A Vertically Integrated Perspective on Nordic Manufacturing Productivity

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Abstract

Specialization, at the national and global level, and a growing importance of knowledge-based capital in current growth processes have led to a renewed interest in a vertically integrated perspective on productivity. This means that the focus is on all steps of the production process, regardless of in what sector or country the value creation takes place. From this perspective, Norway has improved its relative productivity since 2000 and is now the leader among the Nordic countries. Finland – and Sweden to some extent – have performed relatively poorly. Using import multipliers and splitting the domestic production chain into two productivity measures, this article shows that the vertically integrated perspective can contribute to new insights about productivity developments in trade-dependent and highly specialized countries. Important aspects of a policy for an enhanced vertically-integrated productivity are the quality of human capital, enhanced diffusion of knowledge and innovations and a holistic view of economic growth.

According to economic theory, labour productivity is determined by human capital, capital stock, intermediate inputs and a residual: multifactor productivity.[2] Based on theory, empirical research on productivity usually focuses on analyses of individual countries and sectors.[3] Accordingly, there is less emphasis on how the necessary trade in intermediate inputs – within and between countries – affects productivity. This exclusive focus of productivity analysis on the final stage of the production process does not capture the implications for productivity from changes in the

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2 Multifactor productivity (MFP) reflects the total efficiency at which the production factors are combined in the production process. MFP growth is often interpreted as a measure of technical change, but this is not entirely correct since new technologies can also be channelled through the capital stock and the intermediate inputs. See OECD (2001).

3 Carvalho (2014), Timmer (2017), Gu and Yan (2017) and Timmer and Ye (2018, 2020). See also Acemoglu and Azar (2020).

4 Timmer and Ye (2020:425) argue in the following way about productivity research: "...the canonical KLEMS framework is versatile and when appropriately modified, can also be applied outside the traditional confines of analyses of economic growth in individual countries and industries..."

organization of production.[4]

However, in recent years, there has been a renewed academic and policy interest in a vertically integrated production and productivity perspective.[5] This means that the focus is on the entire production process, irrespective of in what country or sector the value creation takes place. Therefore, the limelight is on how trade in intermediate inputs creates and diffuses productivity by linking different stages of the production process, which finally end up as a final product.

Taking the fact that this perspective is particularly relevant for the most technologically advanced, highly specialized and trade-dependent countries as the starting point, this article aims at empirically analyzing the vertically integrated productivity of the manufacturing sector in the Nordic countries for the first time.[6] The article addresses the following questions: (1) How has the productivity of the manufacturing sector developed, in absolute and relative terms, since the turn of the millennium? (2) How has the productivity of the manufacturing sub-sectors developed, in absolute and relative terms, since the turn of the millennium? (3) What role does the use of imported intermediate inputs play for vertically integrated productivity?

To put these three questions into some perspective, a fourth question is: (4) how and to what extent does this vertically integrated perspective give new or nuanced productivity insights? This is explored by splitting the domestic production process into two productivity measures: the conventional, sectoral-based labour productivity and the labour productivity along the domestic supply chains. The period studied is 2000-14.

The article is structured as follows. The next section clarifies the theoretical and empirical framework. Then follows an empirical section, sub-divided into separate but related topics. In a concluding section, the empirical results are synthesized and some policy perspectives are presented.

Theoretical and Empirical Framework

Renewed Interest in a Vertically Integrated Productivity Perspective

One reason behind the renewed interest in a vertically integrated productivity perspective is the ICT-driven, intensified interaction between different parts of the economy, in particular between the manufacturing sector and the service sector. This means that the network of intermediate input flows has become denser and often more complicated (Acemoglu and Azar, 2020). This integration, driven by specialization and a larger presence of services in the production and delivery of manufacturing products, has become increasingly high-skilled.

One explanation for this is that the knowledge-based (or intangible) capital –

5 From a production perspective, see, for example, OECD (2013a), Timmer *et al.* (2013), Timmer *et al.* (2014), Statistics Denmark (2017), OECD (2017), ECB (2019), IMF (2019), WTO (2019), Ponte *et al.* (2019) and World Bank (2020). See also Baldwin (2016, 2017, 2019).

6 The Nordic countries are defined as Sweden, Norway, Finland, and Denmark.

such as data, skill development, management and governance, trademark and research and development (R&D) – has become increasingly important for the productivity of manufacturing production (Jona-Lasinio and Meliciani, 2019).[7] In the wake of this, we have seen a strong growth in the sector for knowledge-intensive business services and it contributes to the value creation of manufacturing production to an increasing extent, not the least in the Nordic countries (Criscuolo and Timmis, 2018a). As a consequence, manufacturing production in the Nordic countries has become more specialized in those production activities that are related to high-skilled labour (Timmer *et al.*, 2014).

A second explanation for the renewed interest is that, not the least in the wake of the financial crisis in 2008 and the catastrophe in Fukushima in 2011, there is an enhanced focus on how productivity shocks at the micro level, through the intermediate input structure, can affect macroeconomic performance (Carvalho and Tahbaz-Salehi, 2019). This means that, as a consequence of their central role as subcontractors in the production system, a few sectors can be decisive for the aggregate development (Acemoglu *et al.*, 2016). The research on how inefficiencies at the micro level, through the intermediate input structure, affect the efficiency at the macro level is closely related to this, and can contribute to the understanding of the large differences in material welfare between countries (Jones, 2013; Restuccia and Rogerson, 2017).

A third explanation concerns the emergence of global value chains and how the global trade in intermediate inputs affects the productivity of the firms involved (Timmer and Ye, 2020).[8] This means that a manufacturing product today contains a considerably larger share of imported intermediates than before. Apart from weakening the link between global trade and domestic growth, a consequence of these chains is that the difference in productivity between the globally oriented and the most productive firms, and the domestically-oriented firms seems to have widened. Based on this productivity gap, OECD (2015) concludes that the diffusion of productivity within countries cannot be taken for granted and that the political system should therefore implement policies to improve the national diffusion process.

Manufacturing production is particularly relevant in this context, since it is highly specialized and thus buys considerable amounts of intermediate inputs from other sectors and countries. With a more efficient diffusion process, the gains from an improved productivity will also be more

7 A significant part of knowledge-based capital is classified as current consumption in the national accounts (Corrado *et al.* 2009; OECD 2013b; Corrado *et al.*, 2020). This means that this type of capital is often diffused in the economy through the intermediate input structure, not through the capital stock. With a growing use of knowledge-based capital, trade in intermediate inputs has thus become a more important channel for the productivity development. Based on the argument that standard macroeconomic and growth models often ignore the role of intermediate inputs, Jones (2013) argues that in the long run, there is no difference between capital and intermediate inputs: both are produced factors of production. Therefore, intermediate inputs can be seen as another form of capital. When Corrado *et al.* (2020:364) treat these two types of capital as one, they use the wording: "This broad view of investment. . . ".

8 See also the overview in Criscuolo and Timmis (2017) and the results in Criscuolo and Timmis (2018b) and Gal and Witheridge (2019).

evenly spread among the working population (OECD, 2016).

Earlier Research on Vertically Integrated Productivity

Behind the renewed interest in a vertically integrated productivity perspective, there are some research traditions that have more explicitly been interested in the interaction between sectors and the importance of the intermediate input structure in the post war period. Without any claim to being a complete overview, Leontief (1936, 1941) and the input-output theory (IO) which is established therein constitute an empirical starting point for much of this research. The focus of this theory is on the interdependencies between sectors that are created by the trade in intermediate inputs, and from a (labour-) productivity perspective, the central question is how much labour that is required to finalize a product, regardless of where in the economy the employment is generated.[9]

Another research tradition takes its starting point in an evolutionary perspective on how technical change and innovations are created and diffused in the economy.[10] A central objective in this research is to open the black box and in more detail understand what drives productivity. The interaction within and between firms and sectors is central here – how production is organized and how the interaction works between the micro and macro level of the economy.

Pasinetti's Theory on Economic Growth and Dynamics

A third research area which more explicitly considers productivity from a vertically integrated perspective belongs to the post-Keynesian tradition. With the ambition to reconnect to the classical economists, such as Adam Smith and his reasoning on what production steps are required to produce a woolen coat, Sraffa (1960) established the concept of a sub-system.[11] This involves a vertical intersection of the economy – a production process from the very beginning to the very end, where labour used in earlier production stages is embedded in the final product. Taking the classical economists as well as Leontief and Sraffa as his starting point, Pasinetti (1973, 1981, 1993) develops a growth theory based on the premises that economic theory should take a larger and more detailed interest in technical change, technology diffusion and structural change.[12]

The core of Pasinetti's theory lies in the production process, with division of labour and specialization. Following the classical political economists, the theory seeks to an-

9 Carter (1970) constitutes an early and important contribution to productivity research from an IO perspective.

10 See Nelson and Winter (1982) and Rosenberg (1982). In a Nordic context, related discussions are found in Dahmén (1950, 1988), Lundvall (2001) and Fagerberg (2002).

11 Brondino (2019) uses sub-systems in order to analyze the productivity development of the Chinese economy in the period 1995-2009.

12 With a focus on technical change and its effect on the dynamic course of the economy, Pasinetti also finds inspiration from the evolutionary theory, in particular Schumpeter. See the contributions in Arena and Porta (2012) for a discussion of Pasinetti's theory. See also Garbellini and Wirkierman (2014).

swer the question of how a "pure" labour economy – where production is carried out with labour as the only primary factor of production – and its productivity are developed over time as a consequence of individual and collective learning.[13] This learning contributes to the technical change, which in turn affects how much and what kind of intermediate inputs that are required to finalize a product.[14] Hence, the dynamics and the structural change in the economy are captured by how the need for labour per produced product changes over time – through labour productivity. With the purpose of operationalizing these dynamics, Pasinetti establishes the concept of vertically integrated sectors and the total labour coefficient (TLC). The former refers to the different vertical cross section parts of the economy, and the latter to the total amount of labour needed in the domestic economy to make a product.

Leontief's Inverse and Pasinetti's Total Labour Coefficients

Taking interdependent sectors as the starting point, the IO-analysis takes off from the classical political economy. Based on this, Leontief developed a production theory which aims at carefully studying how production processes are organized and how they affect the functioning of the economy.[15] Leontief (1991) compared his approach to opening the hood in order to obtain an in-depth understanding of how the economic engine works. The main tool for this improved understanding is equation (1), in which the relation between final demand, (f), and gross output, (x), is clarified:

$$x = (I - A)^{-1} f = Lf \qquad (1)$$

where $(I - A)^{-1} = L = [l_{ij}]$ is the Leontief inverse – the core of the IO-analysis. l_{ij} is a partial derivative and expresses the total effect on production in sector i of a one unit change in final demand in sector $j(l_{ij} = (\delta x_i)/(\delta f_j))$, including all subsequent rounds of indirect demand for intermediate inputs.

The learning that affects the use of technology in Pasinetti's theory changes the partial derivatives in the Leontief inverse – how much and what kind of intermediate inputs that are required in different sectors in order to finalize a product. However, Pasinetti argues that Leontief's view of the trade in intermediate inputs should be supplemented in order to better understand the dynamics of the economy. The reason for this extension is that changes in individual coefficients in the Leontief inverse make it difficult to compare the whole production system over time, since there are continuous changes in its underlying structure. Therefore, the focus should not pri-

13 In recent models focusing on productivity from a vertically integrated perspective, the starting point is often also a "pure" labour economy, where the primary production factor labour and intermediate inputs are transformed into final products. See, for example, Acemoglu *et al.* (2016).

14 This learning is related to what is defined by Lundvall (2001) as the learning economy: how networks of and cooperation between suppliers, customers and competitors can contribute to learning and innovation, how these networks contribute to the diffusion process, and therefore improve productivity growth.

15 See Miller and Blair (2009) for a review of IO theory and its applications.

marily be on individual cells in the Leontief inverse, but on each sector's column sum. These are economically relevant even if the technical change alters the size of individual coefficients and their mutual relationships in Leontief's inverse. Consequently, Pasinetti considers Leontief's IO-analysis and his growth theory as complements, where the latter has a dynamic focus and the former focuses more on detailed analyses of the functioning of the economy in a given period.

In order to calculate Pasinetti's total labour coefficients, the Leontief inverse is pre-multiplied by a matrix, consisting of the direct labour coefficient (DLC) of each sector in the economy, expressed as the inverse of the gross output per person employed, on the main diagonal, and zeros elsewhere. The result is the matrix – total labour coefficients (TLC). The column sum of sector i in period t in this matrix expresses the amount of employment that is required in all production stages within the domestic economy in order to finalize a unit of production in sector i:

$$TLC = DLC(I - A)^{-1} \tag{2}$$

The sum of the columns constitutes the labour productivity measure used in this article.[16] The change in the TLC coefficient for sector i therefore captures the "net effect" of the changes in labour use in those sectors that are part of the vertically integrated production process of sector i – in all of the upstream activities that are required to finalize the product.

The statistics used in this article are from the World Input-output Database (WIOD) and are expressed in constant prices $(t-1)$.[17] The conversion into a common currency (dollar) is made using market exchange rates.[18] Employment is defined as the number of people engaged. The IO tables follow ISIC Rev 4 and SNA 2008.[19]

Empirical Analysis

Vertically Integrated Productivity in Nordic Manufacturing Sub-sectors

As stated earlier, the main approach of productivity research has for a long time been to focus on individual sectors and countries.[20] Apart from the arguments already put forward, there are good reasons for research to empirically explore the theoretical insights of Domar (1961) and Hultén (1978), that productivity in individual sectors affects other parts of the economy through the intermediate input struc-

16 Multifactor productivity can also be used when applying a vertically integrated perspective. See, for example, Gu and Yan (2017) and Timmer (2017).

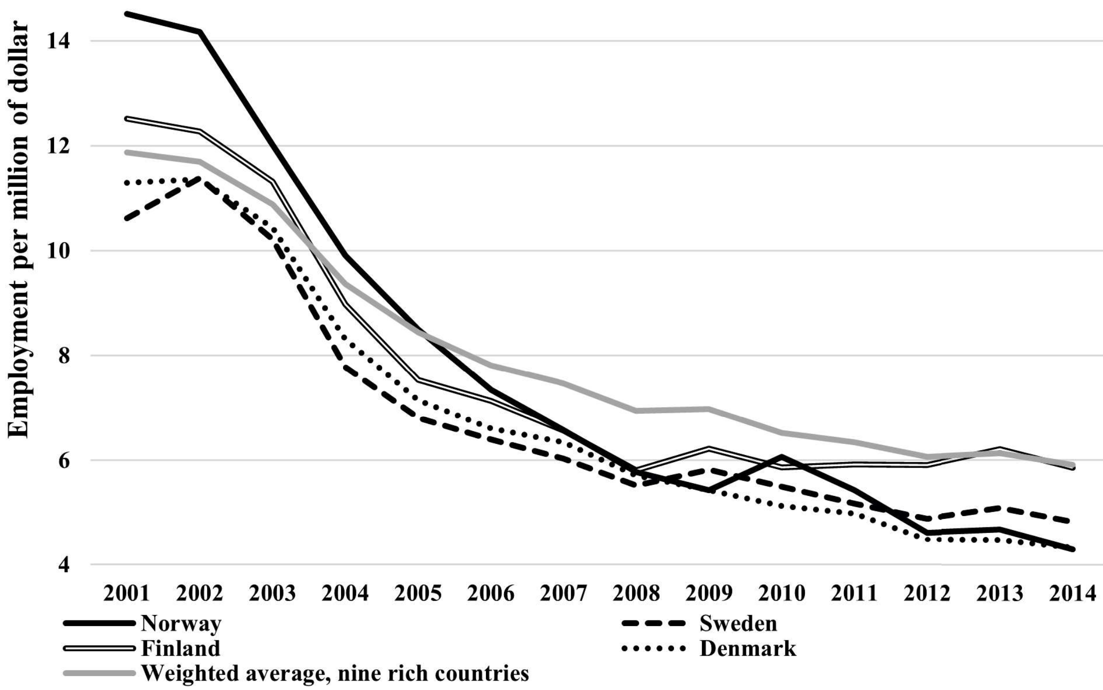
17 See Dietzenbacher *et al.* (2013) and Timmer *et al.* (2016) for a description of the database.

18 Samuels and Strassner (2019) discuss how WIOD and similar, globally oriented, databases should be improved. Not the least, it is argued, this would enhance the understanding of where productivity is generated in the world economy, and how it is diffused through the global trade in intermediate inputs.

19 In this article, the manufacturing sector is defined as SNA 10-33.

20 Gu and Yan (2017:113) argue in the following way about the traditional growth accounting framework and standard measures of productivity: "...fail to capture the impact that productivity gains in upstream industries have on productivity gains in downstream industries."

Chart 1: Labour Productivity Levels in the Nordic Countries and the Western World, Expressed as TLC Coefficients, 2001-14.



Note:Total Labour Coefficient (TLC) is defined as the number of employed that are needed in the domestic economy in order to produce a manufacturing product at the value of one million (constant dollars).
Source: WIOD and author's calculations

ture.[21]

How has Nordic manufacturing production developed from a vertically integrated productivity perspective since the turn of the millennium? Based on equation 2, the TLC coefficients was calculated for the manufacturing sector for the Nordic countries and an average of nine rich Western countries.[22] This means that Chart 1 answers the question: how much labour is needed in the domestic economy in order to finalize the production of a manufacturing product at a value of one million dollar? As appears from the chart, the distribution in 2001 was between 10.6 workers in Sweden and 14.5 workers in Norway – with Denmark (11.3) and Finland (12.5) in between. In relation to Sweden, this means that at the turn of the millennium, about 35 per cent more labour was required along the

21 Domar (1961) operationalizes this insight by weighting sectors into larger aggregates with weights that sum to more than one (Domar's weights). Hultén (1978) formalized this line of thought. See Baqaee and Farhi (2020) for a recent analysis of Domar's and Hultén's theory with less restrictive assumptions. Apart from the references previously mentioned, see also the following examples of productivity research with the starting point in a vertically integrated perspective: Wolff (1994, 2011), De Juan and Febrero (2000), Dietzenbacher *et al.* (2000), Ten Raa and Wolff (2000, 2001, 2012), Garbellini and Wirkierman (2009), Garbellini (2014) and Lind (2014).

22 Timmer (2017) and Timmer and Ye (2018, 2020) are examples of recent research using TLC coefficients. The nine rich countries are the United States, Germany, Great Britain, France, the Netherlands, Belgium, Denmark, Finland and Norway. Final demand has been used as weigths when creating the averages for the aggregate manufacturing sector.

manufacturing production chains in Norway in order to produce a manufacturing product.

At an overall level, Chart 1 illustrates the favourable productivity growth that characterized the Western world in the years after the turn of the millennium – in this case expressed as a large reduction in the need for labour per manufacturing product – but that the growth rate was weakened already in the years before the financial crisis. Between 2001 and 2008, the need for labour per manufacturing product decreased by an average of 12.3 per cent per year in Norway and by 8.9 per cent in Sweden.[23] With an annual productivity growth somewhat above 9 per cent in Denmark, and 10 per cent in Finland, this means that Sweden showed the least favourable growth among the Nordic countries in these years, although being ahead of the average of the nine rich countries (-7.4 per cent). After the financial crisis, we see a continued synchronized weakening of the productivity growth in the domestic manufacturing production processes in the Nordic countries. However, Norway is still at the top with a reduced need for labour of about 4.5 per cent per year in the years 2009-14 (Denmark -4.4 per cent). Sweden falls back to 3.7 per cent, but the weak growth in Finland is particularly remarkable – with an average productivity growth of only 1.2 per cent per year after the financial crisis.

Altogether, the pattern between 2001 and 2014 means that the need for labour per manufacturing product decreased by 70 per cent in Norway, by slightly more than 60 per cent in Denmark and by slightly more than 50 per cent in Sweden and Finland. Besides the fact that this shows how dependent the manufacturing sector is on a growing (global) demand for maintaining its role as an employment generator, this gives a good indication of the competitiveness of the Norwegian manufacturing sector, in terms of its vertically integrated productivity, having shown a strong development in a Nordic perspective since the turn of the millennium. This has also been reinforced after the financial crisis. Finland's productivity advantage of slightly more than 10 per cent versus Norway at the turn of the millennium has been transformed to a productivity lag of more than 30 per cent.

Vertically Integrated Productivity in Nordic Manufacturing

What can we learn from the disaggregated developments underlying the manufacturing sector as a whole? Is the strong Norwegian performance concentrated in a few sub-sectors, or is it broad based and stems from major parts of the manufacturing sector? The World Input-Output Database (WIOD) contains 19 manufacturing sub-sectors. Panel A of Table 1 summarizes the yearly compound growth rates of the total labour coefficient of these 19 sub-sectors for the four Nordic countries – and an unweighted average of these countries (Nordics) – between 2001 and 2014 (Δ

23 As will be clear later on in the article, these extraordinary high growth rates are partly due to an substantial increase in the use of imported intermediate inputs.

Table 1: Total Labour Coefficient in Manufacturing Industries in Nordic Countries

Panel A: Yearly Compound Productivity Growth Rate between 2001 and 2014 (Δ (%))					
	Denmark	Finland	Norway	Sweden	Nordics
Food, beverage, tobacco	-7.4	-6.0	-8.4	-6.2	-7.0
Textile, clothing, leather	-7.0	-6.1	-7.7	-5.4	-6.5
Wood and cork	-5.4	-5.0	-5.1	-5.1	-5.2
Paper and pulp	-6.2	-4.3	-4.8	-4.4	-4.9
Printing and recorded media	-5.2	-3.8	-6.7	-4.8	-5.1
Coke and petroleum	-7.5	-8.7	-9.8	-5	-7.8
Chemicals	-7.9	-5.5	-10.1	-6.0	-7.4
Pharmaceuticals	-6.0	-8.6	-11.8	-5.4	-8.0
Rubber and plastics	-6.4	-5.7	-7.6	-5.2	-6.2
Other non-metallic	-6.6	-5.5	-8.4	-6.5	-6.7
Basic metals	-6.7	-5.7	-6.5	-6.1	-6.2
Metals, except machinery	-5.6	-5.2	-7.1	-5.9	-5.9
Computer and electronics	-5.6	-4.5	-6.6	-7.6	-6.1
Electrical equipment	-6.7	-6.2	-7.7	-5.7	-6.6
Machinery and equipment	-7.2	-6.5	-8.9	-5.9	-7.1
Motor vehicles	-7.0	-6.3	-7.6	-5.9	-6.7
Other transport (e.g ships)	-4.6	-6.4	-8.1	-5.6	-6.2
Furniture	-6.4	-4.5	-6.9	-5.2	-5.8
Repair of machinery	-7.1	-5.4	-6.9	-4.7	-6.0
Panel B: Labour Productivity Level in 2014					
	Denmark	Finland	Norway	Sweden	Nordics
Food, beverage, tobacco	5.1	9.8	5.4	7.0	6.8
Textile, clothing, leather	4.1	9.2	5.8	6.8	6.5
Wood and cork	6.6	7.6	6.5	6.9	6.9
Paper and pulp	5.1	5.2	5.1	5.0	5.1
Printing and recorded media	7.1	9.1	5.4	7.7	7.3
Coke and petroleum	1.0	1.5	2.2	1.4	1.5
Chemicals	2.8	4.0	2.4	3	3.1
Pharmaceuticals	3.3	3.2	2.2	3.3	3.0
Rubber and plastics	4.7	6.2	4.3	5.8	5.2
Other non-metallic	5.3	6.8	4.1	5.6	5.5
Basic metals	4.2	3.9	2.8	4.2	3.8
Metals, except machinery	6.3	7.9	5	6.4	6.4
Computer and electronics	4.0	4.4	3.9	3.0	3.8
Electrical equipment	4.5	5.1	4.1	5.2	4.7
Machinery and equipment	4.2	5.2	3.6	5.2	4.6
Motor vehicles	4.0	5.5	3.7	4.4	4.4
Other transport (e.g ships)	5.8	6.2	3.9	4.7	5.1
Furniture	5.3	9.6	5.9	6.3	6.8
Repair of machinery	5.2	7.4	4.6	7.2	6.1

Note: Panel A shows the yearly compound productivity growth rate in 19 manufacturing sub-sectors in the Nordic countries between 2001 and 2014, expressed as TLC coefficients. Panel B shows the labour productivity level in 2014, expressed as TLC coefficients.
Source: WIOD and author's calculations.

(%)). Panel B of Table 1 shows the TLC level for the final year of the period.

The table is rather self-explanatory, but a few points should be emphasized. First, the strongest productivity growth of the countries' average (Nordics) is found in pharmaceuticals, with a yearly reduction of the labour needed per unit of final demand of 8.0 per cent between 2001 and 2014. Paper and pulp is found at the other end of the spectrum, with a yearly productivity growth of 4.9 per cent. Second, when it comes to the productivity levels of the countries' average (Nordics) in 2014, with 1.5 employed persons per million dollar, coke and petroleum stands out, as it usually does. With a TLC level of 7.3 workers, the amount of labour needed is almost five times higher in printing and recorded media than in coke and petroleum. Finally, when comparing the rate of productivity growth, it is clear that Norway's strong performance is broad based: In 17 of the 19 sub-sectors, the yearly growth rate between 2001 and 2014 was higher in Norway than the average for the four countries.[24]

To further explore the relative labour productivity performance among the Nordic countries, the most pronounced change in the TLC-ranking among the manufacturing sub-sectors is found in Norway.[25] Its average ranking in 2001 was 2.6, but in 2014 it had increased to 1.5 – an improvement of more than 40 per cent. Consequently, Norway has moved from being the second to last country to becoming the country with the best average ranking position. In 2014, Norway was the top ranked Nordic country in 13 sub-sectors, and first or second in 17 sub-sectors. The flip side of this strong performance is mainly that Sweden's ranking has deteriorated substantially since 2001. In that year, Sweden was the leading Nordic country in terms of the average ranking position, but 13 years later the country was surpassed by both Norway and Denmark. For Denmark and Finland, the average rank was almost unchanged between 2001 and 2014. Denmark is still the second highest ranked country, and Finland is still lagging behind the other countries.

The Role of Imported Intermediate Inputs in Nordic Manufacturing Production

One important aspect of Pasinetti's – gross output based – vertically integrated productivity is the use of imported intermediate inputs. Obviously, this aspect has become increasingly relevant in the wake of intensified vertical specialization and this is also apparent in the latest vertically integrated productivity research.[26] In this context, the reasonable hypothesis is that countries with a large import multiplier have a smaller domestic need for labour per manufacturing product, everything else equal, since a larger share of the necessary employment is embedded in the imported intermediates.

Using equation (3) – where direct import multiplier DIM, is a matrix containing each sector's intermediate input imports per unit of gross output, and the column sum for sector i in period t in total import multiplier, TIM matrix, expresses the use of imports per unit of final demand – the import multipliers have been estimated for the Nordic countries (Dietzenbacher *et al.*, 2000).

$$TIM = DIM(I - A)^{-1} \tag{3}$$

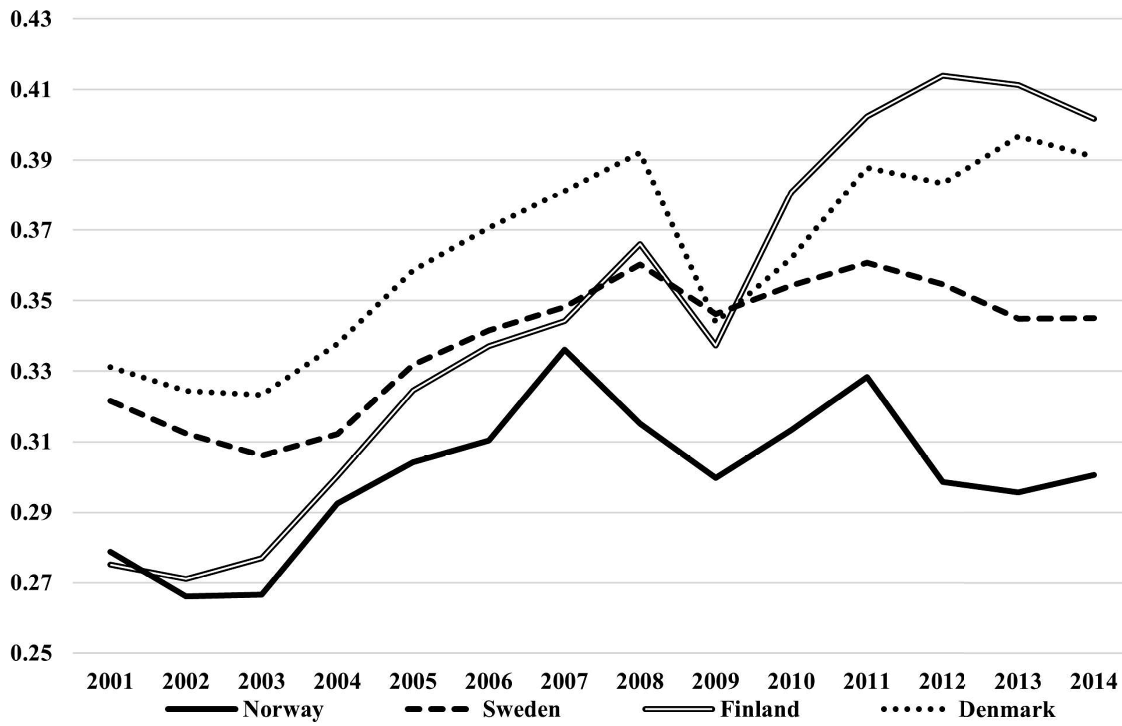
Chart 2 shows that manufacturing production in the Nordic countries since the turn of the millennium has become increasingly dependent on intermediate input imports. This means that for each unit of manufacturing final demand, there is a need for a larger share of imported in-

24 If the productivity growth in the Nordics column is related to the Nordics TLC level in 2001, there is a slight divergence, with sub-sectors with a low TLC level in 2001 also showing an above average decrease in the labour needed to make a product.

25 Each sub-sector in each of the four countries is ranked between 1-4 from highest to lowest.

26 Timmer (2017), Timmer and Ye (2018, 2020), and Pahl and Timmer (2019).

Chart 2: The Use of Imported Intermediate Inputs per Unit of Final Demand (Import Multiplier), the Aggregate Manufacturing Sector in the four Nordic Countries, 2001-14



Source: WIOD and author's calculations

termediate inputs in order to finalize the product.[27] This pattern has been particularly strong and uniform during the years up to the financial crisis. The result has been that a manufacturing product gradually generated less value added and employment in the domestic economy.

After an initial reduction of the import multiplier in connection with the financial crisis, the import dependency of manufacturing production has developed in different ways in the Nordic countries. Finland is the country that primarily stands out. In this case, the import dependency has continued to increase at the same rate as before the financial crisis, which has resulted in the multiplier amounting to 0.4 in 2014. For Denmark, a considerable decrease in the import dependency in connection with the financial crisis has now rebounded to the same level as in 2008-09. For Sweden and Norway, the import multiplier is still lower than at the start of the financial crisis, but in both cases after an initial recoil back to the level before the crisis.

Finland's import multiplier has grown fastest among the Nordic countries since the turn of the millennium (46 per cent) from 27.4 per cent to 40.2 per cent. It has grown most slowly in Sweden (7.3 per cent) and Norway (7.8 per cent). Norway's modest increase in its share of intermedi-

27 The level of imported intermediate inputs have been used as weights when creating the averages for the aggregate manufacturing sector.

ate goods imports in final demand over the 2001-2014 period is explained by the fall in this share after the financial crisis. Finland has thus moved from being a country with a low import dependency to being a country with a high import dependency. Norway's position as a country with a distinctively high dependency on domestic intermediate inputs has become more apparent.

The ensuing question from this analysis is: do the level and growth differences of the import multipliers of the Nordic countries affect the interpretation of vertically integrated productivity growth since the turn of the millennium? If we focus on the change between 2001 and 2014, it does not seem to be the case that the rate of reduction in the amount of labour needed in the domestic economy has been the highest in those countries with the largest increase in their intermediate import dependency. It has been quite the opposite. Despite having the strongest growth in the import multiplier, the Finnish reduction in labour needed in the domestic economy has been the lowest.

In the same spirit, the Swedish import multiplier has increased by one sixth of the Finnish import multiplier, but the reduction in the domestic need for labour per manufacturing product has been approximately as large in both countries. Third, Norway succeeded in achieving the highest domestic productivity growth despite, together with Sweden, having the slowest growth of the import multiplier. Altogether, this suggests that the vertically integrated productivity performance of Norwegian manufacturing improved relative to that of the other Nordic countries even if due consideration is given to how the intermediate import dependency has developed. The opposite is apparent for Finland.

The Role of Imported Intermediate Imports in Nordic Manufacturing Production: An Econometric Exercise

The previous section supports the argument in the literature that it is important to explicitly include the import of intermediate inputs when empirically analyzing Pasinetti's total labour coefficients (Arena and Porta, 2012). The foundation of this argument is that large countries tend to import less intermediate inputs than small countries. However, this implied difference in the level of import multiplier should – as was also suggested in the previous section – be complemented with a time-dimension: to what extent do changes in the import multiplier affect the change of the domestic need for labour per unit of manufacturing product. In order to obtain a more statistically robust picture of the role of imported intermediates in a Pasinetti framework, an econometric exercise in this section is performed which explores both the cross-section (level, time-invariant) and the time dimension.[28]

Table 2 summarizes the results. When estimating the model that focuses on the level of imported intermediates (Be: be-

28 This exercise was inspired by Gu and Yan (2017), Timmer (2017), Criscuolo and Timmis (2018ab), Timmer and Ye (2018; 2020), Gal and Witheridge (2019), Jona-Lasinio and Meliciani (2019) and Acemoglu and Azar (2020).

Table 2: Relationship between Total Labour Coefficients and Import Multipliers in Nordic Manufacturing Industries

	2001-14			2001-08			2009-14		
	Model			Model			Model		
Dependent variable: TLC	Be	Fe	Re	Be	Fe	Re	Be	Fe	Re
Coefficient	-0.633	0.111	0.056	-0.622	0.181	-0.058	-0.507	-0.036	-0.092
Std. error	0.224	0.134	0.109	0.219	0.201	0.177	0.22	0.141	0.094
t	-2.74	0.82	0.51	-2.85	0.88	-0.33	-2.31	-0.26	-0.98
P>|t|	0.008	0.496	0.607	0.006	0.471	0.744	0.025	0.82	0.328
Sign.level	99%	NS	NS	99%	NS	NS	95%	NS	NS
Obs.	1064	1064	1064	608	608	608	456	456	456

Note: The table shows the correlations (elasticities) between the import multiplier and the total labour coefficient (TLC) in Nordic manufacturing production − after the control of three other, domestically oriented, variables: the capital multiplier, the human capital multiplier and the output multiplier. Following equation (2), the capital multiplier for each sub-sector is defined as the column sum of the matrix $CAM = \frac{CapitalStock}{GrossOutput}(I - A)^{-1}$, and the human capital multiplier is, accordingly, defined as the column sum of the matrix $HCAM = \frac{Highskilledlabour}{Totallabour}(I - A)^{-1}$, where high skilled labour is defined as individuals with a university degree. The output multiplier is defined as the column sum of the Leontief inverse, but excluding each sub-sector's intermediate inputs trade with itself.
Sources: WIOD, EU Klems and author's calculations.

tween estimator[29]), meaning that it excludes changes over time, the result is clear and intuitive: a large average import multiplier is strongly associated with a low average total labour coefficient. Hence, the more imports that are used in the production process, the less domestic labour is needed to finalize the product. This holds for the whole period and for the two subperiods. As the data used in these estimations is in log-log format, the coefficient of -0.633 indicates that we can expect a 0.63 per cent lower average labour productivity level with a one per cent higher average import multiplier.[30] For the whole period and before the financial crisis, this correlation is significant at the 99 per cent level, but falls back to the 95 per cent level between 2009 and 2014.

When estimating the model which concentrates on the time dimension of the data (Fe: fixed effect/within estimator[31]), the result is equally clear: there is no correlation between the changes of the import multiplier over time and the changes in Pasinetti's total labour coefficients.[32] This is true for the whole period and for the two sub-periods. This means that any change in the use of imported intermediate inputs in the production process does not give any information on the change in the to-

29 The Be-estimator runs an ordinary least square model based on the average of each variable over the time period.

30 This elasticity is larger than the absolute value of the import multiplier, suggesting that the use of imported intermediates is productivity enhancing.

31 The Fe-estimator runs the regression on each variable's difference between its yearly value and its average value over the time period.

32 NS means not significant at the 95 per cent level. To give the model somewhat of a causal interpretation, I have experimented with time lags of the control variables. These do not alter the results. The within and random effect estimations are adjusted for (robust) clusters.

33 However, this does not exclude the possibility that changes in the composition of the imported intermediates have had an effect on the domestic need for labour per manufacturing product.

tal labour coefficients.[33]

Finally, when estimating the model which combines the cross-sectional and the time dimension (Re: random effect), the result is also clear: there is no correlation between the import multiplier and the TLC.[34]

Supply Chain Productivity in Nordic Manufacturing Production

From a theoretical point of view, the vertically integrated productivity perspective more closely resembles real world production than the conventional, sectoral-based perspective, since trade in intermediate inputs, nationally and globally, is an essential part of any production system with any degree of specialization. From an empirical point of view, the previous section connected the use of imported labour – embodied in the intermediate inputs – with the domestic use of labour. By splitting the domestic production chain into separate parts, a similar connection can be made within the domestic economy. The main question then becomes the following: to what extent do different segments of the domestic production chain contribute to the reduction of Pasinetti's total labour coefficients?

In order to explore this empirically, I create two vertically oriented – but this time, value added based labour productivity measures. This is done using the following two matrices (vertical value added (VVA) and vertical employment(VEMP)):

$$VVA = \frac{VA}{GO}(I - A)^{-1}FD \qquad (4)$$

$$VEMP = \frac{EMP}{GO}(I - A)^{-1}FD \qquad (5)$$

Each column sum in VVA and $VEMP$ expresses the total value added and employment, respectively, needed somewhere in the domestic economy to satisfy each sector's final demand, including all subsequent rounds of intermediate demand. Consequently, if the value added and the employment generated within each sub-sector's "own" sector is excluded (e.g the value added and employment generated in motor vehicles from the final demand for motor vehicles),[35] the labour productivity of the sub-sector's domestic supply chains can be estimated. This is called supply chain productivity. "Own" productivity is identical to conventional, sectoral-based labour productivity.[36]

Table 3 summarizes the relation between these two productivity measures. Three conclusions emerge. First, in some sub-sectors, the productivity level is higher

34 The Hausman test shows that the fixed effect model is a more appropriate model than the random effect (Re) model.

35 With a matrix language, Miller and Lahr (2009) define these "own" sectors as the on-diagonal elements, or the internal linkages.

36 OECD (2001) argues that sectoral, value added based labour productivity is the most common productivity measure. This is thus a measure which focuses on separate sectors as they are defined in the national accounts and excludes the intermediate inputs that are used in the sector's production processes. The productivity of the whole domestic prodution process is just the weighted sum of the sectoral and the supply chain productivities. In practice, this can be found by dividing each sub-sector's column sum in VVA with its corresponding column sum in $VEMP$.

Table 3: Two Labour Productivity Measures in Nordic Manufacturing Production, Levels and Changes, 2001-14

	2001		2014		Δ2001-14 (%)		Supply Chain/ Sectoral	
	Sectoral	Supply Chain	Sectoral	Supply Chain	Sectoral	Supply Chain	2001	2014
Food, beverage, tobacco	51.2	40.0	108.0	90.6	5.9	6.5	0.78	0.84
Textile, clothing, leather	36.9	55.4	78.8	122.3	6.0	6.3	1.50	1.55
Wood and cork	46.8	63.7	80.5	126.9	4.3	5.4	1.36	1.58
Paper and pulp	91.4	65.8	132.7	134.2	2.9	5.6	0.72	1.01
Printing and recorded media	47.7	65.1	86.5	130.2	4.7	5.5	1.36	1.50
Coke and petroleum	145.0	115.9	187.6	324.7	2.0	8.2	0.80	1.73
Chemicals	98.0	60.1	241.4	176.6	7.2	8.6	0.61	0.73
Pharmaceuticals	119.9	57.9	338.3	169.6	8.3	8.6	0.48	0.50
Rubber and plastics	52.4	58.7	109.5	126.7	5.8	6.1	1.12	1.16
Other non-metallic	50.6	59.2	114.7	146.3	6.5	7.2	1.17	1.27
Basic metals	75.8	60.4	122.7	138.8	3.8	6.6	0.80	1.13
Metals, except machinery	47.5	58.1	98.3	128.1	5.8	6.3	1.22	1.30
Computer and electronics	109.2	53.9	225.2	117.0	5.7	6.1	0.49	0.52
Electrical equipment	57.2	56.2	131.1	118.0	6.6	5.9	0.98	0.90
Machinery and equipment	56.1	54.3	151.7	117.4	7.9	6.1	0.97	0.77
Motor vehicles	56.0	57.2	126.4	121.0	6.5	5.9	1.02	0.96
Other transport (e.g ships)	50.9	55.6	130.7	128.1	7.5	6.6	1.09	0.98
Furniture	47.2	55.7	99.6	119.0	5.9	6.0	1.18	1.19
Repair of machinery	46.8	55.9	109.2	121.4	6.7	6.2	1.19	1.11
Average	67.7	60.5	140.7	139.8	5.8	6.5	0.89	0.99

Note: The average is unweighted. Changes over time, (Δ 2001-14 (%)), are defined as the annual compound growth rate. Productivity levels are expressed in thousands of constant US dollars of value added per person engaged.
Source: WIOD and author's calculations.

from the sectoral than from the supply chain perspective, but in other sub-sectors the opposite is the case.[37] The last column shows that the largest positive difference for the supply chain measure in 2014 is found in coke and petroleum and Wood and cork, respectively.[38] In terms of the sectoral measure, the largest positive difference is found in pharmaceuticals and computer and electronics, respectively.

Second, in 2001 the supply chain productivity level did, on average, reach 89 per cent of the sectoral productivity level (i.e. 60.6/67.7). Due to a stronger supply chain productivity growth until 2014, there was a convergence between the two measures – leading to the conclusion that in 2014, the average level of productivity within the Nordic manufacturing production system is more or less the same in terms of sectoral and supply chain productivities (i.e. 139.8/140.7).

Third, the table indicates that the Spearman rank correlation between the two measures is rather weak. At a closer inspection, the rank correlation in 2001 amounted to 0.2, and in 2014 it had increased slightly to 0.25.

37 As can be seen from the table, the standard deviation is lower for the supply chain productivity. The reason for this is that the manufacturing sub-sectors use similar types of intermediate inputs to a substantial extent.

38 If the sectoral productivity is compared to Pasinetti's total labour coefficients, a few sub-sectors also stand out. For example, in 2014 computer and electronics improves its rank with five positions and printing and recorded media with four, when productivity is measured in value added terms instead of the total labour coefficients. Metal, excluding machinery, goes in the other direction to a similar extent. Other sub-sectors with a non-negligible difference between the two measures are basic metals, furniture and repair of machinery, respectively.

Table 4: Relationship between Total Labour Coefficients, Sectoral Productivity, Supply Chain Productivity and Import Multiplier in Nordic Manufacturing Industries

	2001-14			2001-08			2009-14		
	Model			Model			Model		
Dependent variable: TLC	Be	Fe	Re	Be	Fe	Re	Be	Fe	Re
Coefficients/elasticities									
Sectoral productivity	-0.613	-0.244	-0.303	-0.600	-0.424	-0.468	-0.578	-0.170	-0.236
Supply chain productivity	-0.749	-0.777	-0.721	-0.650	-0.622	-0.574	-0.807	-0.765	-0.774
Import multiplier	-0.475	-0.388	-0.441	-0.447	-0.383	-0.425	-0.553	-0.430	-0.492

Note: The table shows the correlations (elasticities) between three variables and Pasinetti's total labour coefficient (TLC) in Nordic manufacturing production. There were 1064 observations in 2001-14, 608 in 2001-08 and 456 in 2009-14
Source: WIOD, EU Klems and author's calculations.

Supply Chain Productivity in Nordic Manufacturing Production: An Econometric Exercise

With the two value-added based productivity measures analyzed in the previous section, it is possible to increase our understanding of the main forces behind Pasinetti's total labour coefficients. Therefore, in this section, the variation in TLC is explained by three separate parts of the manufacturing production process: (1) the sectoral productivity, (2) the supply chain productivity, and (3) the import multiplier. The main purpose of this set up is to answer the question: what is the relative contribution of these two productivity measures to the variation in Pasinetti's total labour coefficients?

Using the same econometric approach as before, we can expect very high R2-values, t-values and significance levels, as we are studying correlations between related productivity measures.[39] The main result from Table 4 is that a 1 per cent change in the supply chain productivity indicates a substantially larger effect on Pasinetti's TLC's than the same change in sectoral productivity, regardless of which model is estimated and what period is studied. For example, with the preferred Fe-model, and during the period 2001-14, a 1 per cent change in the supply chain productivity increased TLC by 0.78 per cent, but only by 0.24 per cent in terms of sectoral productivity.

This shows that a vertically integrated perspective, with a distinction between "own" and supply chain productivity, can give us new insights into the main drivers behind changes in Pasinetti's total labour coefficients – or the amount of labour needed in the domestic economy in order to finalize a manufacturing product. Finally, Table 4 indicates that the sectoral productivity performs relatively better with the Be-estimator; hence, when the time dimension is not considered, and the regressions are based on each variable's average value over the period. Consequently, this implies that the sectoral productivity measure is relatively worse in explaining the development of Pasinetti's total labour coefficients

39 Naturally, this indicates a strong reversed causality. The level of significance in all model estimations in Table 4 is above 99.9 per cent. The overall R2-values are often above 0.9, but in general they are decreasing after the financial crisis. The data used in the estimations is in log-log format. The Hausman test shows that the Fe-model is the appropriate model. The within and random effect estimations are adjusted for (robust) clusters. Using one and two time lags of the independent variables does not alter the results.

since the millennium. As can be seen from the table, this is especially the case after the financial crisis. During this period, the contribution to the variation in TLC is even more than twice as large for the import multiplier than for sectoral productivity.

Conclusion

Contributions and Main Results

The starting point of this article is that specialization, within and between countries, and an increased importance of knowledge-based capital in current growth processes, have led to a renewed interest in a vertically integrated perspective on productivity. This article contributes to this renewed interest by the use of Pasinetti's total labour coefficients in the context of Nordic manufacturing production. A second contribution of this article is the empirically based discussion of the contributions of the vertically integrated productivity perspective to the understanding of the current growth process among trade-dependent and highly specialized countries.

The main results are the following. Among the Nordic countries, Norway has improved its relative manufacturing productivity since the millennium, and this improvement is broadly based among the manufacturing sub-sectors.When the change in the use of imported intermediate inputs is considered, the strong Norwegian performance becomes even clearer. The flip side of this is that Sweden, on the relative scale, has lost its position as the productivity leader to Norway, and has also been surpassed by Denmark. However, on an absolute scale, it is clear that Finland's performance after the financial crisis has been particularly poor, and this is exacerbated if the rapid growth in the use of imported intermediate inputs is taken into account; despite the fastest growth of the import multiplier among the Nordic countries, the reduction in the domestic need for labour was the slowest.

This rather counterintuitive relation between the change in the use of imported intermediates and the change in the use of labour in the domestic economy is confirmed econometrically. Within the Nordic manufacturing production system, the development of the use of imported intermediates cannot say anything statistically significant about the rate of change in the amount of labour needed in the domestic economy in order to finalize a product. However, when the regressions are based on the time period average – and, hence, excluding any change in the variables during the time period – a large import multiplier is strongly associated with a low total labour coefficient.

To further investigate the main drivers behind Pasinetti's total labour coefficients, an empirical distinction is made between the conventional, sectoral based labour productivity measure and a productivity measure based on the domestic supply chain. With this approach, it is shown that the rank correlation between the two measures is low and that the latter has converged to the same level as the former since the millennium. Along these lines, an econometric exercise shows that the absolute contribution to the total labour coefficient is considerably greater in terms of supply chain productivity than in terms of sectoral based productivity. Predicting changes in Pasinetti's total labour coefficients without the vertically integrated perspective would thus leave out relevant information.

Some Policy Aspects

What is required to reverse the weak labour productivity growth that we have seen in the Nordic countries and the rest of the Western world after the financial crisis? At a fundamental level, this is, of course, about well-functioning markets, free trade and a modern infrastructure. Taking the starting point that Nordic manufacturing production is at the technological front, I would, however, like to emphasize the importance of a well thought out innovation policy and how such a policy contributes to moving the frontier.

In a recent survey of the research on policies to improve innovation, Bloom *et al.* (2019) consider that certain measures are indeed efficient in the short run, while others are more efficient in the long run and the political system tends to focus too much on the short run. In the short run, tax incentives for and public funding of R&D are of crucial importance but the longer is the perspective, the larger should the focus be on human capital – on how the quality of the production factor labour can be improved. This means that the educational system and its role for life-long learning should be given higher priority and that the responsibilities for employers increase in this respect. This also includes improving the quality of higher education and reforms to attract highly skilled labour from abroad. In Sweden, the resources the government spends on each university student has decreased by 30-50 per cent since the 1990s.

In addition, productivity-enhancing policies, according to the OECD (2015, 2016), should become more "holistic". For example, this includes considering the fact that growing income differences can damage the productive base of the economy and that low-wage jobs reduce aggregate productivity. Moreover, resource allocation is improved if the equality of educational opportunities increases, discrimination is pushed back and the social mobility moves in the right direction. A high level of well-being at work is productive and profitable.

Another aspect that should be pointed out in this context is that the rate of diffusion of new technology and knowledge within countries seems to have fallen, with the consequence that the productivity difference between globally oriented firms and other firms have increased. What should be achievements that all firms can invest in and benefit from, such as automatization connected to artificial intelligence, have so far mainly benefitted certain parts of the business sector. This leads to questions on how receptive domestically-oriented firms are to developments that mainly take place in globally oriented firms, but also to what extent new technologies are firm-specific and can only be spread to other firms with considerable supplementary investments.

This diffusion has become increasingly important since a larger share of the "capital" generating productivity growth is defined as intermediate inputs and is therefore distributed in the economy through the intermediate input structure. Accordingly, an important aspect for individual firms is to, as a subcontractor, connect to globally oriented firms. Becoming an indirect exporter is – in the light of the resources that are required and the difficulties that smaller firms might meet in their export venture – often good enough and beneficial to the economy in the same way as exporting on their own. Considering their central role as a subcontractor and their importance for the contemporary growth process, the knowledge-intensive business services constitute a key to the Nordic countries as future manufacturing nations. It is not about the manufacturing sector or the service sector – it is about both.

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