}^X_{kt}\right)$ for Norway and the USA. The export share s^X in 2010 was 0.41 in Norway and 0.12 in the USA, which yields an average export share equal to 0.26. The export share out of net exports $\tilde{s}^X$ in Norway was 3.39 and it was -3.55 in the USA, reflecting a negative trade balance. Since one country is running a trade surplus and the other country is running a trade deficit, the mean of these export shares can be close to zero. In this case the mean was -0.08. To get the overall weight, this number must be multiplied with the mean net export share of total GDP. In Norway the net export share was 0.12 and in the USA it was -0.03, which yields a mean equal to 0.05. The aggregate product of mean net export shares and mean export shares then equals -0.003. As a result, the export price growth in the two-step approach in Equation 5 is given negligible (and negative) weight compared with the one-step approach in Equation 6.

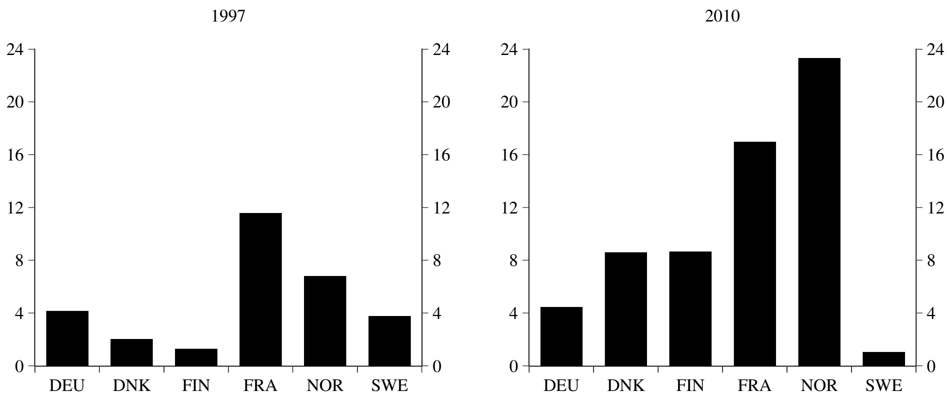


Figure 3 – Difference between constant production PPPs and current expenditure PPPs in 1997 and 2010, per cent. Sources: OECD and EU KLEMS, author's calculations. The constant production PPPs are from Timmer et al. (2006) and aggregated over all industries except petroleum and computers. PPPs are measured in local currency per USD at basic prices, i.e., USA=1. The current expenditure PPP from OECD is converted to basic prices by multiplying with the relative ratio of GDP measured at basic and purchasers' prices between Norway and USA.

Figure 2 compares the results from applying Equation 5 and Equation 6 when relative export and import price indices are used as proxies for $PPP^X_{NOR,USA}$ and $PPP^M_{NOR,USA}$. The two-step aggregation procedure (Equation 5) yields by all practical means no contribution to aggregate PPP after 1999. In contrast, the one-step aggregation (Equation 6) shows that net exports contributes to a 16 per cent higher PPP in 2010 compared with the level in 1997. For the sake of comparison, the semi-current production PPP for all industries given in Figure 1 was 24 per cent higher than the official current PPP published by OECD in 2010. Figure 2 also shows the contribution to changes in PPPs when using the official exchange rate as a reference PPP for net exports (Equation 3). The volatility of the series between 1997 and 2002 reflects the large changes in Norway's net export share during this time span. In 2010 the level was on par with the value in 1997, indicating that using the exchange rate as reference PPP has not contributed to the aggregate PPP between Norway and USA between 1997 and 2010. The relative price indices for exports and imports might be poor proxies for the development of relative export and import prices (due to the tableau effect). Nevertheless, since index theory fails when value aggregates approaches zero, the results from Figure 2 point to the aggregation of net exports as a potential important cause underlying the widening gap between current and constant PPPs.

3.3 Is the first premise of the Norwegian productivity puzzle real?

As noted in the introduction, the first premise of the Norwegian productivity puzzle is the high measured level of productivity in Norway. Several issues treated above have shed new light on this premise. It has been shown that how net exports are treated by Eurostat and OECD in the calculation of overall PPPs can be the cause of the widening gap between constant production PPPs and current expenditure PPPs after 1998. As a result, using current expenditure PPPs instead of production PPPs can lead to significant overestimation of the level of productivity, as illustrated in Figure 3.[6] It shows the ratio of expenditure PPPs to production PPPs across countries in 1997 and 2010. In the basis year 1997 the difference is positive for all countries, indicating that productivity is overrated when using the PPPs calculated from the expenditure side. The difference is most pronounced in France at 11.6 per cent and for Norway the difference is 6.8 per cent. For all countries but Sweden, the difference between the current expenditure PPP in 2010 and the constant production PPP in 2010 has increased, in particular for Noway. This general increase across most countries should be viewed in conjunction with how hedonic regressions are widely used by the U.S. Bureau of Economic Analysis to control for quality changes. In the specific case of Noway, however, the increase has been particularly large. As a result, using constant production PPPs from Timmer et al. (2006) to evaluate productivity in 2010 yields a 23.3 per cent lower level of productivity in Norway compared with using current expenditure PPPs. The first premise of the Norwegian productivity puzzle can thus be an artifact of the choice of PPPs and the strong assumption that exchange rates are a good proxy for relative net export prices.

Figure 4 shows levels of labour productivity across countries, measured as value added per hour worked in all industries except petroleum and computers, converted from domestic currency to US dollars using constant production PPPs from Timmer et al. (2006). In the 1970s, the level of labour productivity in Norway was 28 per cent below the level in the USA, 7 per cent below the level in Sweden and 4 per cent below the level in Denmark, but 30 per cent higher than in Finland. During the 1980s the growth in labour productivity was lower than in most of the other countries, but in the mid 1990s, growth picked up. By 2005, the level of labour productivity in Norway was at par with the levels in Sweden and France, and the distance to the level in the USA had shrunk to 7 per cent. In contrast to the first premise of the Norwegian productivity puzzle, Figure 4 illustrates that Norway is not particularly productive compared with the USA, Germany, Sweden and France when measured by production PPPs, although performance has been good from the mid 1990s.

4 Comparing productivity growth across countries

In the previous section it was shown that when using constant production PPPs from Timmer et al. (2006) the level of productivity in Norway is on par with the level in Sweden and France and somewhat lower than

[6] Recently, Warner et al. (2014) shows how the use of PPPs with different benchmark years impacts the level and trend of global inequality.

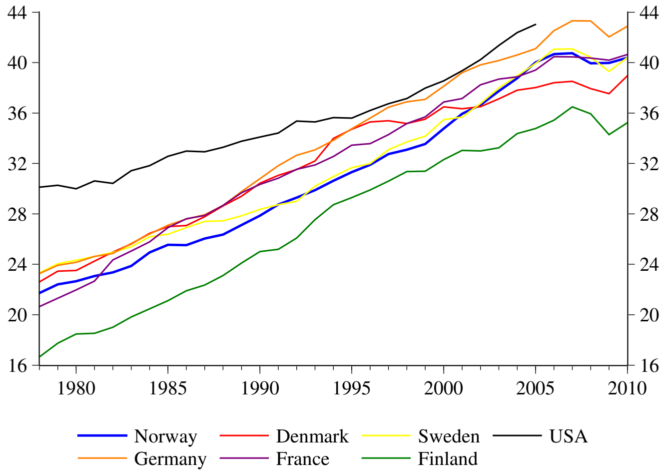


Figure 4 – Value added per hour worked. Sources: OECD and EU KLEMS, author's calculations. Measured in basic prices and USD using constant production PPPs from Timmer et al. (2006). All industries except petroleum and computers.

in the USA and Germany. Nevertheless, except for Sweden, trend productivity growth was somewhat higher from the mid 1990s. In light of moderate R&D spending, is the development in Norway still a puzzle? In this section, I answer this question by estimating a model suitable for identifying the role of technology transfer, R&D capital and human capital for productivity growth across countries.

4.1 Econometric specification

In this section I outline the basis for the econometric model. Value added Y_{ijt} in industry i in country j at time t is produced with labour L_{ijt} and capital K_{ijt} according to the production technology

$$Y_{ijt} = A_{ijt} F_{ij}(L_{ijt}, K_{ijt}), \tag{7}$$

where the function $F_{ij}(\cdot)$ is assumed to be homogenous of degree one and to exhibit diminishing marginal return to each factor. A_{ijt} is an index for total factor productivity (TFP) and is allowed to vary across industries, countries and time. The country with the highest level of TFP in industry i at time t is defined as the frontier country, denoted by A_{iFt}.

The starting point of the analysis is the literature connecting the index for TFP (A_{ijt}) with R&D and the level of technology at the frontier. I employ a model that is a combination of the ones used by Griffith et al. (2004), Cameron et al. (2005) and Coe et al. (2009). Griffith et al. (2004) and Cameron et al. (2005) modelled TFP growth as a function of the distance to the technology frontier and R&D intensity, among other things. In contrast to Griffith et al. (2004), who focused on the rate of change in TFP, Coe et al. (2009)

analysed the level of TFP. The level was modelled as a function of both the domestic R&D capital stock and the foreign R&D capital stock. The starting point of the model used in the current paper is a specification where TFP in levels (log transformed) in industry i of country j is a function of both the TFP level in the frontier industry A_{iFt}, the R&D capital stock R_{ijt}, and human capital S_{ijt}, proxied by high skilled workers' share in total hours worked

$$\ln A_{ijt} = c_{ij} + \eta_{ijt} \ln R_{ijt} + \gamma_{ijt} \ln A_{iFt} + \phi S_{ijt}. \tag{8}$$

Both elasticities of TFP with respect to TFP in the frontier country (γ_{ijt}) and R&D (η_{ijt}) are time varying. A constant elasticity of TFP with respect to R&D is "not consistent with any reasonable optimal R&D behaviour" if there are large differences in the R&D intensity (Griliches 1998, p. 221). A more reasonable assumption is to let the real rate of return $\tilde{\eta} = \partial Y_{ijt}/\partial R_{ijt}$ be common across industries. Also, the extent to which the level of TFP depends on the frontier level of TFP is time dependant. It is reasonable to expect the potential for technology transfer to be greater when the distance to the frontier is large. To be specific, γ_{ijt} should go towards zero when the productivity level goes towards the productivity level in the frontier. One functional form that satisfies this criterion is $\gamma_{ijt} = \tilde{\gamma} \ln(A_{iF,t-1}/A_{ij,t-1})$. Inserting this relationship and the relationship that the elasticity of R&D equals the product of the real return of R&D and the R&D intensity ($\eta_{ijt} = \tilde{\eta}\ R_{ijt}/Y_{ijt}$) back into Equation 8 yields the equilibrium relationship

$$\ln A_{ijt} = c_{ij} + \tilde{\eta} \ln \tilde{R}_{ijt} + \tilde{\gamma} \ln \tilde{A}_{iFt} + \phi S_{ijt}. \tag{9}$$

where I have defined the auxiliary variables

$$\tilde{R}_t = e^{(R_{ijt}/Y_{ijt}) \ln R_{ijt}} \quad \text{and} \quad \tilde{A}_{iFt} = e^{\ln(A_{iF,t-1}/A_{ij,t-1}) \ln A_{iFt}}.$$

The model will be estimated using a panel of annual data for seven OECD countries spanning 1978 - 2007. To analyse if productivity growth in Norway represents a puzzle I compare the unexplained level of productivity growth in Norway between 1995 and 2005 with the unexplained productivity growth in Sweden, Denmark, Finland, France, Germany and the USA.

4.2 Data description

Data are taken from the OECD STAN database, the EU KLEMS database and Statistics Norway. Data on value added, hours worked, labour compensation, the capital stock, etc. are for Norway, Sweden, Denmark, Finland, Germany and France taken from the OECD STAN database. The only exception is the construction and the Wholesale and retail trade industry in Norway, where data are taken from Statistics Norway. For USA, the National Accounts data by industry are taken from the EU KLEMS database where data from both the 2008 and 2009 release have been used, see O'Mahony and Timmer (2009). Data sources are thus consistent within these countries, but vary between USA and the other countries. The exception is data on hours worked and labour compensation for different educational groups. These data are taken from EU KLEMS for all countries but Norway, where data are taken from Statistics Norway. There are some discrepancies between the industry classification for educational data and the ISIC Rev. 4 classification. For example, the Norwegian data exclude the *Transport via pipelines* industry from the aggregate transportation industry. Also, companies and organisations that are labeled as private enterprises within the *Public administration and defence*; *education*; *human health and social work activities* (D84t88) are a part of the *Other services* industry in the Norwegian data. Also, data for Sweden and Germany have been extrapolated backwards using the growth rates from the EU KLEMS database. Purchasing power parities for gross fixed capital formation are taken from OECD and Eurostat (2008). EU KLEMS data and OECD data for France have been mapped from the ISIC Rev. 3 classification to ISIC Rev. 4 classification using the approximate 2-digit mapping provided in The OECD Compendium of Productivity Indicators 2013 (OECD 2013, Annex D), see also the appendix, Section 6.4. Data from EU KLEMS (USA) and OECD ISIC Rev. 3 (FRA), such as value added and gross production, have been extrapolated with growth rates from the OECD STAN ISIC Rev. 4 database if the variables were available. Population and employment data are taken from the Labour force survey (LFS). For Germany data have been extrapolated assuming a constant level between 1990 and 1991 and using the growth rates from LFS prior to 1990 to extend the series backwards in time.

R&D investments are taken from the OECD database ISIC Rev 4. For many countries, R&D surveys have not been completed every year. Log linear interpolation has been used to impute missing observations. Nominal R&D expenditure has been extrapolated backwards using the growth rate from both OECD ISIC Rev. 3 data and ISIC Rev.2 data, see the appendix, Section 6.3. For Denmark and Sweden the levels from the ISIC Rev. 2 data have been used. The R&D deflator is the output price index from the R&D sector (D72) if it was available, otherwise the R&D deflator from the Main Science and Technology Indicators by OECD is used. If the output price index from the R&D sector was available it has been extrapolated using the growth rate from the R&D deflator in the Main Science and Technology Indicators. To get a measure of R&D capital in industry i of country j (R_{ijt}) I apply the Perpetual Inventory Method

$$R_{ijt} = (1 - \delta)R_{ij,t-1} + I_{ijt}, \tag{10}$$

where I_{ijt} is real R&D investments constructed from nominal R&D investments and the R&D deflator using the product rule[7] and where I have used the depreciation rate $\delta = 0.15$ and the initial condition $R_{ij0} = I_{ij0}/(\delta + 0.05)$ by following Hollanders and ter Weel (2002, p. 588). Table 1 shows the median R&D intensity, defined as the ratio of real R&D investments to value added (I_{ijt}/Y_{ijt}), between 2005 and 2010 across industries and countries. The R&D intensity in Manufacturing in Norway is roughly half the mean intensity in the other countries. A low level of R&D intensity is consistent with the low level of productivity growth in manufacturing. Overall, the R&D intensity in Manufacturing is much higher than in the other industries. The R&D intensity in Information and communication is also relatively high in all countries. In the Wholesale and retail trade industry however, it is below unity in all countries. The puzzling productivity growth in this industry for Norway can therefore not be explained by the level of R&D investments. The total R&D intensity in Norway, calculated as a weighted average of the industry specific intensities using value added shares as weights, is 2.0 per cent. All of the other countries have a higher total R&D intensity, where the highest is in Finland and Sweden at 4.6 per cent. The low overall R&D intensity in Norway is thus partly a result of a low R&D intensity in manufacturing in combination with manufacturing accounting for a lower share of total value added in Norway than in the other countries.

To get a measure for the distance to the frontier I apply the spatial productivity index suggested by Caves et al. (1982)

$$\ln A_{ij} - \overline{\ln A_i} = \left(\ln Y_{ij} - \overline{\ln Y_i}\right) - 1/2(s_{ij}^K + \overline{s_i^K})\left(\ln K_{ij} - \overline{\ln K_i}\right) - 1/2(s_{ij}^L + \overline{s_i^L})\left(\ln L_{ij} - \overline{\ln L_i}\right), \qquad (11)$$

where Y_{ij}, K_{ij}, L_{ij} and s_{ij} represent value added, the net capital stock, hours worked and the factor shares respectively. $\overline{\ln Y_i}$, $\overline{\ln K_i}$ and $\overline{\ln L_i}$ are the geometric means of value added, the net capital stock and hours worked across $n = 7$ countries, e.g., $\overline{\ln Y_i} = \frac{1}{n}\sum_{j=1}^{n} \ln Y_{ij}$, and $\overline{s}_i$ is the arithmetic mean of the respective factor share across countries, i.e., $\overline{s_i} = \frac{1}{n}\sum_{j=1}^{n} s_{ij}$. The frontier A_{iF} is defined as the country with the highest index value $\left(\ln A_{ij} - \overline{\ln A_i}\right)$ in any given time period. An industry's distance to the frontier is measured by $\left(\ln A_{ij} - \overline{\ln A_i}\right) - \left(\ln A_{iF} - \overline{\ln A_i}\right) = (\ln A_{ij} - \ln A_{iF})$ in a given base year.

In Figure 5, the development of industry productivity is shown relative to USA $(A_{i,j,t}/A_{i,USA,t})$ between 1978 and 2007 for Manufacturing and Wholesale and retail trade. In Manufacturing, the USA was the frontier country for most of the time period. All countries but Denmark and Norway show a tendency for convergence. The productivity level in Norway has been between 60 and 70 per cent below the productivity level in the USA during this time period. In contrast, Finland has shown a great surge in relative productivity growth, a development that should be viewed in relation to the development of the mobile phone producer Nokia during this time period. The development in Wholesale and retail trade differs from Manufacturing

[7] The product rule refers to the identity of a value ratio being equal to a price ratio times a quantity ratio, see Frisch (1930).

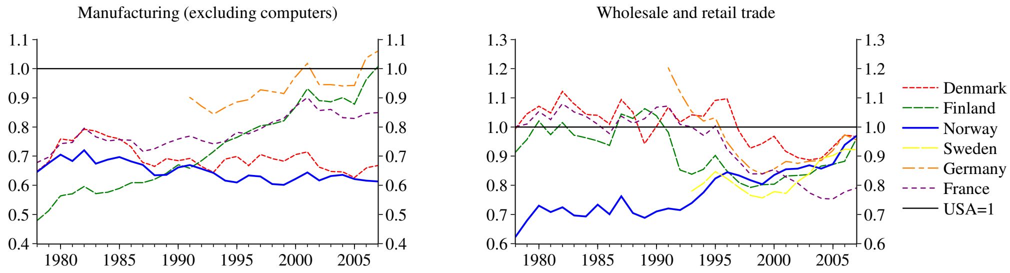


Figure 5 – Comparing TFP levels across countries. Sources: OECD and EU KLEMS, author's calculations. The figure illustrates the TFP levels of industry i in country j relative to industry i in the USA, i.e., $(A_{ij}/A_{i,USA})$.

in several respects. While the USA was by far the technology leader in Manufacturing in the 1980s, almost all countries were at the level of USA in Wholesale and retail trade. The exception is Norway. In 1978 the relative productivity level was 60 per cent compared with the USA. At that time there were not many chain stores and not many shopping malls in Norway.[8] From a state of great inefficiency, Norway has had surge in productivity growth, even when compared to the USA which growth were much higher than in Europe during the 1990s. In 2007 the productivity in Norway is at level of Sweden, Denmark, and Germany, but still about 3 per cent lower than in the USA. Table 1 shows productivity levels across industries. There are large variations in productivity levels across countries. Except for the Wholesale and retail trade and Information and communication industries, the technology level in Norway is about 45 to 65 per cent of the technology leader. Interestingly, with the exception of these two industries, the other countries are ahead of Norway in most of the other industries. One exception is the low level of productivity in Germany in Financial and insurance activities.

Table 1 also shows the share of high skilled labour in total hours worked. Due to different education systems the definition of high and low skilled varies across countries. In Norway, labour with no formal qualifications, primary eduction, secondary school (excluding vocational eduction) or unknown are defined as low skilled. Labour with either vocational or tertiary education are defined as high skilled. For the remaining countries high skilled are defined by: long to short-cycle higher education and vocational education and training in Denmark, postgraduates, undergraduates, higher and intermediate vocational in Sweden, university graduates, higher education below degree, low intermediate and vocational education in France, tertiary schooling (or parts thereof), upper secondary level with or without matriculation in Finland and university graduates and intermediate education in Germany (Timmer et al. 2010, Table 3A.4, includes both high and medium skilled). The difference in educational systems and the different definitions of high

[8]The first chain store *Jernia* was established around 1960 and what was referred to as the first shopping mall *Eiksmarka senter* was established in 1953. But the surge in shopping malls began first in the late 1980s and in the 1990s (Rasmussen and Reidarson 2007).

Table 1 – Descriptive statistics

	NOR	USA	DNK	SWE	FRA	FIN	DEU
TFP as Proportion of Frontier TFP (per cent)[a]							
Agriculture, forestry and fishing	51.5	100	79.5	93.2	55.7	36.3	85.8
Manufacturing	47.2	92.4	48.9	99.3	67.2	98.5	79.6
Construction	78.5	64.9	71.6	63.5	71.0	100	69.0
Wholesale and retail trade	95.4	100	89.9	88.0	76.8	94.4	96.1
Transportation and storage	51.8	100	64.5	61.8	78.2	83.8	69.1
Information and communication	98.3	100	62.2	94.6	n/a	60.1	71.6
Financial and insurance activities	61.2	88.1	100	86.1	71.3	78.3	37.2
Total	69.6	92.1	72.5	88.5	64.3	87.9	76.8
R&D intensity[b]							
Agriculture, forestry and fishing	1.7	n/a	0.3	n/a	0.3	0.0	0.5
Manufacturing	4.7	10.4	9.9	12.5	7.0	10.2	7.7
Construction	0.5	0.2	0.0	0.2	0.1	0.3	0.1
Wholesale and retail trade	0.3	0.2	0.6	0.0	0.5	0.4	0.1
Transportation and storage	0.1	0.0	0.2	n/a	0.1	0.2	0.1
Information and communication	4.7	5.9	7.1	n/a	3.0	4.5	2.0
Financial and insurance activities	1.2	0.1	2.0	0.5	0.2	1.5	0.2
Total	2.0	3.7	3.0	4.6	2.3	4.6	3.5
Share of high skilled in total hours worked[c]							
Agriculture, forestry and fishing	54.5	n/a	45.8	69.4	70.3	73.7	57.7
Manufacturing	61.3	n/a	67.5	79.7	76.4	79.1	73.5
Construction	61.4	n/a	68.7	77.8	69.5	75.5	70.9
Wholesale and retail trade	43.8	n/a	66.0	78.7	80.7	77.2	66.4
Transportation and storage	51.6	n/a	61.2	82.6	76.9	70.1	66.4
Information and communication	72.3	n/a	27.9	n/a	21.8	23.0	17.7
Financial and insurance activities	54.5	n/a	89.3	95.9	95.0	84.0	89.0
Total	55.1	n/a	63.5	74.0	74.1	72.8	67.7

Sources: OECD, Statistics Norway and EU KLEMS, author's calculations. Sample: 2005 – 2010, medians.

[a] Defined as $100 \times (A_{ij}/A_{iF})$, where A_{ij} is TFP in industry i in country j and where A_{iF} is TFP in the frontier country. (A_{ij}/A_{iF}) is calculated using the spatial productivity index in Caves et al. (1982), see Equation 11. *Total* is calculated as a weighted average across industries where the weights are value added shares.

[b] Calculated as the ratio of real R&D investments to real value added. *Total* is calculated as a weighted average across industries where the weights are value added shares.

[c] For Norway, labour with either vocational or tertiary education are defined as high skilled. For the remaining countries high skilled are defined as DNK: Long to short-cycle higher education and vocational education and training, SWE: Postgraduates, undergraduates, higher and intermediate vocational, FRA: University graduates, higher education below degree, low intermediate and vocational education, FIN: Tertiary schooling (or parts thereof), upper secondary level with or without matriculation, DEU: University graduates and intermediate education, see Timmer et al. (2010, Table 3A.4, includes both high and medium skilled). *Total* is calculated as a weighted average across industries where the weights are shares in total hours worked.

skilled means that the high skill share in total hours worked is not directly comparable across countries. Equation 9 is therefore estimated both with and without the human capital variable. Nevertheless, there are important differences across countries. The largest share of high skilled can be found in the Information and

Table 2 – Panel unit root tests

	TFP	R&D	TFP–frontier	Skill intensity
Levin et al. (2002)[a]	2.24	0.81	-15.38**	1.78
	(0.99)	(0.79)	(0.00)	(0.96)
Breitung (2000)[b]	6.58	1.96	0.46	1.76
	(1.00)	(0.97)	(0.68)	(0.96)
Hadri (2000)[c]	17.95**	14.07**	11.23**	14.22**
	(0.00)	(0.00)	(0.00)	(0.00)

Sample: 1977 – 2008, 7 countries, 6 industries. The 10 and 5 per cent significance levels are marked with * and **, respectively. p–values in parenthesis. The TFP variable is defined by $\ln A_{ijt}$. The R&D and TFP–frontier variables are defined by the auxiliary variables $\tilde{R}_t = e^{(R_{ijt}/Y_{ijt}) \ln R_{ijt}}$ and $\tilde{A}_{iFt} = e^{\ln(A_{iF,t-1}/A_{ij,t-1}) \ln A_{iFt}}$, where R, Y and A represent R&D investments, value added and TFP, respectively, and where the index F denotes the frontier country with the highest level of TFP. Skill intensity is defined by high skilled workers' share in total hours worked. Countries included: USA, Germany, France, Finland, Sweden, Denmark and Norway. Industries included: Manufacturing (only for Norway, Denmark, France and Germany); Construction; Wholesale and retail trade; Transportation and storage; Information and communication; and Financial and insurance activities.
[a] Null hypothesis: Unit root.
[b] Null hypothesis: Stationarity.

communication industry in Norway. In contrast, in all other countries, this industry has the lowest share of high skilled. Also, the high skill share in both Wholesale and retail trade and in Financial and insurance activities is lower in Norway than in the other countries. In all countries but Norway, the largest high skill share can be found in the Financial and insurance activities.

4.3 Results

Before estimating the long run relationship in Equation 9, the variables are tested for unit roots and cointegration. Three different types of unit root tests are conducted, based on the methods in Levin et al. (2002), Breitung (2000) and Hadri (2000), see Table 2. All variables shows sign of unit roots. In the first two tests the null hypothesis is that the series contain a unit root, whereas in Hadri (2000) the null hypothesis is that the series are stationary. Except for the test of the frontier variable $\ln \tilde{A}_{iFt}$ using the method in Levin et al. (2002), none of the tests reject the null hypothesis of a unit root. Both the Breitung (2000) test and the Hadri (2000) test point to a unit root also in the frontier series $\ln \tilde{A}_{iFt}$.

Tests for cointegration among the variables (Pedroni 1999) are based on a pooled sample and by imposing both a deterministic intercept and trend, see Table 3. These tests indicate that the series are cointegrated. The evidence is weakest for the panel ρ-statistic, where the null hypothesis of no cointegration cannot be

Table 3 – Panel cointegration tests

	Panel v	Panel ρ	PP	ADF
TFP, R&D	13.48**	0.89	-0.33	-1.45*
TFP, R&D, TFP–frontier	12.81**	1.26	-2.26**	-3.79**
TFP, R&D, TFP–frontier, Skill intensity	2.11**	2.01	-2.67**	-4.07**

Sample: 1977 – 2008, 7 countries, 6 industries. Pedroni (1999) cointegration tests, assuming both a deterministic intercept and trend. The 10 and 5 per cent significance levels are marked with * and **, respectively. The null hypothesis of no cointegration is rejected if the test statistic is significant. The TFP variable is defined by $\ln A_{ijt}$. The R&D and TFP–frontier variables are defined by the log of the auxiliary variables $\tilde{R}_t = e^{(R_{ijt}/Y_{ijt})\ln R_{ijt}}$ and $\tilde{A}_{iFt} = e^{\ln(A_{iF,t-1}/A_{ij,t-1})\ln A_{iFt}}$, where R, Y and A represent R&D investments, value added and TFP, respectively, and where the index F denotes the frontier country with the highest level of TFP. Skill intensity is defined by high skilled workers' share in total hours worked. Countries included: USA, Germany, France, Finland, Sweden, Denmark and Norway. Industries included: Manufacturing (only for Norway, Denmark, France and Germany); Construction; Wholesale and retail trade; Transportation and storage; Information and communication; and Financial and insurance activities.

rejected at the 10 per cent significance level. However, the three other tests all reject the null hypothesis of no cointegration at least at the 10 per cent significance level, with the only exception for the PP test between the TFP and the R&D variable. Interestingly, the evidence is stronger in the specifications that includes the distance to the frontier and the share of high skilled labour (S_{ijt}). These results suggest that a stable long-run relation can be estimated using a pooled estimation technique.

Three different models are estimated and the results are reported in Table 4. Dynamic OLS (DOLS) has been used to estimate both models. This estimator was suggested by Saikkonen (1991) and it has been commonly used in the literature, see e.g., Kao et al. (1999) and Coe et al. (2009). In contrast to the standard OLS estimator, the DOLS estimator controls for both serial correlation and endogeneity among the regressors, and in Monte Carlo experiments it also outperforms the Fully Modified OLS estimator, see Kao and Chiang (2000). It is a suitable estimator also when the time series are dependant across industries since the data is demeaned over the cross-section dimension before the augmented cointegrating regression is estimated, see Mark and Sul (2003, p. 668).

Only the R&D variable enter as explanatory variable in Model 1. The estimated return to R&D, estimated to 5 per cent, is significant at the 5 per cent significance level. An estimated return to R&D of 5 per cent is lower than what is found in many other studies. As shown in Hall et al. (2010) there is great variation in estimated returns to R&D, but most studies find rate of returns larger than 10 per cent. One exception is the study by Parisi et al. (2006) who estimate the return of R&D to approximately 4 per cent using Italian

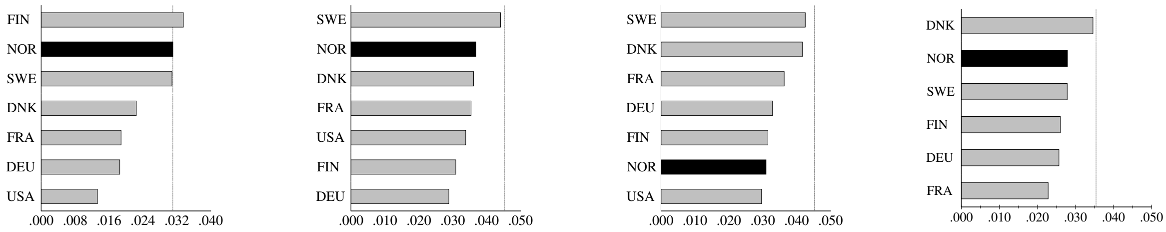
Table 4 – Estimation results

	Model 1	Model 2	Model 3
R&D	0.05**	0.05**	0.00
	(0.01)	(0.01)	(0.01)
TFP–frontier		0.80**	0.92**
		(0.14)	(0.16)
Skill intensity			0.95**
			(0.09)
Standard error	0.12	0.11	0.09
R^2	0.92	0.94	0.96
Observations	409	384	337
Sample	1977 – 2007	1977 – 2007	1977 – 2007
Estimator	DOLS	DOLS	DOLS

The dependent variable is the natural logarithm of total factor productivity ($\ln A_{ijt}$). The 10 and 5 per cent significance levels are marked with * and **, respectively. Standard errors in parenthesis. Estimation is conducted using Panel Dynamic OLS (DOLS) where leads and lags specifications are based on the AIC criterion. The R&D and TFP–frontier variables are defined by the log of the auxiliary variables $\tilde{R}_t = e^{(R_{ijt}/Y_{ijt}) \ln R_{ijt}}$ and $\tilde{A}_{iFt} = e^{\ln(A_{iF,t-1}/A_{ij,t-1}) \ln A_{iFt}}$, where R, Y and A represent R&D investments, value added and TFP, respectively, and where the index F denotes the frontier country with the highest level of TFP. Skill intensity is defined by high skilled workers' share in total hours worked. Countries included: USA, Germany, France, Finland, Sweden, Denmark and Norway. Industries included: Manufacturing (only for Norway, Denmark, France and Germany); Construction; Wholesale and retail trade; Transportation and storage; Information and communication; and Financial and insurance activities.

data. In Model 2 the impact from the distance to the technological frontier is included and significantly estimated. The inclusion of this variable has negligible effect on the estimated return to R&D. In Model 3 the share of high skilled is also added as an explanatory variable. It is estimated significantly at the 5 per cent level. Interestingly, when the share of high skilled is added as an explanatory variable, the return to R&D, which was estimated significantly at 5 per cent, drops to 0 per cent and is insignificant.

The main purpose of this section is to see if there has been a particular development of productivity in Norway during the period 1995 – 2005. To this end, I use the framework developed above and analyse the difference between actual TFP growth and the TFP growth implied by Models 1 – 3 in Figure 6. For all countries are Construction; Wholesale and retail trade; Transportation and storage; Information and communication; and Financial and insurance activities included, but only for only for Norway, Denmark,



(a) Actual **(b)** Model 1 **(c)** Model 2 **(d)** Model 3

Figure 6 – Actual and unexplained TFP growth. Sample: 1995 - 2005. Median growth rate. Actual TFP growth for country j is calculated as the weighted average across industries i of actual TFP growth ($\Delta\ln A_{ijt}$), i.e., $\sum_i s_{ijt}\Delta\ln A_{ijt}$, where the weights s_{ijt} are value added shares measured in current prices. Unexplained TFP growth in country j is calculated as the weighted average across industries i of the difference between actual and model predicted TFP growth ($\Delta\ln A^M_{ijt}$) in absolute terms, i.e., $\sum_i s_{ijt}\left|\Delta\ln A_{ijt} - \Delta\ln A^M_{ijt}\right|$. Industries included: Manufacturing (only for Norway, Denmark, France and Germany); Construction; Wholesale and retail trade; Transportation and storage; Information and communication; and Financial and insurance activities. The vertical line is 0.9 standard deviations above the mean across countries in each panel.

France and Germany is the Manufacturing industry included in the sample. Actual TFP growth for country j is calculated as the weighted average across industries i of actual ($\Delta\ln A_{ijt}$) TFP growth, i.e., $\sum_i s_{ijt}\Delta\ln A_{ijt}$, where the weights s_{ijt} are value added shares measured in current prices. The unexplained growth in country j is calculated as the weighted average across industries i of the difference between actual and model predicted ($\Delta\ln A^M_{ijt}$) TFP growth in absolute terms, i.e., $\sum_i s_{ijt}\left|\Delta\ln A_{ijt} - \Delta\ln A^M_{ijt}\right|$. Note that the unexplained TFP growth in Models 1 – 3 in Figure 6 does not show the error of how the models would predict aggregate TFP growth in each country. Such a measure would yield smaller errors since a negative prediction error in one industry would be offset by a positive prediction error in another industry.

Figure 6(a) shows the median growth rate in actual TFP. Growth in TFP has been much higher in the Nordic countries between 1995 and 2005 compared with the growth in USA, Germany and France. In Norway the median growth rate was 3.1 per cent and 0.9 standard deviations above the mean, represented by the vertical line.

A productivity puzzle can loosely be defined as a high level of actual TFP growth compared with a low level of the determinants of TFP, such as R&D. If a productivity puzzle exists, one would expect the unexplained level of TFP to be higher in Norway when taking the determinants of TFP into account. To analyse if there has been a productivity puzzle in Norway, I compare the level of unexplained TFP in Norway when using Models 1 – 3. If a puzzle exists, one would expect the unexplained level of TFP in Norway being further away from the mean compared with the distance to the mean of actual TFP (0.9 standard deviations). As shown in Figure 6(b) – Figure 6(d), for all models, the unexplained level of TFP in Norway is less than 0.9 standard deviations from the mean. In Model 1, when taking only R&D into account, the unexplained level of TFP in Norway is 0.3 standard deviations above the mean. In Model 2 and 3 the distance to the mean is -0.8 and 0.1 standard deviations, respectively. In other words, when taking the standard determinants of TFP into account, productivity in Norway is *less* puzzling than what the relatively high growth rate in actual TFP could indicate. Based on these results there is no reason to claim that the development of total factor productivity in Norway between 1995 and 2005 represents a puzzle.

5 Concluding remarks

The Norwegian productivity puzzle is rooted in the seemingly contradictory "facts" that Norway is one of the most productive OECD countries, Norway has experienced high growth in productivity and that the level of R&D investments has been low. The aim of this article has been twofold. The first was to analyse if productivity in Norway really has been as high as reported statistics suggest. I have shown that using PPPs from the expenditure side can grossly overestimate productivity in Norway, mainly because it is assumed that relative net export prices can be proxied by the market exchange rate in the calculation of expenditure PPPs. Since price indices fail when value aggregates, such as net exports, are close to zero, small deviations between the terms of trade and the market exchange rate can yield a large bias in the contribution from export prices and import prices to the overall PPP. It was shown that using terms of trade instead of market exchange rate can account for most of the gap between current expenditure and constant production PPPs. As a result, using expenditure PPPs instead of production PPPs overrates productivity in Norway by 23.3 per cent compared with the USA in 2010. When measured using the production PPPs from Timmer et al. (2006), Norway is not particularly productive compared with either the USA, Germany, Sweden or France. The exceptionally high productivity level in Norway, which was the premise of the Norwegian productivity puzzle, can thus be an artifact of the strong assumption that exchange rates are a good proxy for relative net export prices and the sizable price increase in statistical discrepancies.

The second aim of the article was to analyse the relatively high growth in productivity beginning in the mid 1990s. Using an empirical model that took the level of human capital, R&D capital stock and the distance to the technological frontier into account, it was shown that unexplained productivity growth has not been significantly higher in Norway compared with other countries. In contrast to what a productivity puzzle implies, the unexplained growth in TFP when taking R&D, distance to the technological frontier and human capital into account, is less pronounced in Norway compared with actual growth TFP. Based on these results there is thus no reason to claim that the development of productivity in Norway represents a puzzle.

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6 Appendix

6.1 The Èltetö-Köves-Szulc (EKS) index

An index number formula PPP_{jk} is said to satisfy the transitivity property if and only if for all choices of j, k and l, the index satisfies $PPP_{jk} = PPP_{jl} \times PPP_{lk}$. (ILO et al. 2004, p. 497). The transitivity property implies that attaining the PPP between Norway and Germany directly is equivalent to the indirect comparison between Norway and a third country, and the third country and Germany. The EKS method yields a transitive index. Although the transitivity property is an important requirement, as pointed out by Deaton and Heston (2010), the transitivity property implies that 'the price index for any pair of countries depends on prices and budget shares in third countries, a violation of the independence of irrelevant country property' (p. 8). As shown by Veelen (2002), any method of comparing wealth of nations must violate either the independence of irrelevant country property, or one of three other reasonable requirements.[9] However, when countries have relatively similar structures, which is the case for the countries in this article, the EKS index is not very sensitive to budget shares in third countries. This follows since the EKS method also attempts to provide PPPs that retain the essential features of indices comparing pairs of countries separately, i.e., the index deviates least from pairwise Fisher binary comparisons (Eurostat and OECD 2012, p. 245). The EKS index PPP^{EKS} for a particular industry aggregation, e.g., manufacturing, is calculated as a geometric mean of all the indirect Fisher indices PPP^F between countries j and k

$$PPP_{jk}^{EKS} = \prod_{l=1}^{M} \left(PPP_{jl}^{F} \times PPP_{lk}^{F}\right)^{1/M}. \tag{12}$$

The Fisher index is the geometric average between the Paasche (PPP^P) and Laspeyres indices (PPP^L)

$$PPP_{jl}^{F} = \left(PPP_{jl}^{L} \times PPP_{jl}^{P}\right)^{1/2}. \tag{13}$$

The Laspeyres and Paasche indices are defined by

$$PPP_{jl}^{L} = \sum_{i=1}^{I} \frac{PPP_{ij}}{PPP_{il}} s_{il} \qquad \text{and} \qquad PPP_{jl}^{P} = \left(\sum_{i=1}^{I} \left(\frac{PPP_{ij}}{PPP_{il}}\right)^{-1} s_{ij}\right)^{-1},$$

where i runs across sub industries within manufacturing and where the weight s_{il} is industry i's gross output share in manufacturing in country l.

[9] The three properties are Weak continuity, Dependence on prices and Weak Ranking Restrictions.

6.2 PPPs for capital input

To calculate PPPs for capital input I have used the PPPs for gross fixed capital formation provided by OECD and Eurostat (2008). The use of PPPs for gross fixed capital formation implies the assumption that the relative price between capital and investment is equal between all countries. Following Inklaar and Timmer (2008, p. 35), if P^K denote the user cost of capital and P^I is the price of real gross fixed investments, the PPP for capital between country j and the USA can be written as

$$PPP_j^K = PPP_j^I \frac{P_j^K / P_j^I}{P_{USA}^K / P_{USA}^I}. \tag{14}$$

Since I do not hold the user cost of capital for all countries it is assumed that the ratio of relative capital to investment prices are equal between countries, i.e., $P_j^K / P_j^I = P_{USA}^K / P_{USA}^I$ for all j, and that the PPPs for investment are good proxies for the PPPs for capital.

6.3 Mapping from ISIC Rev. 2 to ISIC Rev. 3

Longer time series for R&D were created by extending ISIC Rev. 3 data backwards in time using the growth rates of ISIC Rev. 2 data. To this end, the approximate mapping scheme outlined in the documentation of the STAN databse (OECD 2005, Annex 1, p. 25) were applied. This mapping is also illustrated in Table 5. To illustrate how precise the approximation is, the percentage deviation (in absolute terms) between the official ISIC Rev. 3 data and the transformed ISIC Rev. 2 data for R&D expenditure in 1990 in Norway is shown in column 3 and 6 of Table 5.

6.4 Mapping from ISIC Rev. 3 to ISIC Rev. 4

The ISIC Rev. 4 was officially released 11 August 2008. Data in ISIC Rev. 3 format have been mapped to the new ISIC Rev. 4 classification using the approximate 2-digit mapping provided in The OECD Compendium of Productivity Indicators 2013 (OECD 2013, Annex D). This mapping is also provided in Table 6. To illustrate how precise the approximation is, the percentage deviation (in absolute value) between the official ISIC Rev. 4 data and the transformed ISIC Rev. 3 data for value added in current prices ($VALU$) between 1990 and 2000 across industries in Denmark is shown next to the industry codes. For many industries there is a close correspondence between the ISIC Rev. 4 series and the transformed ISIC Rev. 3 series. However for industries such as Computer, electronic and optical products (d26), Furniture, other manufacturing and repair and installation of machinery and equipment (d31t33), Warehousing and support activities for transportation (d52) and Professional, scientific, technical, administrative and support service activities (d69t82) the mean discrepancy between the two series was more than 10 per cent.

Table 5 – Approximate mapping from ISIC Rev. 2 to ISIC Rev. 3 – R&D expenditure in Norway in 1990

Rev. 3	Rev. b	Deviation (%)	Rev. 3	Rev. 2	Deviation (%)
c01t99	b01t99	0.0	c30	b3825	0.0
c15t37	b3	0.0	c31	b383x	0.0
c15t16	b31	0.0	c32	b2832	0.0
c17t19	b32	0.2	c33	b385	0.0
c20	b33		c34	b3843	0.0
c21t22	b34		c351	b3841	0.0
c23t25	b35	0.0	c353	b3845	0.1
c24x	b3512x	0.0	c352a9	b3842a	0.5
c2423	b3522	0.0	c35	b3841+b3845+b3842a	0.0
c23	b3534a	0.0	c36	b39	
c24	b3512x+b3522	0.0	c40t99	b4t9	0.0
c25	b3556a	0.0	c40t41	b4	0.0
c26	b36	0.0	c45	b5	0.0
c27	b37	0.0	c60t63	b71	
c28	b381	0.0	c64	b72	
c29	b382x	0.0	c74	b8284	0.0

The table shows the approximate mapping between the 2nd and 3rd revision of the International Standard Industrial Classification in the STAN OECD database, see the documentation of the STAN database (OECD 2005, Annex 1., p. 25). Columns 3 and 6 show the absolute value of the mean deviation of R&D expenditure in 1990 in Norway in current prices

For some industries the approximation follows a one-to-one mapping between the classification systems. Some ISIC Rev. 3 industries are however split between two ISIC Rev. 4 industries. This is shown with an asterisk ($*$) in Table 6. For example, the Post and telecommunications industry (c64) is split between the two ISIC Rev. 4 industries Postal and courier activities (d53) and Telecommunications (d61). To calculate the two ISIC Rev. 4 industries one must provide a weighting scheme between the two industries, i.e., $X_{d53} = w_{d53}X_{c64}$ and $X_{d61} = w_{d61}X_{c64}$, where the weights are given by $w_{d53} = \frac{Y_{d53}}{Y_{d53}+Y_{d61}}$ and $w_{d61} = \frac{Y_{d61}}{Y_{d53}+Y_{d61}}$ for a given weighting variable Y. For most variables, such as value added, gross output and intermediate input, the weights were taken from OECD STAN ISIC Rev. 4 using $Y = X$. The weights were extrapolated using constant shares if needed. For some variables, the weighting variables differed from the variable being transformed. For example, the mapping of the capital stock used gross fixed capital formation (GFCF) as weighting variable.

For some variables the information at the ISIC Rev. 3 classification level was not detailed enough and the ISIC Rev. 3 data has been disaggregated before the mapping procedure were applied. For example, the real fixed capital stock were only available from EU KLEMS for the Pulp, paper, printing and publishing industry (c21t22) for the USA. However, to map the capital level to the ISIC Rev. 4 industries Printing and reproduction of recorded media (d18) and Publishing activities (d58), the Pulp, paper, printing and publishing industry (c21t22) were split into Pulp, paper and paper products (c21) and Printing and publishing (c22) using capital compensation as weighting variable. For some countries, there is thus greater uncertainty surrounding those industries were a one-to-one mapping was not sufficient.

Data for France are based on the ISIC Rev. 3 version of the STAN database. The data have been mapped to ISIC Rev. 4 and extrapolated backwards using the growth rates from the STAN ISIC Rev. 4 database. This was done since net capital was not available in the ISIC Rev. 4 database.

The EKS index requires a weight for gross output for all countries. To map the PPPs from Timmer et al. (2006) to ISIC Rev. 4 some assumption were made when information for gross output was not available. In particular, gross output for Postal and courier activities (d53) in Sweden were not available, and the auxiliary weight for this industry was created using the gross output from the aggregate industry Transportation and storage (d49t53) and multiplying with the share of d53 from d49t53 in Norway, i.e., $X_{d53,SWE} = X_{d49t53,SWE}(\frac{X_{d53,NOR}}{X_{d49t53,NOR}})$. Correspondingly, auxiliary weights for Printing and reproduction of recorded media (d18), Publishing activities (d58), Audiovisual and broadcasting activities (d59t60) in France, and Electricity, gas, steam and hot water supply (c41) and Recycling (c37) in the USA was created using weights from Germany. Thus, also for the mapping of PPPs is there greater uncertainty surrounding those industries were a one-to-one mapping was not sufficient. To map the industry Chemical, rubber, plastics, fuel products and other non-metallic mineral products (d19t23) for Norway as a sum of c23 to c26, the gross output for c23 to c26 is needed. Since there are currently only two operating oil refineries in Norway, the gross output for Coke, refined petroleum products and nuclear fuel (c23) and Chemicals and chemical products (c24) are not published in the main series of the National Accounts. However, in 1997, which is the benchmark year in Timmer et al. (2006), there were three refineries operating and Statistics Norway published gross output for these sectors separately in the Input-Output tables, see https://www.ssb.no/a/english/kortnavn/nr_en/supply_use.html.

Only value and price variables were mapped. Price indices were aggregated using the Törnqvist price index. After the mapping of value and price series, volume series were then constructed from the product rule., i.e., the identity of a value ratio being equal to a price ratio times a quantity ratio, see Frisch (1930).

Table 6 – Approximate mapping from ISIC Rev. 3 to ISIC Rev. 4, Value added in Denmark, 1990–2000

Rev. 4	Rev. 3	Deviation (%)	Rev. 4	Rev. 3	Deviation (%)
d01t99	c01t99	0.0	d35t39	c37+c40t41+c90	0.0
d01t03	c01t05	3.2	d36t39	c37+c41+c90	0.0
d01t02	c01t02	3.5	d37t39	c37+c90	0.0
d01	c01	4.0	d35	c40	0.0
d02	c02	7.7	d36	c41	0.0
d03	c05	0.0	d41t43	c45	0.0
d05t09	c10t14	0.7	d45t47	c50t52	0.5
d05t06	c10t12	0.7	d45t56	c50t55+c60t63	3.2
d07t09	c13t14	0.7	d45	c50	7.5
d10t33	c15t37	4.8	d46	c51	0.0
d10t12	c15t16	0.7	d47	c52	1.1
d10t11	c15	0.7	d49t53	c60t63	12.8
d12	c16	0.0	d49	c60	0.0
d13t15	c17t19	0.5	d50	c61	0.8
d13t14	c17t18	0.9	d51	c62	0.0
d15	c19	3.0	d52	c63	13.0
d16	c20	0.4	d53	c64*	0.0
d16t18	c20+c21+c22*	3.1	d55t56	c55	0.0
d17	c21	5.1	d58t63	c22*+c64*+c92*+c72	
d18	c22*	4.3	d59t60	c92*	0.8
d19	c23	0.0	d61	c64*	0.0
d19t23	c23t25+c26	0.6	d62t63	c72	7.5
d20t21	c24	0.6	d64t66	c65t67	0.2
d22t23	c25+c26	0.7	d64	c65	0.3
d22	c25	0.7	d65	c66	0.0
d23	c26	2.2	d66	c67	0.0
d24t25	c27t28	3.6	d68t82	c70t74	4.6
d24	c27	5.7	d68	c70	0.3
d25	c28	6.1	d69t82	c71t74	11.8
d26t28	c29t33	8.7	d72	c73	0.0
d26t27	c30t33		d84t99	c75t99	4.0
d26	c30+c32+c33	14.6	d84t88	c75+c80+c85	0.4
d27	c31	1.3	d84	c75	0.5
d28	c29	7.6	d85	c80	0.0
d29t30	c34t35	9.3	d86t88	c85	0.6
d29	c34	5.6	d90t99	c91+c92*+c93+c95	8.8
d30	c35	19.2	d90t93	c92*	0.8
d31t33	c36	44.9	d97t98	c95	0.0

The table shows the approximate mapping between the 3rd and 4th revision of the International Standard Industrial Classification in the STAN OECD databse, see The OECD Compendium of Productivity Indicators 2013 (OECD 2013, Annex D). Columns 3 and 6 show the absolute value of the mean deviation of value added in current prices (VALU) in Denmark between 1990 and 2000. The asterisk ($*$) indicates that the ISIC Rev. 3 industry is split between two ISIC Rev. 4 industries, e.g., $X_{d53} = w_{d53}X_{c64}$ and $X_{d61} = w_{d61}X_{c64}$, where the weights are given by $w_{d53} = \frac{Y_{d53}}{Y_{d53}+Y_{d61}}$ and $w_{d61} = \frac{Y_{d61}}{Y_{d53}+Y_{d61}}$ for a given weighting variable Y.

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