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Chapter 1

Introduction

The question of what drives productivity is a much discussed and often disputed subject. As such, both theory and empirics lean in many different directions. What this master-thesis investigates is how openness affects industrial sector productivity, using import and export as measures of openness. The analysis in this thesis looks specifically at the industrial sector, broken into different parts. This thesis does not look at the Norwegian economy as a whole, but concentrates on classical industry.

Openness can itself be a diffuse term. In this thesis, the term openness refers to the degree to which a country is interlinked with the outside world and a technological frontier. The degree of openness can be determined by anything from trade policy to the interest of industry in new markets. At any rate, here this link is gaged by the ratio of export and import to total production. Other works on the subject have used different measures of openness. Harding and Rattsø (2010) for instance use tariff policy as a measure of openness.

In order to narrow the scope of this paper, only a selected number of sectors of industry is included in the analysis. The dataset is in panel form, using several observations on the same sector over time. There are in all 11 sectors of industry, with observations from 1970 to 2011. The analysis completely disregards the service industry as it is traditionally non-exportable and non-importable, making import and export poor indicators of openness. Public services are also excluded for the same reasons. Furthermore, because the oil industry has such a unique role for the Norwegian economy in the time period, certain considerations are made for it as well.

The sectors included are primarily traditional industrial sectors such as mining, textiles and heavy machinery. These sectors are chosen to best represent what is considered traditional industry in Norway for the time period. This means that the findings in this thesis are directed at industry. A full list of the sectors included in the analysis can be found in appendix B (Table B.2).

1.1 Theory

The theory behind this thesis is based on an old idea of productivity growth and technology diffusion[1]. There is assumed to be a technological frontier, and for the purposes of this thesis, it is assumed the United States of America is this frontier. The productivity of other nations is subject to their own ability to catch up to the technological frontier.

Gerschenkron (1962) proposed a catch-up hypothesis which was formalized by Nelson and Phelps (1966). They offered a new hypothesis for describing economic growth. Productivity in the domestic economy depends on the implementation of discoveries made at the technological frontier. The technological distance to the frontier and the level of human capital in the country affects the rate at which the gap between the technological frontier and the domestic country is closed. Nelson and Phelps did not just consider human capital an input into the production function; the level of human capital represented more. Nelson and Phelps assumed that human capital entered the function indirectly through productivity growth.

Building on this, Benhabib and Spiegel asked why a country, or a firm within an industry, incurs costs in order to innovate, when seemingly they could use no extra resources and simply wait for technology diffusion to happen cost- and effortlessly. Mindful of this weakness in the Nelson and Phelps model, Benhabib and Spiegel made a logistic model of technology diffusion. The logistic model of technology diffusion ensured that in order to converge with the technological frontier, it required some minimum level of human capital. When Benhabib and Spiegel test their hypothesis with post-WWII data they report that their findings support their model.

Expanding on both the Benhabib-Spiegel and Nelson-Phelps model, this thesis looks at

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[1] See Veblen, T (1915), Imperial Germany and the Industrial Revolution

the possibility of openness playing a role in whether a country converges with the technological frontier or falls behind with little productivity growth. If the level of human capital in a country is high enough to allow for convergence with the technological frontier, but the level of openness is not, this would also lead to the country not converging with the technological frontier. As such, given a level of human capital, there is also a requirement of openness in order to attain substantial productivity growth, according to this model. The level of human capital and openness also determines the rate at which the convergence with the technology frontier happens. The Benhabib-Spiegel and Nelson-Phelps models are covered in chapter 2.

1.2 Total Factor Productivity

In order to observe productivity, this thesis uses total factor productivity (TFP). TFP accounts for the output that is not attributed to the physical measurers of input such as labor and capital. Below is an expression of the TFP growth.

$$A_g = Y_g - \alpha L_g - (1 - \alpha) K_g \tag{1.1}$$

The TFP growth rate[2] (A_g) is the production growth, Y_g minus the labor growth L_g and capital growth K_g weighted by the parameter α. In the Cobb-Douglas production function, α is the exponent. This aspect of the thesis is explored in chapter 4.

A critique that can be made against this way of representing TFP is that it oversimplifies labor and capital as factors of production. Looking at capital specifically, there are many different types of capital goods and it might not be natural to look at them as the same thing. Furthermore, aggregating all the capital in a specific sector and saying it is now macro-level data might also be overly simple[3]. However, for the purposes of this thesis, this simple representation should be sufficient.

TFP was calculated based on data from Statistics Norway. A_g was calculated for each year and for the 11 sectors. Because the form[4] of the source data required me to make it growth-form, some observations fall away, reducing the sample.

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[2] The g denotes that these are growth rates

[3] See Cambridge capital controversy

[4] The data is in panel form. See 4.3 and 5.5 for more on panel form data

The US TFP or US multi-factor productivity (mfp) is also included in the analysis. A problem with the US TFP is that I was not able to find US TFP divided into sectors resembling the ones used on the Norwegian data. By repeating the time series for aggregated US TFP in each Norwegian sector for the period I circumvented the problem. Again, this is hardly optimal, but for the purposes of this thesis it should be workable.

1.3 Econometrics

In order to investigate if openness is a determinant of productivity, an econometric study is required. The analysis is done using the error-correction model. This model allows for easy analysis of long-term relationships. The model also works with lagged values, which can to some degree help deal with some of the econometric challenges that are related to this analysis.

There are several problems that are associated with the subject of openness with regards to productivity and some more general econometric challenges that need to be handled in this thesis. A problem with using panel data is that it may no longer be reasonable to assume that all observations are independent of each other, as there are repeated observations of the same units over time. Endogeneity is a problem when looking at how openness affects productivity. The problem arises as the measure of openness is very likely correlated with some other factor(s) that effect TFP[5].

Self-selection is another problem, especially when looking to export in order to describe productivity. Aw, Chung and Roberts (1998) look at the idea that higher productivity producers self-select themselves into highly competitive export markets. They find evidence for self-selection. Matters relating to econometrics are covered in chapter 5.

1.4 Results

The statistical analysis is based on two regressions. One is focusing on the effect of export as part of production's (*exp_p*) role in determining domestic productivity, while the other

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[5] See Edwards (1997) and Lee, Ricci and Rigobon (2004)

looks at import as part of production's (*imp_p*) role. Furthermore, the analysis is conducted with and without the oil sector in order to determine if it drives any of the findings. The full specifications using export[6] as a measure of openness are found below[7].

$$\begin{aligned}\Delta lnTFP\_I_{it} =& \delta + \theta lnTFP\_I_{i,t-1} + \beta_1 \Delta exp\_p_{it} + \beta_2 exp\_p_{i,t-1} \\ & + \beta_3 \Delta lnmfp\_I_{it} + \beta_4 lnmfp\_I_{i,t-1} + \beta_5 exp\_p_{i,t-1} \times mfp\_I_{i,t-1} + \epsilon_{it}\end{aligned}$$

Stability requires that θ is both negative and between 0 and -1. This requirement is generally fulfilled and significant.

Both export and import as part of production comes out as having a positive and mostly significant effect on TFP growth. These effects seem to be there both in the short- and long-term. What this means is not immediately clear. Whether export and import as part of production is a good measure of openness and this shows openness yielding higher productivity, or if there are some other effects at hand is not self-evident.

Removing the petroleum sector from the analysis does not have much effect on import; however the export analysis has its coefficients reduced while mostly retaining signs and significance. One way to interpret this would be that the oil sector has a more profound effect on export than import. At any rate, export and import as part of production should be considered separately.

The technological frontier represented by US TFP is also included in the analysis. The lagged US TFP is significant and positive in more or less every specification. However the interaction term between the openness terms and US TFP never come out as significant at the 5%-level. This means that US TFP drives productivity to some degree, but is not significantly linked to export and import as measures of openness.

The analysis is repeated for the same data, but using only every third observation. The reason for this is that it will hopefully reduce the results driven by shocks. The result of this part of the analysis is somewhat ambiguous. When using export as an indicator of openness, the results are not structurally changed. However, when considering import as a measure of

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[6] The full specification using import as a measure of openness is exactly like this one with the exception that all the export terms are replaced with their corresponding import terms.

[7] See appendix B for full variable description.

openness, the results come out quite different compared to the initial results when using all observations. The results of the econometric analysis can be found in chapter 6.

Chapter 2

Theoretical Backround

When considering the *productivity of a nation's industry*, the issue of what determines the productivity growth rate becomes important. The focus in this paper will be on how import and export affects total factor productivity growth. The presumption is that in trade, there are productivity gains through absorption of foreign technology.

To begin with, it is assumed that there is perfect openness in the economy. This means that there are no barriers to technology diffusion due to policy that hinders openness between countries.

Foreign technology is the technology theoretically obtainable. This can also be called a technology frontier. For the purposes of this paper, the total factor productivity of the US is assumed to represent this frontier.

2.1 Nelson and Phelps

The Veblen-Gerschenkron catching-up hypothesis was formalized by Nelson and Phelps (1966). This states that the more backward the economy is, the larger the possibility of productivity growth. They went on to posit that a more educated labor force could more easily implement productivity increasing technology. That is, the human capital level impacts how technology is absorbed.

Nelson and Phelps used the following example from US agriculture to illustrate human capital guiding technological diffusion: *"The better educated farmer is quicker to adopt prof-*

itable new processes and products since, for him, the expected payoff from innovation is likely to be greater and the risk likely to be smaller; for he is better able to discriminate between promising and unpromising idea, and hence less likely to make mistakes."

Nelson and Phelps consider the following production function, where output, Q, is a function of L (labor), K (capital) and t (time).

$$Q(t) = F[K(t), A(t)L(t)] \tag{2.1}$$

The variable $A(t)$ reperesents an index of technology in practice. It gauges the level of technology. Furthermore, they also introduced a theoretical level of technology, $T(t)$, comparable to the technology frontier mentioned earlier. The assumption is that the theoretical technology level advances exogenously at λ, a constant exponential rate ($\lambda > 0$). T_0 is the initial level of technology at the frontier.

$$T(t) = T(0)e^{\lambda t} \tag{2.2}$$

The model of $A(t)$ describes how the rate at which the latest technology is realized in improved technological practice is dependent on human capital, h, and on the gap between the technological frontier and real technological attainment.

$$\dot{A}(t) = \Phi(h)[T(t) - A(t)] \tag{2.3}$$

$$\frac{\dot{A}(t)}{A(t)} = \Phi(h)\left[\frac{T(t) - A(t)}{A(t)}\right] = \Phi(h)\left[\frac{1}{A(t)/T(t)} - 1\right] \tag{2.4}$$

$$\Phi(0) = 0,\ \Phi'(h) > 0$$

In order to get a better understanding of the dynamics of equation (2.4) the first and second derivative is found. Using this information, figure 2.1 is constructed.

$$\frac{d\left(\frac{\dot{A}(t)}{A(t)}\right)}{d\left(\frac{A(t)}{T(t)}\right)} = -\Phi(h)\left[\frac{A(t)}{T(t)}\right]^{-2} < 0$$

$$\frac{d^2\left(\frac{\dot{A}(t)}{A(t)}\right)}{d\left(\frac{A(t)}{T(t)}\right)^2} = 2\Phi(h)\left[\frac{A(t)}{T(t)}\right]^{-3} > 0$$

Because the first derivative is negative and the second derivative is positive, we know that the curve is falling and convex respectively. Furthermore, if we set $A(t)/T(t) = 1$, from (2.4) we have that $\dot{A}(t)/A(t) = 0$ and conversely if $A(t)/T(t)$ goes towards zero, $\dot{A}(t)/A(t)$ will go towards infinity.

In the long-run, the model predicts convergence, so in the long-run the domestic technology advancement matches that of the frontier.

$$\frac{\dot{A}(t)}{A(t)} = \lambda \text{ (long-run)} \tag{2.5}$$

Combine (2.4) and (2.5) and solve for the relative productivity, A/T :

$$\lambda = \Phi(h)\left[\frac{1}{A(t)/T(t)} - 1\right] = \Phi(h)\frac{1}{A(t)/T(t)} - \Phi(h)$$

$$\lambda + \Phi(h) = \frac{\Phi(h)}{A(t)/T(t)}$$

$$\frac{A(t)}{T(t)} = \frac{\Phi(h)}{\lambda + \Phi(h)}$$

Here we have the long-term equilibrium solution showed in figure 2.1. As stated above; in the long-run with a positive h, λ is equal the rate at which the level of technology in practice increases, $\dot{A}(t)/A(t)^1$. Imagine for a second that the domestic economy is to the left of the long-run equilibrium ($\dot{A}(t)/A(t) > \lambda$) in figure 2.1. The TFP growth rate is greater than that of the technological frontier. This means that the productivity relative to the technological frontier ($A(t)/T(t)$) is increasing. In the long-run, the domestic economy will converge with

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[1] The partial derivative with regard to time

the technology frontier. Conversely, if the domestic economy is to the right of the long-run equilibrium, the opposite would happen. If domestic TFP growth is lower than that of the technological frontier, yielding a decreasing productivity relative to the technological frontier until the point where the TFP growth matches that of the frontier.

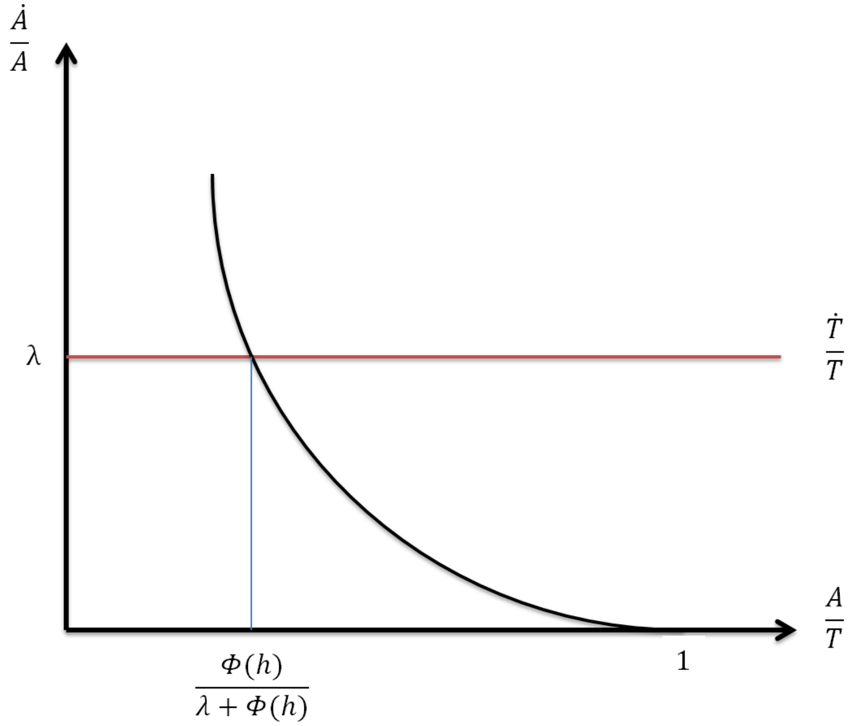

Figure 2.1: Nelson-Phelps: Path of technology

An important point in this is that the further the economy is from the frontier, the more it can learn and improve. The speed at which the equilibrium is achieved in figure 2.1 is contingent on the distance to the technological frontier, which is expressed by the relative productivity on the x-axis.

A point Nelson and Phelps made with this short article[2] is that the simple insertion of some index of educational attainment in the production function could lead to misspecification of the relation between education and the intricacies of production. They instead tried to describe the dynamics of production using a technological frontier, human capital, and how those factors relate. The introduction of openness as a factor on production is introduced later in this chapter.

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[2] 7 page article in American Economic Review 56, pages 69-75.

Modified Nelson-Phelps model

Benhabib and Spiegel (1994) presented the original Nelson-Phelps model of technology diffusion in a different way. They added a term to capture innovation ($g(h)$). In this modified model there are now two sources of productivity growth, the catch-up to the technological frontier and innovation. Both are contingent on the level of human capital.

$$\frac{\dot{A}(t)}{A(t)} = g(h) + c(h)\left[\frac{T(t)}{A(t)} - 1\right] \tag{2.6}$$

Here $A(t)$ is the total factor productivity, $g(h)$ is the contribution to TFP growth that originates from innovation which in turn is driven by the level of education (human capital), h. The technology adoption from the technological frontier to the domestic country is expressed by $c(h)\left[\frac{T(t)}{A(t)} - 1\right]$. The level of education, h affects the rate at which the technological gap is closed $\left[\frac{T(t)}{A(t)} - 1\right]$. The concept of human capital as its own factor is new here. Benhabib and Spiegel (1994) added the $g(h)$ term to the original Nelson-Phelps model. Figure 2.2 illustrates the modified Nelson-Phelps model. Notice the difference between figure 2.1 and 2.2. The introduction of the $g(h)$ term "lifts" the TFP growth path above the x-axis in figure 2.2.

In this model, the frontier country will work as the lead rider in a cycling race, pulling all the other riders behind him and shielding them from drag. The catch-up mechanism here means that all countries grow at the same rate eventually, even with different levels of education [3].The level of human capital only determines the speed at which the technological frontier is reached. Note that this holds for both the original and the modified Nelson-Phelps models.

2.2 Trade and openness

The discussion earlier in this chapter has centered on how much an economy has to learn (the technology gap) and the ability of the workforce to utilize and understand the technology they are presented with (human capital). Up to this point perfect access to the technology

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[3] This is known as the confined exponential diffusion process. See: Banks(1994).

frontier has been assumed. Moving forward, it will be considered to which degree the economy has access to other technology. That is, to which degree they participate in an international setting where they are forced to adapt and learn.

There is a rich literature about how openness and interaction with the rest of the world affects the total factor productivity. Rattsø and Stokke (2012) establish an index of openness which they then use to investigate the effect of on among other things, productivity in South Africa. The authors use the Benhabib and Spiegel logistic technology diffusion framework. They find that permanent anticipated trade liberalization leads to a higher long-run productivity level. In their model, the degree of openness is determined by foreign capital. In this thesis however, the degree of openness is wholly exogenously determined.

Coe et al. (1997) investigate the effect of foreign R & D and look at the spillovers from trade. They report that return to R & D capital is very high with regards to domestic and international spillovers. Rattsø and Stokke (2012) also suggested that technology spillovers as a result of openness were important.

The inclusion of an estimator for openness that has an effect on the human capital and its ability to utilize foreign technology could be a legitimate extension of the Benhabib-Spiegel approach. If there are barriers to technology transfer, it must be taken into account.

$$\frac{\dot{A}(t)}{A(t)} = g(h) + s(x)c(h)\left[\frac{T(t)}{A(t)} - 1\right] \tag{2.7}$$

Where s is an increasing function of the degree of openness x. When x goes to infinity, then $s = 1$. In any other case $0 < s(x) < 1$. It is important to note that this does not change any of the existing dynamics of the Benhabib-Spiegel approach; it only adds a new dimension of considering openness. The reason that it does not change any of the dynamics is because x is an exogenous variable.

Even if the dynamics remain unchanged, the inclusion of $s(x)$ changes the long-term equilibrium. As before, in the long-run with a positive h, λ is equal the rate at which the level of technology in practice increases, $\dot{A}(t)/A(t)$. We use this and solve for $\dot{A}(t)/A(t)$.

$$\lambda = g(h) + s(x)c(h)\left[\frac{T(t)}{A(t)} - 1\right]$$

$$\lambda = g(h) + s(x)c(h)\frac{T(t)}{A(t)} - s(x)c(h)$$

$$\lambda + s(x)c(h) - g(h) = -s(x)c(h)\frac{1}{A(t)/T(t)}$$

$$\frac{A(t)}{T(t)} = \frac{s(x)c(h)}{s(x)c(h) + \lambda - g(h)} = \Omega > 0$$

Note that it would be natural to assume that $\lambda > g(h)$, as the technology frontier should have the highest level of human capital.

$$\lim_{t\to\infty} \frac{A(t)}{T(t)} = \Omega \tag{2.8}$$

Because of the assumption $\lambda > g(h)$, the denominator will always be greater than the numerator. If the assumption holds, the following must also be true

$$0 < \Omega < 1$$

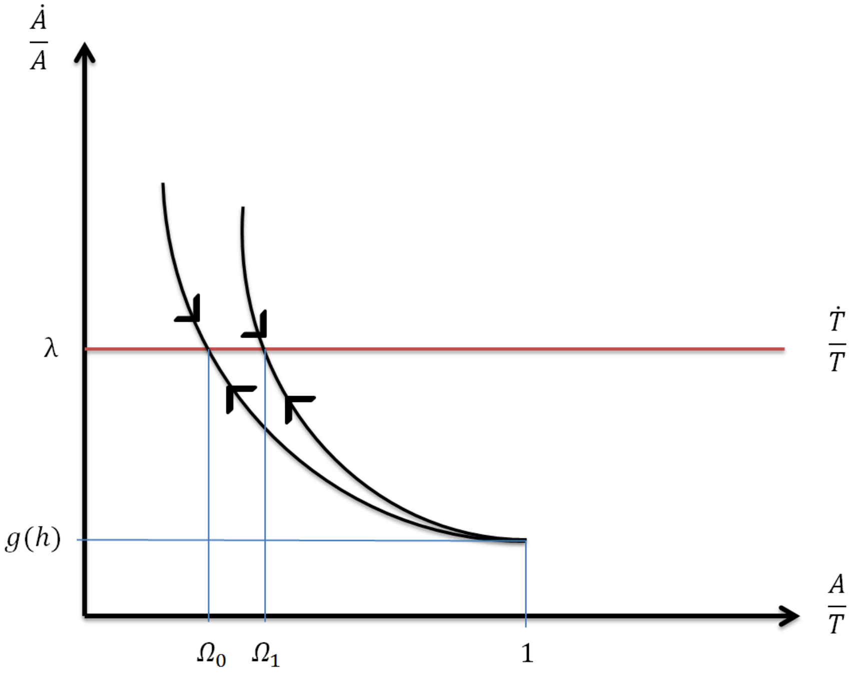

Figure 2.2: Effects of increase in openness on modified Nelson-Phelps productivity dynamics

If we assume that h is constant and the technology leader has long-term TFP growth at λ, figure 2.2 can serve to show the dynamics graphically. Figure 2.2 illustrates two different degrees of openness, with differing equilibriums ($\Omega_0 \neq \Omega_1$). Notice that both converge with the technology frontier. On the left hand side of the equilibrium, the TFP growth rate is higher than the technological frontier. This means that the relative productivity (A/T) is increasing. This continues until the TFP growth rate is matched with the technological frontier. Note that the domestic TFP level is lower than the technological frontier at equilibrium even if the growth rate is the same.

With constant h, the solution to the differential equation in (2.7) is seen below where $T(0)$ and $A(0)$ represent the initial levels of technology in the technology frontier and domestic country respectively.

$$A(t) = (A(0) - \Omega T(0))e^{(g(h)-s(x)c(h))t} + \Omega T(0)e^{\lambda t} \tag{2.9}$$

The result in this model would be that eventually all countries grow at the same rate. What the degree of openness changes is both the speed at which convergence with the technological frontier occurs as well as the long-run equilibrium relative productivity. If the degree of openness is increased, there is a long-term effect on the TFP level ($\Omega_0 \rightarrow \Omega_1$).

2.3 The logistic model of technology diffusion

Benhabib and Spiegel (2005) modified the Nelson and Phelps catch-up model of technology diffusion. Their model accounted for logistical technology diffusion, where some nations exhibited high growth and some low, depending on the levels of human capital. That is, the logistical model limits the advantage of relative backwardness where the Nelson-Phelps model does not. This opens up for the possibility of divergence relative to the technological frontier. Based on an empirical test of a cross-section of nations during 1960-1995, Benhabib and Spiegel find evidence for their logistic diffusion. This is the logistic model of technology diffusion expanded with the inclusion of openness.

$$\begin{aligned}\frac{\dot{A}(t)}{A(t)} &= g(h) + s(x)c(h)\left[1 - \frac{A(t)}{T(t)}\right] && (2.10)\\ &= g(h) + s(x)c(h)\left[\frac{T(t)}{A(t)} - 1\right]\left[\frac{A(t)}{T(t)}\right] && (2.11)\end{aligned}$$

In the new model a new term is introduced, $\left[\frac{A(t)}{T(t)}\right]$. This makes the difference in the dynamics of the model. Benhabib and Spiegel make the point that this term dampens the rate of diffusion as the distance to the technological frontier increases. They speculate that this might be the result of difficulty of adopting technologies far ahead of their own.

To better understand the path of $\dot{A}(t)/A(t)$, the first and second derivative with regards the relative productivity is found.

$$\frac{d\left(\frac{\dot{A}(t)}{A(t)}\right)}{d\left(\frac{A(t)}{T(t)}\right)} = -s(x)c(h) < 0$$

$$\frac{d^2\left(\frac{\dot{A}(t)}{A(t)}\right)}{d\left(\frac{A(t)}{T(t)}\right)^2} = 0$$

From this it is apparent that the curve is falling and linear. Moreover, from (2.10) we have that if $A(t)/T(t)$ goes towards zero (as a result of $T(t)$ being very high relative to $A(t)$), $\dot{A}(t)/A(t)$ does not go towards infinity as we found in the original Nelson-Phelps model. On the other end of the scale, where $T(t) = A(t)$, we have that simply $\dot{A}(t)/A(t) = g(h)$. See figure 2.3 and 2.4 for a graphical representation of this.

As earlier, the long-term equilibrium is found by using $\lambda = \dot{A}(t)/A(t)$, then solving for the relative productivity.

$$\lambda = g(h) + s(x)c(h)\left[1 - \frac{A(t)}{T(t)}\right]$$

$$\lambda - g(h) - s(x)c(h) = -s(x)c(h)\frac{A(t)}{T(t)}$$

$$\frac{A(t)}{T(t)} = \frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)} \tag{2.12}$$

In figure 2.3, the case with high and low human capital ($h_1 > h_0$) is presented. Here, the degree of openness is constant. Because the level of human capital is so low at h_0, in this instance, there will be no convergence with the technological frontier. If the human capital is sufficiently low, the previous assumption of $\lambda = \dot{A}(t)/A(t)$ will not hold, and the equilibrium found above in (2.12) will not be achieved. Reducing the level of human capital also reduced the slope of the curve. Figure 2.3 also shows the case where the human capital level is sufficiently high (h_1) to result in convergence.

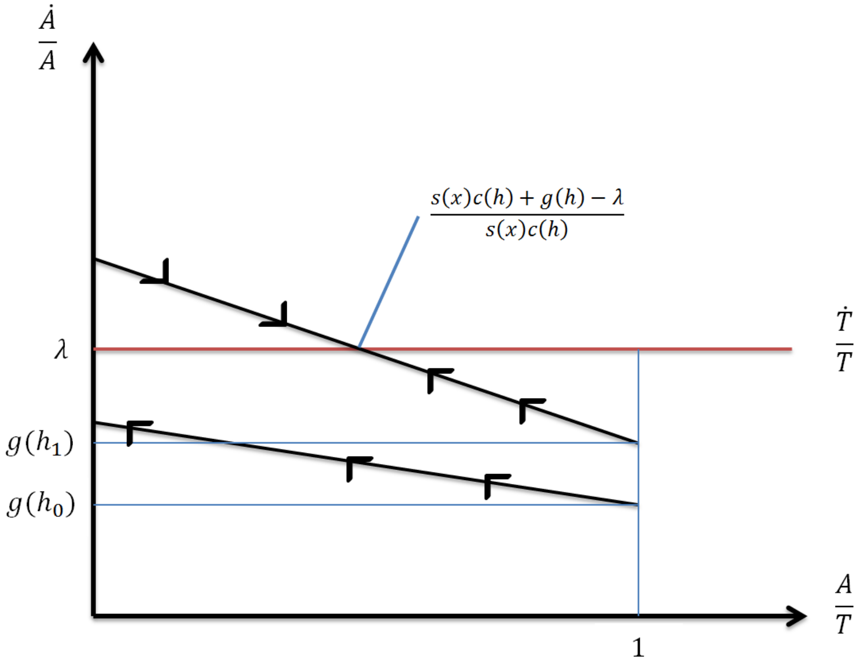

Figure 2.3: Logistic technology diffusion with low and high human capital

The result of low human capital might be *convergence clubs*. This is where some countries are able to keep up with the lead rider, while others fall off (diverge) creating another group of cyclists. In theory, the ones that diverge could get back to a converging path with the technological frontier if they increase their investment in human capital ($h_0 \rightarrow h_1$) or increase their openness.

The degree of openness plays an important role here. If there is non-perfect openness, that is if $s(x) < 1$, the ability to learn from the frontier is hindered.

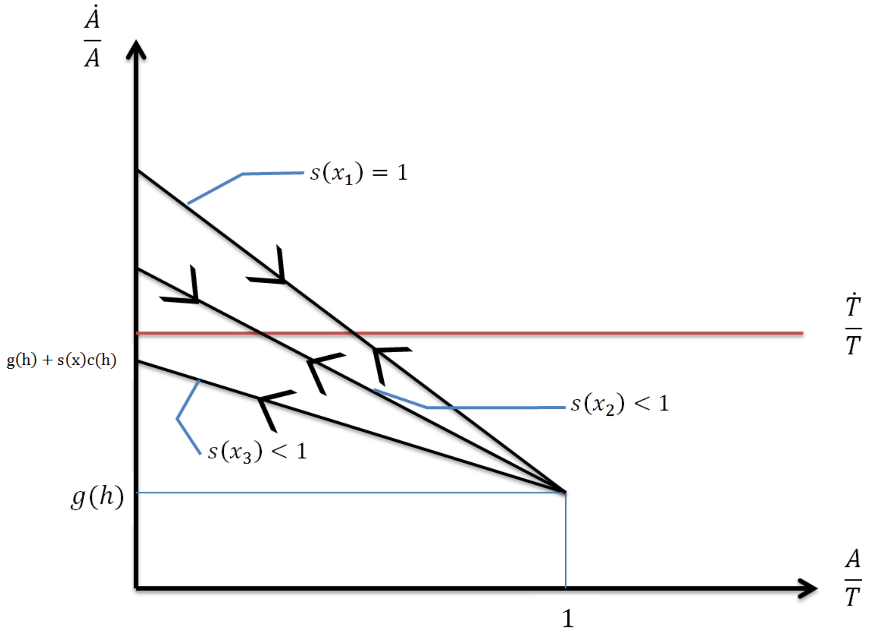

Figure 2.4: Logistic diffusion with and without barrier to technology transfer

In figure 2.4, the degree of openness is explored in a logistic technology diffusion model. The degree of openness varies between $s(x_1) > s(x_2) > s(x_3)$. When there is sufficient openness ($s(x_1)$ and $s(x_2)$), the domestic economy will converge with the technological frontier. However, if the barriers to openness are large enough ($s(x_3)$), there will not be convergence and growth will not converge with λ or $\frac{\dot{T}}{T}$ which is the long-term growth of the technology frontier.

To get a better understanding of the dynamics involved, a closer look at the logistic growth equation might be informative. We can express these types of growth in stationary variables by defining the following (Benhabib and Spiegel (2005)):

$$B(t) = \frac{A(t)}{T(0)} e^{-\lambda t} \tag{2.13}$$

And for the logistic growth:

$$\frac{\dot{B}}{B} = s(x)c(h)(1 - B) + g(h) - \lambda \tag{2.14}$$

$$\dot{B} = (s(x)c(h) + g(h) - \lambda)B - s(x)c(h)B^2 \tag{2.15}$$

Given fixed h and x, the solution can be shown to be

$$B(t) = \left(\frac{s(x)c(h) + g(h) - \lambda}{s(x)c(h)}\right) \left[1 + \left(\left(\frac{s(x)c(h) + g(h) - \lambda}{s(x)c(h)}\right)\left(\frac{T(0)}{A(0)}\right) - 1\right) e^{-\left(\frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)}\right)t}\right]^{-1} \tag{2.16}$$

In order to better understand (2.16), we will take a closer look at what happens at different levels of human capital and openness. For the purposes of the analysis, it does not matter if it is human capital or openness that varies. The issue is if $s(x)c(h) + g(h) - \lambda >$ or $=$ or < 0. For a more thorough and comprehensive look at the math, see appendix C.

First, we will have a look at the case where $s(x)c(h) + g(h) - \lambda > 0$. The pivotal expression in (2.16) here becomes the exponential term at the end. When $t \to \infty$, the right hand term in the square brackets goes toward zero. The result of this can be seen below in (2.17).

$$\lim_{t\to\infty} B(t) = \left(\frac{s(x)c(h) + g(h) - \lambda}{s(x)c(h)}\right) \tag{2.17}$$

In the next case, we turn the previous case on its head and get $s(x)c(h) + g(h) - \lambda < 0$. In this instance, the openness or human capital was not strong enough to contend with the foreign productivity growth. In other words, this is a non-converging path. The long-term solution of such a path is seen below in (2.18).

$$\lim_{t\to\infty} B(t) = 0 \tag{2.18}$$

To illustrate the concept of *convergence clubs*, here is a plain representation of the rule that dictates which *club* you belong to.

$$\lim_{t\to\infty} \frac{A(t)}{T(t)} = \begin{cases} \frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)} & \text{if } s(x)c(h) + g(h) - \lambda > 0 \\ 0 & \text{if } s(x)c(h) + g(h) - \lambda \leq 0 \end{cases}$$

This shows how a country's level of education compared to the technological frontier determines whether the country converges or diverges. Intuitively, a highly skilled worker in a highly developed economy would profit from a slightly faster computer while a worker in a barley industrialized society would not even know how to operate it.

Furthermore, the inclusion of $s(x)$ means that the level of openness also helps determine which *convergence club* any given country would belong to.

2.4 Hypothesis

Based on the theory in this chapter, it is possible to make a hypothesis that can be tested in the econometric part of this thesis. The theory developed in this chapter points to there being a link between openness and productivity growth. Whether this link is a short-term adjustment or a long-term equilibrium could possibly be interesting to look at.

Based on the theory, increased openness should give a temporary positive effect on the productivity growth rate. This would be a short-term effect when catching up to the technological frontier. Furthermore, the theory predicts that openness has a permanent (long-term) effect on the productivity level. The logistic model also predicts a long-term effect on the growth rate given low enough h and x, however this is likely unrealistic for Norway. In the empirical part of this thesis I will test and discuss the hypothesis presented here.

Chapter 3

Existing Emperical Studies

In this chapter econometric studies relevant to this thesis will be covered. I could not find any one study that included all the same aspects of the thesis. I was however able to find many different studies that covered different aspects of this thesis. Because openness is the focus of this thesis, emphasis will be put on empirical work dealing with this. A portion of this chapter will also be dedicated to exploring self-selection.

Hall and Jones (1999) compared high and low productivity nations, showing that it is not only physical capital and educational level that explains income levels, but also social structure. Applying this to Norway, where there are high levels of physical capital, educational level as well as an excellent social structure, the evidence from their empirical study suggests that Norway should have high productivity. Furthermore, they show that influence by Western Europe is also a determinant of productivity, which again fits well with Norway.

Benhabib and Spiegel (as discussed in chapter 2) test their theory that countries with sufficiently small capital stock will have trouble catching up to the technological frontier. They report robust findings that their theory is correct. This leads them to conclude that human capital indeed plays a positive role in determining total factor productivity. They do however warn that the performance of human capital on its own is less robust.

Further, they make predictions based on their model that empirically seem to prove their point, that there is a critical level of human capital needed for positive productivity growth in the period 1960-1995. In other words, they likely found evidence for *convergence clubs* which were discussed in chapter 2.

Møen (1998) finds that there was weak Norwegian productivity growth in the 1980s. When dividing the economy into sectors, the author finds differing productivity growth rates. He singles out among others machinery, metal and electrical work and repair (sector 9) as a high productivity growth sector in the period.

3.1 Openness

There are many examples of studies that look at openness as a factor in determining growth. The results seem to show that openness empirically is a positive factor in TFP. The problem and an often used criticism is that the measure of openness is endogenous.

Fischer (2001) makes the point that trade can have positive effects on some while it can have negative effects on others. The winners and losers in an economy or between nations are determined by their characteristics. Furthermore, Fischer acknowledges the methodological challenges with doing empirical work on the effects of openness.

Harding and Rattsø (2010) look at the effect of tariffs on labor productivity. They note that tariff policy is designed to promote economic development and the industrial sector tariffs structure may very well reflect characteristics of the industries that they are designed to protect. This would lead to tariff policy endogenity. They take advantage of multilateral tariff liberalization by looking at reduction in industrial sector tariffs in other countries over the period 1988-2003 and use this information as an instrument for sectoral tariff reduction in South Africa.

Moreover, Harding and Rattsø observe that the OLS [1] estimates show a downward bias, which they claim confirms the endogenity of tariffs. They feel that they have circumvented the methodological challenge of tariff policy endogenity by using other countries' sectoral tariff developments as predictors of tariff policy in South Africa. Their analysis links tariff reduction to increasing labor productivity in the South African industrial sectors for the period. Harding and Rattsø also find some support for the importance of the world technology frontier. The world technology frontier is represented by labor productivity in US industries[2].

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[1] Ordinary Least-Squares

[2] This is also done in this paper. See chapter 4, 5 and 6

Harding and Rattsø also have a 2005 paper that uses South African data from 1970 to 2003. This paper investigate how large changes in South Africa [3] affects its growth. Their findings support the barrier model of productivity growth. The model establishes a long-run relationship between productivity and the world technology frontier. Changing the degree of openness (barriers) can add transitional growth.

Edwards (1998) investigates the relationship between openness and TFP growth in an alternative way that takes into account the problem of endogenity of openness measures. This paper uses 9 alternative indexes of trade policy. Edwards tests if all things being equal, TFP growth is faster with more openness.

The results reported are robust and indicate that more openness usually means faster productivity growth. The instruments used were chosen to deal with endogenity, but the author is unsure to what degree they in reality resolve the problem .

Rodriguez and Rodrik (1999) ask if countries with lower policy-induced barriers to international trade grow faster, given ceteris paribus conditions. They go at this problem by looking back at earlier work and pointing out the weaknesses they perceive. They say that earlier results that strongly favor openness as a route to better productivity and growth are up for interpretation.

Rodriguez and Rodrik claim that the indicators of openness used by researchers are either poor measures of trade barriers or highly correlated with other sources of bad economic performance. Edwards (1998) is among authors that have their methodology criticized by the authors. The conclusion of the paper is that there is little evidence that lower tariffs and non-tariff barriers result in strong economic growth. This conclusion is not to be confused with the result that openness is bad for trade, which there most definitely is no evidence for, according to the authors. Rodriguez and Rodrik make the point that the importance or effect of openness is overstated. In other words: openness is probably good for trade, but not to the degree claimed in some of the research mentioned in this paper.

Lee, Ricci and Rigobon (2004) further question the relationship between openness and growth. They posit that the endogeneity problem is very tricky to handle. They use identification through heteroscadasticity methodology to estimate the effect of openness on growth

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[3] Using sanctions related to the apartheid regime.

while controlling for the effect of growth on openness. In the end, Lee, Ricci and Rigobon find that there is a positive effect from openness on growth. However they do point out that it is not very large.

Balsvik and Haller (2011) use a panel set of Norwegian manufacturing plants to look at how the openness term might be lacking by itself. There is more than one type of openness. They argue that the effects of a foreign presence on the host country productivity may differ depending on the mode of foreign entry. They argue that their findings might help explain some of the ambiguous results in the literature.

The authors find that when the foreign entry is by acquisition of existing production, the productivity of the domestic plants in the same industry is positively affected. This is probably a result of preexisting linkages and classical knowledge spillover.

On the other hand, greenfield entry [4] in the same labor market region and in the same industry has a negative effect on the productivity of domestic plants. The increase in competition and reduced access to production inputs such as qualified labor is given as a cause of this negative effect.

3.2 Self-Selection

While there is a lot of evidence that indicates exporting producers have higher productivity than non-exporting producers, the mechanisms that create this relationship might be unclear. The Aw, Chung and Roberts (1998) paper investigates the idea that higher productivity of exporters might just be a result of self-selection of more efficient producers into highly competitive export markets.

Aw, Chung and Roberts use micro data from a manufacturing census in South Korea and Taiwan to study the link between TFP of producers and whether or not the producer chooses to participate in the export market. Their findings are that if initial productivity is high, the producer will enter the export market. However, if the producer has low productivity, the producer will tend to exit the export market.

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[4] Greenfield entry is when there is the establishment of a new wholly owned subsidiary without any existing constraints imposed by prior work, facilities etc.

Furthermore, Aw, Chung and Roberts find that in several industries, the entry into the export market leads to relative productivity improvements. Something the authors refer to as learning-by-exporting. There are however differences between the findings for South Korea and Taiwan. For example, in the case of South Korea, there seems to be no evidence of productivity increase as a result of export.

Clerides, Lach, and Tybout (1996) using manufacturing data for Colombia, Mexico and Morocco and Bernard and Jensen (1999) using U.S. manufacturing data come to the conclusion that self-selection plays an important part in investigating if export has a causal role in generating higher productivity.

Chapter 4

Calculation of Total Factor Productivity Growth

Total factor productivity (TFP), which is also called multifactor productivity, is a way of accounting for output that cannot be attributed to traditional measures of input such as labor and capital. A way to interpret TFP is to consider it as the long-term technological change which can be decomposed into technological growth and efficiency. Since TFP cannot be measured directly, an alternative method must be devised.

4.1 The Cobb-Douglas equation

Below, there is a Cobb-Douglas equation that shows the total output (Y) as a function of capital input (K) and labor input (L). The effect of these two inputs is then determined by the total factor productivity (A). The share of contribution from labor and capital is determined by α. It is clear that an increase in labor, capital or TFP would lead to an increase in output.

$$Y = AL^{\alpha}K^{(1-\alpha)} \tag{4.1}$$

With basis in this Cobb-Douglas production function, the next step in finding a measure for TFP is to change the above function into growth form. This will also change the inputs to growth form. To achieve this, the logarithmic form is introduced.

$$ln(Y) = ln(AL^{\alpha}K^{(1-\alpha)}) = ln(A) + \alpha ln(L) + (1-\alpha)ln(K) \tag{4.2}$$

and then the implicit derivation with regards to time

$$\frac{\dot{Y}}{Y} = \frac{\dot{A}}{A} + \alpha\frac{\dot{L}}{L} + (1-\alpha)\frac{\dot{K}}{K}$$

$$\widehat{Y} = \widehat{A} + \alpha\widehat{L} + (1-\alpha)\widehat{K} \tag{4.3}$$

In the equation below, TFP growth ($\widehat{A}$) is determined by production growth ($\widehat{Y}$), capital growth ($\widehat{K}$) and employment growth ($\widehat{L}$)

$$\widehat{A} = \widehat{Y} - \alpha\widehat{L} - (1-\alpha)\widehat{K} \tag{4.4}$$

With this measure of TFP growth, there still is the problem of finding the value of the parameter α, the share of contribution from employment growth and capital growth.

4.2 Calculating α

Below is the solution to finding α. First, take the derivative of the Cobb-Douglas function with regards to labor (L). This yields an expression for the wage, the change in production (Y) from a marginal increase in labor. This expression is the first order condition for profit maximization. In other words, the wage is equal to the marginal productivity of labor. The derived equation can now be solved for α. Notice that the denominator is quite similar to the initial Cobb-Douglas function. Multiplying and dividing by L makes the denominator exactly like the Cobb-Douglas function.

$$\frac{\delta Y}{\delta L} = \alpha A L^{\alpha-1} K^{1-\alpha} = w \text{ (wage)}$$

$$\Rightarrow \alpha = \frac{w}{A L^{\alpha-1} K^{1-\alpha}}$$

$$\Rightarrow \alpha = \frac{wL}{A L^{\alpha} K^{1-\alpha}} \Rightarrow \alpha = \frac{wL}{Y}$$

$$\Longrightarrow \alpha = \frac{\text{Wage Expenditures}}{\text{Production}} \tag{4.5}$$

In this thesis, the α-value is calculated based on the equation above. The total labor expenditures divided by total production for each sector for each year.

A full table of average α for each sector is included (Table 4.1). Average alpha spans between 0.151 to 0.342. In order to calculate the alphas, the factors used were all in unadjusted form so that the differing deflators would not affect the calculation.

There is an alternative way of calculating the α. This method requires that you run a regression with production growth against capital growth and employment growth. When you do this, an average for the entire period is found.

4.3 Data

The analysis is based on a panel dataset built from many different datasets obtained from Statistics Norway [1] and the Bureau of Labor Statistics[2], spanning the time period from 1970 to 2011.

Each separate dataset from SSB looks at a certain aspect of the Norwegian economy, such as production and labor costs. The datasets also make the distinction of what sector of the economy the data is from. Not all sectors of the economy are of interest in this analysis, so

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[1] Also known as SSB

[2] www.bls.gov/

some of the sectors have been dropped completely and some have been merged with others, yielding in the end 11 industrial sectors[3].

Furthermore, some parts of the data were already given in 2005 prices while other parts required some adjustments to align with 2005 prices. The deflator used on the unadjusted values was one for the entirety of Norway, while SSB has seemingly used sector specific deflators. This means the same deflators have not been used on all values. While this can be a problem, the base year on all deflators is still 2005 so the problem should be negligible. The alternative approach would be to find all values in their unadjusted form and use the national deflators on everything. This approach was not chosen as it is reasonable that sector specific deflators are more precise and should be used as much as possible.

4.4 Sectors

When collecting all the data, it became apparent that not all the data used the same sectors to divide up the economy. For example the import and export data did not use the same sector distribution as the production data. This meant that the sectors used would have to be made to correspond to the rest of the data[4] which lead to the 11 different sectors as mentioned earlier.

The focus of this analysis is on the industrial part of the Norwegian economy. This part of the economy has been divided into 11 sectors. These sectors include mining sector, production of paper and paper products, petroleum sector etc.

4.5 TFP Index

In order to simplify the analysis, TFP was indexed using the starting year TFP as 1. Looking at the data, some commonalities and differences are worth mentioning. As expected, the oil sector uses this opportunity to show its unique role in the Norwegian economy.

Every sector experienced a marked increase in TFP leading up to the financial crisis of 07/08 with the exception of the oil sector. While the oil sector experienced an increase, it

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[3] See Appendix B for full list of sectors

[4] See Appendix D for full list of sector matching

Table 4.1: Average α for each sector from 1970 to 2011

Sector Id.	**Sector**	**Average α**
1	Mining	0.270
2	Oil industry	0.069
3	Consumables	0.142
4	Tekstiles, leather and clothes	0.292
5	Timber and timber products	0.225
6	Production of paper and paper products	0.175
7	Print and fysical (re)production of media	0.342
8	Petrolium, chemical and mineral products	0.151
9	Machinery, metal and electrical work and repair	0.248
10	Ship building and other transport	0.290
11	Furniture and other industrial production	0.290

was not as marked as it was in the other sectors. After the crisis, all sectors including the oil sector, were faced with a marked dip in TFP. Looking at sector 10 clearly illustrates the increase which is in turn followed by a drop

Over time, most of the sectors seem to have increasing TFP as is very clear with sector 1. However, some sectors initially do have decreasing TFP. All Sectors end up at a higher level of TFP at the end of the period relative to when the period started, with the exception of sector 5.

Several sectors figured below 1 on the index for a significant amount of time. This means that they had lower TFP than they initially entered the period with. Sectors 3, 5, 7 and 11 are the sectors this pertains to. Sector 7 serves to show this pattern.

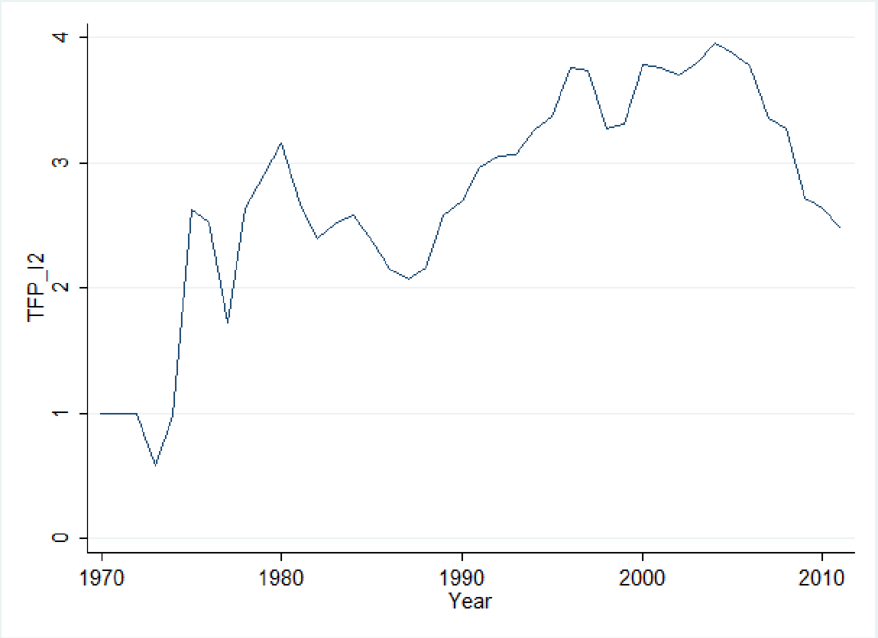

Figure 4.1: TFP Index sector 2 Oil sector

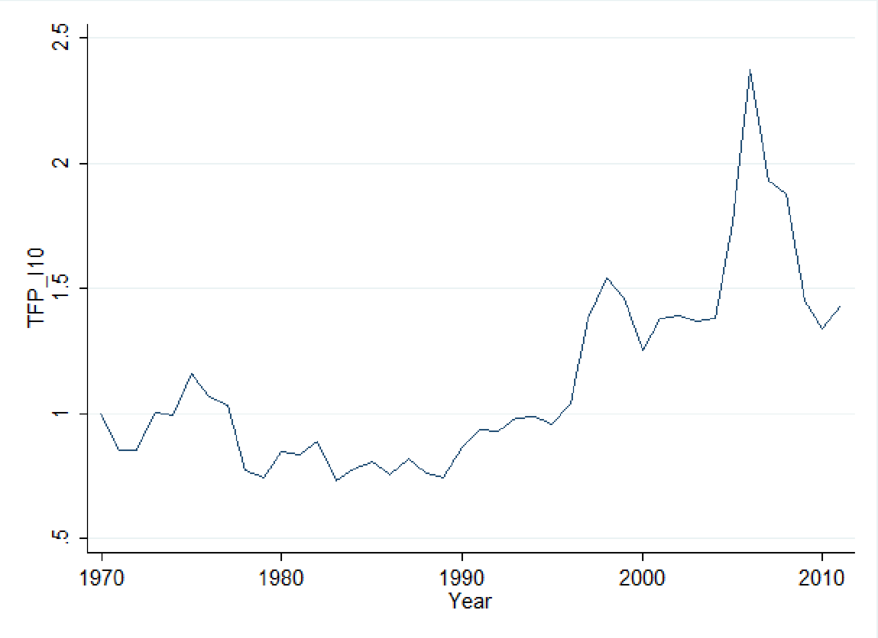

Figure 4.2: TFP Index Sector 10 Ship building and other transport sector

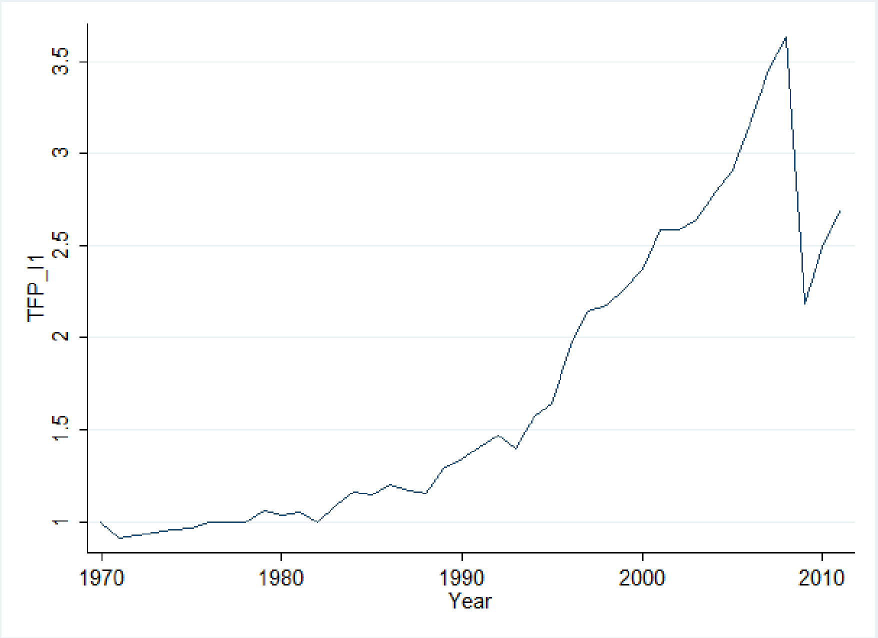

Figure 4.3: TFP index sector 1 Mining

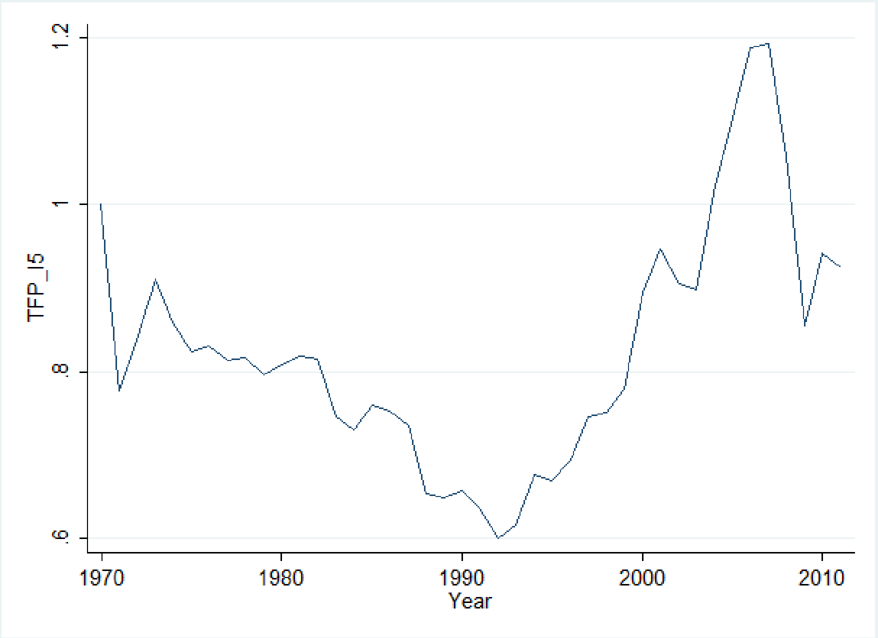

Figure 4.4: TFP Index Sector 5 Timber and timber products

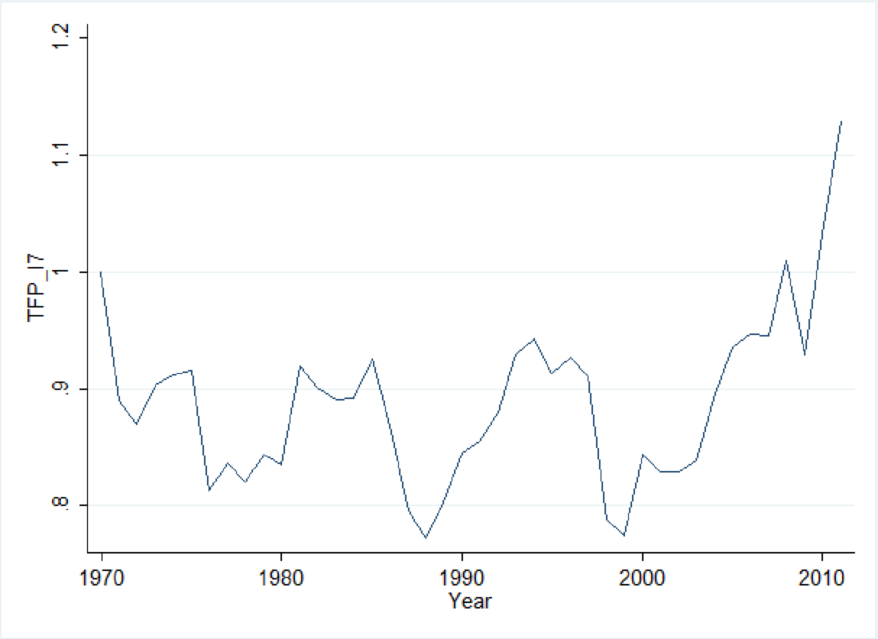

Figure 4.5: TFP Index Sector 7 Print and fysical (re)production of media

Chapter 5

Empirical Specification and Data

In this chapter the econometric aspects of the analysis are presented and discussed. The results of the econometric analysis are found in chapter 6. This chapter presents the error-correction model and takes a look at long-term and short-term effects. The econometric challenges are also covered in this chapter. Endogeneity is chief among the methodological problems for the analysis. Furthermore, some of the weakness of the data will also be discussed.

5.1 Error-correction model

For the purposes of this paper the error-correction model[1] can be utilized. The goal being to identify if/how import and export as part of total production changes the productivity in Norway's industrial sectors while still accounting for the previous year.

$$A_t = \delta + \theta A_{t-1} + \phi_0 X_t + \phi_1 X_{t-1} + \epsilon_t \tag{5.1}$$

Here we will be using A, which can represent TFP, and X, which represents some factor thought to affect TFP over time, t. Let's say that X represents export. The assumption is that ϵ is a white noise process[2] that is independent of $X_t, X_{t-1}, ...$ and $A_t, A_{t-1}, ...$. In order

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[1] To illustrate the basic idea of an error correction model I will be using Verbeek's approach from A Guide To Modern Econometrics.

[2] A white-noise process is a sequence in which each value has a mean of zero, constant variance, and is

to estimate this model[3] consistently, one can use ordinary least squares.

The above equation describes not only current dynamic effects of a change in X_t, but also upon future values of A_t. The immediate effect can be found by taking the partial derivative: $\delta A_t/\delta X_t = \phi_0$. Here we can interpret ϕ_0 as the immediate effect of a one unit increase in X on A. The effect after one and two periods respectively can be found to be:

$$\delta A_{t+1}/\delta X_t = \theta \delta A_t/\delta X_t + \phi_1 = \theta\phi_0 + \phi_1$$
$$\delta A_{t+2}/\delta X_t = \theta \delta A_{t+1}/\delta X_t = \theta(\theta\phi_0 + \phi_1)$$

This process can be continued in the same manner as above. What this shows is that after the first period, the effect is decreasing if $|\theta| < 1$. This is known as the stability condition. Using this, one can determine the long-run effect of a change in X_t. The long-run multiplier[4] is given by

$$\begin{aligned} &\phi_0 + (\theta\phi_0 + \phi_1) + \theta(\theta\phi_0 + \phi_1) + ... \\ &= \phi_0 + (1 + \theta + \theta^2 + ...)(\theta\phi_0 + \phi_1) \\ &= \frac{\phi_0 + \phi_1}{1 - \theta} \end{aligned}$$

This says that if X_t is increased by one unit, the expected cumulative increase in TFP (A) is given by $\frac{\phi_0+\phi_1}{1-\theta}$. Furthermore, if the increase in X_t is permanent, the long-run multiplier is the expected long-run permanent increase in A_t.

There is an alternative derivation of the long-run multiplier. This bases itself on the first equation in this section. The long-run equilibrium relation between A and X is found by imposing $E(A_t) = E(A_{t-1})$.

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uncorrelated with all other realizations. See Applied Econometric Time Series by Enders W.

[3] Autoregressive distributed lag model

[4] The long-run multiplier is also known as the equilibrium multiplier

$$
\begin{aligned}
E[A_t] &= \delta + \theta E[A_t] + \phi_0 E[X_t] + \phi_1 E[X_t] \\
E[A_t] &= \frac{\delta}{1-\theta} + \frac{\phi_0 + \phi_1}{1-\theta} E[X_t] \\
E[A_t] &= \alpha + \beta E[X_t]
\end{aligned}
$$

By subtracting A_{t-1} from both sides of the first equation in this section and rewriting the equation, the following autoregressive distributed lag model appears.

$$\Delta A_t = \delta - (1-\theta)A_{t-1} + \phi_0 \Delta X_t + (\phi_0 + \phi_1)X_{t-1} + \epsilon_t$$

The above equation is an example of an error-correction model. In simple terms, this says that a change in A_t is a result of the current change in X_t and an error-correction term. Consider for a moment that A_{t-1} is above the equilibrium value suggested by X_{t-1}. This would mean that the equilibrium error has an additional negative adjustment for A_t. The speed at which this adjustment happens is determined by the adjustment parameter $(1-\theta)$. If the stability condition from earlier holds, $(1-\theta) > 0$ will hold. In the event that the stability condition were not to hold, it would result in explosive growth.

Even if the model has been rewritten as above, it still has the same long-term result. First, the time notation is removed as it is long-term that is of interest. This means that all the change parts of the equation equal zero ($\Delta A_t = A - A = 0$ and $\phi_0 \Delta X_t = \phi_0(X - X) = 0$) and assume that the error-term is equal to zero in the long-term

$$0 = \delta - (1-\theta)A + (\phi_0 + \phi_1)X$$

Continue by solving for A

$$(1-\theta)A = \delta + (\phi_0 + \phi_1)X$$

$$A = \frac{\delta}{(1-\theta)} + \frac{(\phi_0 + \phi_1)}{(1-\theta)}X$$

Notice that this is the same result as earlier. Finally the derivative of A with regards to X is taken

$$\frac{dA}{dX} = \frac{\phi_0 + \phi_1}{1 - \theta}$$

This is the exact same long-run multiplier found earlier in this section.

The error-correction model can be consistently estimated using least squares. The estimates of the error-correction model and the first equation will be numerically identical as a result of the residual sum of squares that is minimized are the same for both equations.

5.2 Specification

There are two basic specifications in this thesis, one based on export and one based on import. Both expand upon the basic specification below.

$$\Delta lnTFP\_I_{it} = \delta + \theta lnTFP\_I_{i,t-1} + \beta_1 \Delta exp\_p_{it} + \beta_2 exp\_p_{i,t-1} + (...) \tag{5.2}$$

$$\Delta lnTFP\_I_{it} = \delta + \theta lnTFP\_I_{i,t-1} + \alpha_1 \Delta imp\_p_{it} + \alpha_2 imp\_p_{i,t-1} + (...) \tag{5.3}$$

On the left hand side is the growth rate in Norwegian TFP (change in lnTFP). This variable is in log form as it is a growth rate. Furthermore, the TFP of Norway was indexed with 1970 as the base year in order to make the analysis more straight forward.

5.3 Branches of analysis

Because oil has had such a unique role in shaping the Norwegian economy, some special considerations must be made. In the time frame of the dataset, the oil sector swelled from nothing to an important part of the Norwegian economy.

To control for specific effects related to the petroleum sector, datasets that excluded the oil sector were created, leaving only the remaining 10 sectors.

Over time there are fluctuations in an economy that are not necessarily interesting for the analysis. In an attempt to deal with these fluctuations, a separate dataset that only uses every third observation is made. The purpose with this is to show that any results found can be considered more than a spurious relationship.

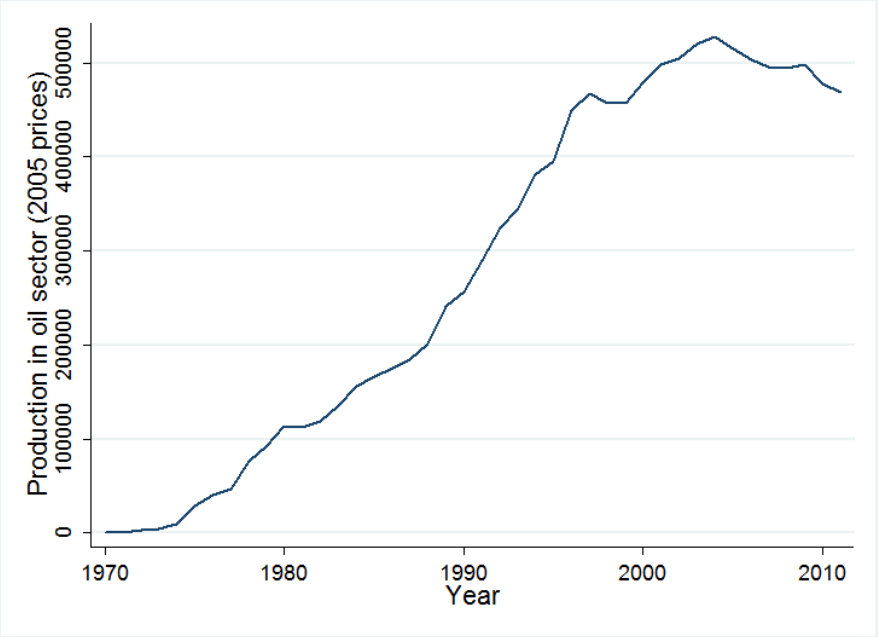

Figure 5.1: Oil sector production in millions (NOK) from 1970 to 2011

The problem of the petroleum sector skewing generality of the results would still be a problem in the three year setting as well, so yet another dataset is made that excludes the petroleum sector and only utilizes the remaining 10 sectors.

5.4 Import and export

Using import and export is an attempt at representing openness and trade with the rest of the world and the technological frontier. This approach leads to the exact monetary value of export and import not necessarily being a relevant way of showing this. The data instead use import and export as part of the total production[5] in their respective sectors. Intuition being that it shows the degree to which a sector is in contact with the outside world and the technological frontier.

In an attempt to get a better picture of how technology diffusion translates into the Norwegian economy, an interaction term is included for some of the specifications. The interaction term is between the US TFP and either import or export. This interaction term allows analysis of an increase in domestic productivity as a result of openness to the

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[5] Export as part of production: *exp_p*. Import as part of production: *imp_p*

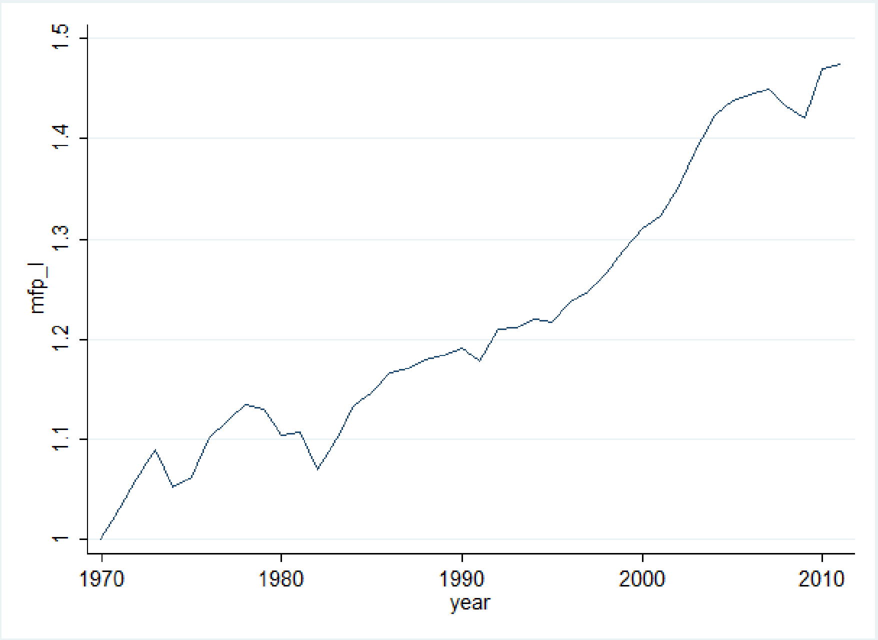

Figure 5.2: The development of US TFP over time

technology frontier. US TFP is also included as its own variable in the error-correction model.

There are however some problems with this interaction term. Because the analysis is based on a panel dataset which is divided by Norwegian industrial sectors, it was a challenge finding US TFP number with the same sector breakdown. The way this is handled here, is by repeating the total US TFP numbers for each sector, creating interaction terms with the same time series repeated for each sector.

The data from Bureau of Labor Statistics was not divided into sectors. The data is multi factor-productivity for the entire US in the period 1970 to 2011. This means that the time series is repeated for each sector. In the analysis, this means that when including multifactor productivity, one must remember that a fixed effects specification would be useless as the multifactor time series does not change between sectors, only over time.

Another problem is that the US may very well not be the technological frontier, or at least not for every sector used in this analysis for every observation over time. This would mean that the interaction term is just an interaction term with another country, and not the technological frontier. Making an analysis on the potentially faulty assumption that the US is the technological frontier would lead to a faulty conclusion.

In appendix A there is a full list of variables with descriptive statistics.

5.5 Econometric challenges

There are several econometric challenges associated with the specification in this analysis. Considering how they impact the results is important for the validity of any econometric analysis.

Endogeneity

A problem widely discussed in the literature, as seen in chapter 3 Existing Empirical Studies, is that of endogeneity of measures of openness. The problem arises as the explanatory variable is correlated with the error term.

$$Corr(X_t, \epsilon_t) \neq 0 \tag{5.4}$$

As an example, imagine that some undefined force causes both an increase in productivity and an increase in the level of export relative to production. This would lead to the basic assumptions required for OLS to be consistent not to be met, making the estimates biased.

Omitted variable bias

Omitted variable bias can arise in the OLS estimator when there is one or more variable omitted from the analysis. It is quite reasonable that there are things that affect productivity that this analysis does not account for. The omitted variable(s) are in this case found in the error term, ϵ_t. The result of which would be

$$Cov(A_t, \epsilon_t) \neq 0 \tag{5.5}$$

The expenditure on R&D is an example of a variable that very likely should have been included. As mentioned in chapter 2, Coe et al. (1997) find that R&D is important in many respects. [6]

Conversely, if a variable that does not fit is included, it would also cause issues. The result would most likely be a lowered efficiency of the analysis.

Causality

A problem that needs to be considered is that it is not the export or import as part of production that causes the change in productivity, but rather the change in productivity that causes the change in export or import as part of production.

In chapter 3 the concept of self-selection is touched upon as a way of looking at the mechanism of how export affects productivity. It is not unreasonable to think that high productivity triggers an industry to look beyond its borders for customers. This would mean that high productivity caused the export and not the other way around.

Panel data

The data set in this analysis is in panel data form. This means that it contains repeated observations over the same units (industries), collected over a number of periods (41 years). The dataset pools individual time series over several industrial sectors. This is done in the hope that it can make for more complicated and realistic models than a more standard single cross-section or a single time series.

An important advantage that panel data affords that time series and cross-section do not, is the ability look closer at certain units. In this analysis this is utilized by dropping the oil sector from the analysis to check if it alone can skew some of the results.

The problem with using panel data is that it may no longer be appropriate to assume that observations are independent, as the dataset contains repeated observations of the same units. This would mean that the OLS estimator could be biased.

As mentioned earlier, the problem of non-stationarity, when the stability condition does not hold, is worth considering as well. This could lead to the analysis giving spurious results.

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[6] The reason such data was not included is because I was not able to find R&D data that fit the format of the rest of the dataset

Another possible complication related to this could be that different sectors of industry in Norway are integrated of different order[7]. Thus making the analysis even more challenging.

Stationarity

The error-correction model requires that the model is stationary. What this really means is that the series does not grow exponentially out of control. This could yield spurious results. The requirements for stationarity can be simply expressed by the following

$$|\theta| < 1 \tag{5.6}$$

$$\theta \in [-1, 0] \tag{5.7}$$

One problem with a non-stationary series is that a shock can strongly influence its behavior over time. If the series is not stationary, a shock will always remain and compound upon itself to infinity. However, if the series is stationary, the shock will simply die out.

The reason a non-stationary series can yield a spurious regression is that two unrelated variables can appear to have a relationship if both are trending over time. This might lead to the erroneous conclusion that they are related somehow even though they both just happen to grow over time.

Lastly, if the variables employed in a regression are non-stationary, the usual way of establishing significance through t-ratios cannot be used. This is due to the standard assumptions for asymptotic analysis not being fulfilled.

Serial correlation

If the omitted relevant variables are correlated across periods, there is a problem of serial correlation in the residual, ϵ. If there is serial correlation, OLS is invalid. The equation below illustrates this eventuality.

$$Corr(\epsilon_t, \epsilon_s) \neq 0 \text{ for all } t \neq s \tag{5.8}$$

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[7] For more on cointegration see chapter 6, Enders, W. Applied Econometric Time Series, Third Edition

Chapter 6

Results

The analysis can be viewed as two different parts. The results of the analysis are shown in the tables below. One part is looking at export as a part of production. The other is looking at import as a part of production. The two basic models are expanded upon, the result of which can be seen in the tables of this chapter.

Firstly, I have made two panel datasets, one which includes all sectors in every year in the period and one that includes all sectors but with only every third year included in the dataset. Secondly, each one of these datasets is considered with and without the oil sector. This means that there are 4 different datasets.

The analysis uses export and import as part of total production in each sector to attempt to get an insight into the role of openness and trade on the total factor productivity.

Tables 6.1 and 6.4 look at the effect of export while tables 6.2 and 6.5 look at the effect of import. Tables 6.4 and 6.5 consist of only observations every third year in order to negate the effects of cycles in the economy. Each table has 6 specifications. Columns 1 through 3 use all 11 sectors of industry, while columns 4 through 6 exclude the oil sector. This is done for datasets with all the years as well as datasets including only every third year.

6.1 Table 6.1: Export, including all years

The most significant finding in table 6.1 is that the lagged ratio of export to total production (exp_p_{-1}) has a positive effect on the TFP level. This means that there is a short-term effect on the growth rate in the industrial sectors that this analysis looks at. The coefficient in the column (1) specification is roughly at 0.10. So, if exp_p_{-1} increases by 0.1, for example from 0.2 to 0.3, the yearly growth rate in TFP ($\Delta lnTFP\_I$) increases by 1%-point. This effect is short-term and represents a temporary shift. This finding suggests that an increase of the ratio of export to production in the previous period has a significant positive effect on the change in total factor productivity.

Notice that the coefficients in front of $lnTFP\_I_{-1}$ are both negative and significant (with the exception of (4)). Furthermore, the coefficients are all between 0 and -1. This means that the effect discussed above is in fact a temporary shift. In an opposite scenario where the coefficients were positive and significant, the increase discussed above would not be temporary, but would cycle through and increase over time. These are the requirements for stationarity.

The long-term relationship between export and TFP level should also be considered for the (1) specification. Since we are considering the long-term relationship, all time notations are void, which results in

$$\underbrace{lnTFP\_I - lnTFP\_I_{-1}}_{=0} = -0.046 lnTFP\_I_{-1} + 0.10 exp\_p_{-1} + (...) \tag{6.1}$$

$$0.046 lnTFP\_I = 0.10 exp\_p_{-1} + (...) \tag{6.2}$$

Continue by solving for $lnTFP\_I$

$$lnTFP\_I = \frac{0.10}{0.046} exp\_p + (...) \tag{6.3}$$

Now, to find the long-term effect, the first derivative of $lnTFP\_I$ with regards to exp_p is found.

$$\frac{\partial lnTFP\_I}{\partial exp\_p} = 2.17 \tag{6.4}$$

Again, we examine the 0.1 increase in exp_p to see what effect this would have on $lnTFP\_I$. From above, it is clear that such an increase in the ratio would lead to a TFP increase of 21.7%.

As discussed with the short-term, because the $lnTFP\_I_{-1}$ coefficient is both negative and significant, the effect of an increase in the ratio is stable. Again, if the coefficient is positive and significant; the shock of an increase would never die out and would carry into infinity compounding on itself.

Factors that include Δ are change factors. They are included to remove short-term changes. The analysis will not spend much time on these factors.

In (2) the model is expanded to include US TFP, widely considered to be the technological frontier. It is not unreasonable to think that the technological frontier has an effect on Norwegian domestic TFP. There seems to be evidence that US TFP to some extent drives productivity growth in Norway. The lagged logarithmic of multifactor productivity ($lnmpf\_I_{-1}$) is positive and significant over all specifications that include it in table 6.1. In column (2), if the US TFP level is increased by 1%, the growth rate in domestic TFP will increase by 0.1843%-points. The long-term effect is found as above. If the long-term US TFP level increases by 1%, the domestic long-term TFP level will increase by 2.44%. This is a high number and indicates that long-term US TFP has a very strong effect on domestic TFP. The long-term effect of US TFP in column (3) is 2.47%, giving further evidence to this extreme long-term link between the US and Norway. Still, this effect is likely overestimated for some reason, as it is unrealistic that it would be so high.

The effect of an increase in exp_p leads to an immediate temporary shift of 0.12 which is greater than that observed in (1). The long-term effect attained the same manner as in (1) is however reduced to 1.63. In this specification, a 0.1 increase in exp_p_{-1} would lead to an increase in TFP of 16.3% in the long-term. The long-term effect is reduced due to the increase in the absolute value of the $lnTFP\_I_{-1}$ coefficient. This significant and negative coefficient causes the effect of the change in exp_p_{-1} to die out faster in (2) than in (1).

The final column including the oil sector (column (3)) introduces an interaction term between export and US TFP. This interaction term observes if there is a relationship between the degree of export and how much US TFP affects domestic TFP. If exp_p is a measure of openness, and increased openness increases the effect the technological frontier has on domestic TFP positively, the coefficient should be positive and significant. However, the coefficient is negative and barely significant at the 10%-level.

$$\frac{\partial \Delta lnTFP\_I}{\partial lnmfp\_I} = (...) + 0.29 - 0.35exp\_p$$

This seems to tell the story that increased openness and positive TFP effect from the US is negatively correlated. A possible explanation for this can be that if you export something to a high degree, it probably means you are uniquely fitted to produce this good and as such might yourself be the technological frontier in that particular sector at that particular time. This would mean that the US economy would not be able to teach you anything, thus creating a negative correlation.

A sector for which Norway can be considered leading in some respects is the oil sector, if for no other reason than the fact that oil deposits exist inside Norway's jurisdiction. To investigate if the oil sector with its considerable size drives any of the findings discussed here, columns (4)-(6) will exclude the oil sector from the analysis.

In the third column the exp_p coefficient (the effect of a change in the ratio of export to production on TFP growth) has grown further to 0.18. Moreover, the long-term effect is now 1.7. The long-term effect is found by using the average value[1] of $lnmpf\_I_{-1}$. Because the coefficient on the interaction term is negative, it serves to reduce the long-term effect.

Excluding the oil sector

As mentioned earlier, the unique role of oil in the Norwegian economy throughout the period calls for an analysis that takes this into account. The exclusion of the oil sector results in some interesting changes, however, most aspects of the analysis retain their significance and sign. Going forward, emphasis will be put on aspects that exhibit change.

The coefficients corresponding to $lnTFP\_I_{-1}$ are all lower in absolute value relative to their counterparts including the petroleum sector and column (4) has a non-significant coefficient. This means ceteris paribus that, when excluding the oil sector shocks take longer to die out. This means that high coefficients corresponding to $lnTFP\_I_{-1}$ lead to an increase in the long-term effect.

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[1] When taking the derivative of (3) with reguards to export as part of production, $lnmpf\_I_{-1}$ is still found in the expression. When evaluating the change, the average value of $lnmpf\_I_{-1}$ is used. This means that the result is fund for the average value of $lnmpf\_I_{-1}$.

Moving on, the coefficients for exp_p_{-1} appear to be relatively lower than their corresponding columns including the oil sector. Low coefficients for exp_p_{-1} mean that the long-term effect is lowered.

The interaction term may be the most notable difference between secifications with and without the oil sector. Here the sign of the coefficient has changed. The significance of the coefficient is however lower, when excluding the oil sector. The positive coefficient means that there is a positive increase in the effect from the technological frontier if the level of export relative to production[2] increases. This tracks better with the theory. However, it is important to remember that the coefficient is not significant.

This difference implies the very important finding that it was the petroleum sector alone that drove the negative coefficient of the interaction term in column (3).

6.2 Table 6.2: Import, including all years

Table 6.2 looks to import as part of production as a way of describing openness. Most variables come out significant with the exception of the interaction term between import and US TFP, which is not significant for any of the specifications.

Columns (1) and (4) does not have a significant $lnTFP\_I_{-1}$ coefficient. All the $lnTFP\_I_{-1}$ coefficients are lower when looking at import relative to export. The implication of this is covered in the discussion of table 6.1.

The lagged effect of import as part of production (imp_p_{-1}) comes out as positive and significant in column (1). Comparing to exp_p_{-1} , the effect of a change in imp_p_{-1} is much lower. This would suggest that domestic productivity is not as positively affected by import as export. However, due to $lnTFP\_I_{-1}$ coefficient not being significant, imp_p_{-1} has a permanent effect on the TFP growth rate. This is unlikely, and we do not have to look further than column (2) for a significant $lnTFP\_I_{-1}$ coefficient, so it would be natural to trust column (2)'s results more.

Column (2) includes US TFP in the regression, which is just as reasonable to include as it was when looking at export. Here all variables come out significant. The effect of imp_p_{-1} is

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[2] Level of export relative to production is understood as a measure of openness

Table 6.1: Looking at export

Variabel	**1**	**2**	**3**	**4**	**5**	**6**
$lnTFP\_I_{-1}$	-0.0456***	-0.0754***	-0.068***	-0.0149	-0.0553***	-0.0621***
	(-3.35)	(-4.80)	(-4.20)	(-1.15)	(-3.55)	(-3.73)
Δexp_p	-0.1228	-0.1116	-0.1152	-0.0453	-0.038	-0.036
	(-1.17)	(-1.07)	(-1.11)	(-0.50)	(-0.42)	(-0.40)
exp_p_{-1}	0.0998***	0.1225***	0.183***	0.0654***	0.0739***	0.0273
	(3.98)	(4.80)	(4.42)	(2.73)	(3.15)	(0.59)
$\Delta lnmfp\_I$		0.4634*	0.4868*		0.4586*	0.4488*
		(1.68)	(1.76)		(1.89)	(1.85)
$lnmfp\_I_{-1}$		0.1843***	0.2903***		0.2076***	0.1454**
		3.67	(3.82)		(4.44)	(2.05)
$exp\_p \times lnmfp\_I_{-1}$			-0.3527*			0.2526
			(-1.85)			(1.16)
With oil sector	Yes	Yes	Yes	No	No	No
Observations	447	447	447	410	410	410
R^2	0.0355	0.07	0.08	0.02	0.07	0.073

TFP including oil (1-3) and excluding oil (4-6)

t values in small text under the coefficients

*** 1% significans level

** 5% significans level

* 10% significans level

further reduced, while the $lnTFP\_I_{-1}$ coefficient is increased in absolute value. This reduces the long-term effect to a 6.3% change in domestic productivity if imp_p_{-1} is increased by 0.1.

The effect of US TFP in the previous period is similar (numerically) to that found in table 6.1, column (2). This can indicate that the technological frontier has a significant and positive effect on domestic productivity when controlling for import.

In column (3), the results of including an interaction term are displayed. While the interaction term is not significant, the rest of the variables come out as significant. The $lnTFP\_I_{-1}$ coefficient remains quite similar to that of column (2), but the short-term effect of imp_p_{-1} is increased.

As with export, the oil sector is excluded in (4), (5) and (6). However the oil sector does not seem to have much of an effect in the analysis of import. This could be explained by oil being an important export good for Norway. The mechanisms and relationships that affect export might not be there for import when relating to domestic productivity.

There seems to be a difference in the nature of import and export. Both are being used as measures of openness but they have differing effects. This points to there being different kinds of openness and the way you measure openness probably influences the result you get.

6.3 Three year interval

To expand on the analysis, separate datasets are created for import and export that only include every third observation. Variables dealing with change from year to year are now variables that deal with the change over 3 years, divided by 3. The lagged variables are no longer from one year previous, but from 3 years back.

The reason an analysis of every third observation is included is to ensure that the findings from tables 6.1 and 6.2 withstand a more long-term view. In only using every third observation, the extreme values resulting from shocks should be dampened. This should make the analysis better reflect the dynamics and in concert with the analysis using all observations yield more robust conclusions.

In this section the focus will be on what differs from the previous section where all observations are included. Table 6.4 which shows the result of looking at export every three

Table 6.2: Looking at import

Variabel	**1**	**2**	**3**	**4**	**5**	**6**
$lnTFP\_I_{-1}$	-0.0139	-0.0338***	-0.0335***	-0.0085	-0.0461***	-0.0457***
	(-1.44)	(-3.12)	(-3.10)	(-0.68)	(-3.08)	(-3.05)
Δimp_p	-0.2921***	-0.3096***	-0.2983***	-0.1216***	-0.1369***	-0.1334***
	(-9.87)	(-10.53)	(-9.58)	(-2.98)	(-3.42)	(-3.31)
imp_p_{-1}	0.0247*	0.0212***	0.0380**	0.0163**	0.0158**	0.0281*
	(3.72)	(3.22)	(2.26)	(2.37)	(2.35)	(1.70)
$\Delta lnmfp\_I$		0.5176**	0.5103**		0.4871**	0.485**
		(2.07)	(2.04)		(2.03)	(2.02)
$lnmfp\_I_{-1}$		0.1720***	0.2069***		0.2049***	0.2307***
		(3.83)	(3.75)		(4.42)	(4.10)
$imp\_p \times lnmfp\_I_{-1}$			-0.0664			-0.0477
			(-1.09)			(-0.81)
With oil sector	Yes	Yes	Yes	No	No	No
Observations	447	447	447	410	410	410
R^2	0.21	0.24	0.24	0.03	0.08	0.08

TFP including oil (1-3) and excluding oil (4-6)

t values in small text under the coefficients

*** 1% significance level

** 5% significance level

* 10% significance level

years will be compared to table 6.1 (table 6.1 shows impact of export including all years). The same comparison is made with import for tables 6.5 and 6.2.

Table 6.4: Export every Three years

In table 6.4 all coefficients for $lnTFP\_I_{-1}$ are significant and negative. While all coefficients were negative in table 6.1, column (4) was not significant. This implies stability of the specifications[3].

In columns (1) through (3), the change in export as part of production (Δexp_p) is suddenly positive, very strong and significant. If this result is compared to table 6.1, where columns (1) through (3) were negative and not significant, the difference is striking. This difference might not be so surprising when considering what the oil sector went through during the relevant time period.[4] This could be what drives the change over three years to come out so strong and positive as opposed to when considering every observation. Below is the path of export for the oil sector between 1970 and 2011 (See fiure 6.1).

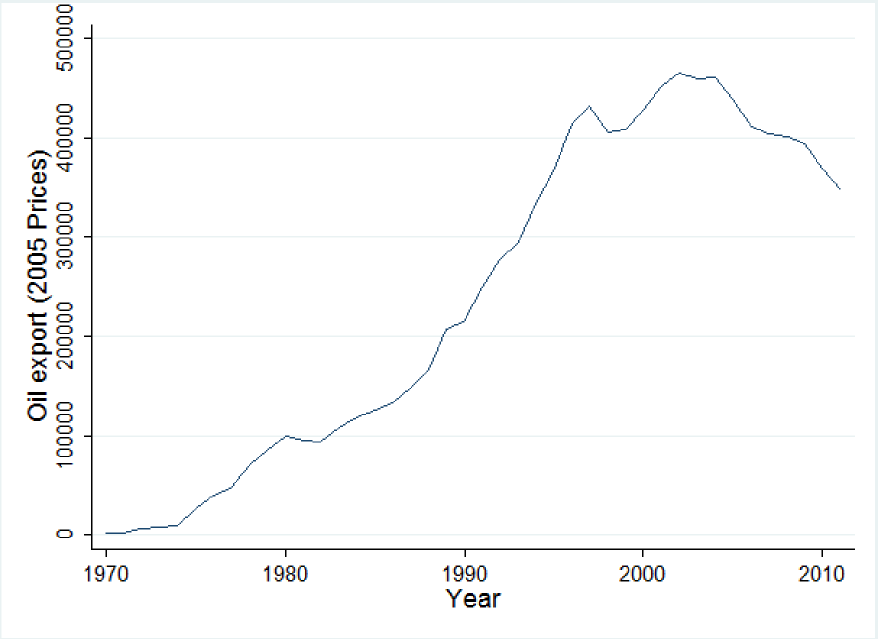

Figure 6.1: Export from oil producing sector in millions(NOK) from 1970 to 2011

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[3] For more on this, see the discussion for table 6.1.

[4] There was an extreme increase of production during this time period. See chapter 5 discussion of the unique role of the oil sector.

In columns (4) through (6) the oil sector observations are dropped and the (Δexp_p) coefficients are now negative.

The effect of lagged export as part of production (exp_p_{-1}) is similar to the results in table 6.1. One difference is the drop in significance for column (3). The inclusion of the interaction term seems to have reduced the significance. The sign of the interaction term is also different, and the significance of the interaction term is much lower. The long-term adjustments from a change in exp_p_{-1} are included below in table 6.3. This table shows that there does not seem to be a large difference compared to table 6.1.

Table 6.3: Long-term adjustment of exp_p_{-1} in table 6.4

Column	**1**	**2**	**3**	**4**	**5**	**6**
exp_p_{-1}	1.995	1.563	1.248	2.291	1.272	0.336

Column including oil (1-3) and excluding oil (4-6)

The export as part of production part in the interaction term is not included in the long-term effect because the interaction terms are not significant in (3) and (6)

The effect of lagged frontier TFP is also different from table 6.1. Columns (2) and (5) are largely unchanged, but (3) and (6) have lost their significance. This also seems to be the result of including the interaction term. The interaction term has a higher significance in column (6) than (3), but not high enough to be significant at either 10% or 5%-level.

While there are differences, they do not seem to differ excessively from the findings in table 6.1, suggesting that table 6.1 has solid results.

Table 6.5: Import every three years

The difference between tables 6.2 and 6.5 is more marked than the difference between tables 6.1 and 6.4. The pattern of significance in table 6.2 is no longer here. Furthermore, the signs have also shifted for some coefficients.

The $lnTFP\_I_{-1}$ coefficient has lost some of its significance in columns (3) and (4). This is a general trend for this table when compared to table 6.2. No variable retains its significance across more than half the specifications.

The technological frontier has a marked increase in significance when excluding the oil

Table 6.4: Export every three years

Variabel	**1**	**2**	**3**	**4**	**5**	**6**
$lnTFP_I - 1$	-0.0436***	-0.0648***	-0.0670***	-0.0316**	-0.0588***	-0.0666***
	(-2.88)	(-3.87)	(-3.86)	(-2.07)	(-3.33)	(-3.57)
Δexp_p	0.8194***	0.8505***	0.8446***	-0.0519	-0.0292	-0.0208
	(6.10)	(6.42)	(6.33)	(-0.29)	(-0.16)	(-0.12)
$exp\_p - 1$	0.0870***	0.1013***	0.0836*	0.0724***	0.0748***	0.0224
	(3.19)	(3.72)	(1.89)	(2.75)	(2.93)	(0.46)
$\Delta lnmfp\_I$		0.6170	0.6046		0.8544**	0.8429**
		(1.49)	(1.46)		(2.23)	(2.21)
$lnmfp\_I - 1$		0.1502***	0.1163		0.1479***	0.0681
		(2.69)	(1.33)		(2.74)	(0.82)
$exp\_p \times lnmfp\_I - 1$			0.1103			0.3103
			(0.51)			(1.26)
With oil sector	Yes	Yes	Yes	No	No	No
Observations	142	142	142	130	130	130
R^2	0.255	0.296	0.297	0.069	0.136	0.147

TFP including oil (1-3) and excluding oil (4-6)

Change variables are calculated over three years and divided by 3. The level terms for the corresponding years.

t values in small text under the coefficients

*** 1% significans level

** 5% significans level

* 10% significans level

sector from the analysis. This might be due to factors affecting both the oil sector as well as US TFP exerting influance. If the oil price were to go up, it would very likely result in better domestic TFP as something done today sold for a better price than it did yesterday. For the US, this price increase might mean that doing something today is more expensive than it was yesterday, which would reduce productivity. This might suggest that oil price might be a missing variable that could wisely be including for some of the specifications. However, due to the scope of this thesis, inclusion of oil price was not manageable.

In conclusion, table 6.5 tells the story of reduced significance when reducing the number of observations. This might mean that the findings in table 6.2 potentially do not reflect the true dynamics. The reduction of observations and averaging serves to reduce the effect of shocks in the analysis. The extreme values resulting from shocks might have driven some of the results in table 6.2.

Table 6.5: Import every three years

Variabel	**1**	**2**	**3**	**4**	**5**	**6**
$lnTFP\_I_{-1}$	-0.0189	-0.0247*	-0.0242*	-0.0234	-0.0503***	-0.0492***
	(-1.47)	(-1.69)	(-1.65)	(-1.53)	(-2.82)	(-2.74)
Δimp_p	0.2969***	0.2927***	0.3081***	-0.0462	-0.0610	-0.0477
	(3.30)	(3.21)	(3.28)	(-0.48)	(-0.65)	(-0.49)
imp_p_{-1}	-0.0002	-0.0010	0.0128	0.0144	0.0148*	0.0258
	(-0.02)	(-0.11)	(0.57)	(1.64)	(1.73)	(1.42)
$\Delta lnmfp\_I$		0.6498	0.6482		0.8227**	0.8196**
		(1.41)	(1.40)		(2.11)	(2.09)
$lnmfp\_I_{-1}$		0.0517	0.0826		0.1485***	0.1738***
		(0.83)	(1.07)		(2.69)	(2.61)
$imp\_p \times lnmfp\_I_{-1}$			-0.0618			-0.0501
			(-0.69)			(-0.68)
With oil sector	Yes	Yes	Yes	No	No	No
Observations	142	142	142	130	130	130
R^2	0.099	0.113	0.009	0.029	0.095	0.098

TFP including oil (1-3) and excluding oil (4-6)

Change variables are calculated over three years and divided by 3. The level terms for the corresponding years.

t values in small text under the coefficients

*** 1% significans level

** 5% significans level

* 10% significans level

Chapter 7

Concluding Remarks

This thesis sought to investigate if openness had a significant effect on productivity in the Norwegian industrial sector. Productivity being measured in TFP and openness measured in import and export as part of total production. If this has been achieved can be disputed.

The base regressions indicate that the import and export as part of total production does have a relationship with productivity. Whether this relationship reflects the dynamics of openness is a different question. In some part, it very likely reflects openness, but there are other aspects that need to be considered.

Export would very likely suffer under the problem of self-selection. Aw, Chung and Roberts (1998) found self-selection to be a relevant factor. Their findings are likely also relevant for Norway. Highly productive sectors would very likely move into export markets, while conversely low productivity producers would exit export markets.

Furthermore, export likely reflects total production, which is also important for TFP. This means that export and productivity are linked in other ways than through productivity. In other words, there is very likely some endogeneity in the analysis.

US TFP does seem to have an effect on the domestic productivity in Norway. But the question is if the US is the technology frontier, or just a large economy that affects the domestic economy of Norway whether it is open to it or not.

Moreover, the interaction term between import/export is never found to be significant at the 5%-level. This may mean that the link between the US and the domestic economy of Norway is not governed in any significant way by the level of import/export relative to production.

Repeating the analysis without including the oil sector was a good idea. It seems that in certain instances, it had the ability to drive some of the results. This is not so surprising considering the strong effect the sector has had with regards to export in the Norwegian economy the last forty or so years. This aspect of the analysis could have yielded some interesting results, however it fell outside the scope of this thesis.

The extension of Benhabib and Spiegel's logistic model of technology diffusion to include a measure of openness as a central determinant of growth is very likely a legitimate one. Using import and export as part of production might however not be the best empirical measure of openness. Using import and/or export as a part of an index with other factors might be a better way to measure openness. Development of a better measure of openness ($s(x)$) can be an interesting avenue for further study.

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Data

In the interest of full disclosure the Norwegian description of each dataset is included for clarity.

1. Production from SSB tab 09170 (Produksjon i basisverdi)
2. Wage costs from SSB tab 09170 (Lønnskostnader)
3. Employment from SSB tab 09174 (Sysselsatte personer, lønnstakere og selvstendige, endring fra året før, prosent)
4. Capital from SSB tab 09181 (Fast realkapital, løpende priser)
5. Export from SSB tab 07336
6. Import from SSB tab 07337
7. US Multifactor productivity from US Bureau of Labor Statistics (Table: Net Multifactor Productivity and Cost, 1948 - 2011, FOR MAY 9, 2012 PUBLICATION)

Appendix A

Descriptive Statistics

I have included full descriptive statistics for all the variables used in the econometric analysis (Table A.1). The descriptive statistics are based on the dataset that uses all observations. This means that all years and all sectors are included.

Table A.1: Descriptive Statistics

Variable	**obs**	**Mean**	**Std. Dev**	**Min**	**Max**	
$\Delta lnTFP\_I$	451	.0114542	.1039938	-.5413449	.97781	dependent var.
$lnTFP\_I_{-1}$	451	.1339603	.4336776	-.5413449	1.374495	explanatory var.
$lnmfp\_I_{-1}$	451	.190208	.1068957	0	.3848343	explanatory var.
$\Delta lnmfp\_I$	451	.0094569	.0165295	-.0351135	.0356876	explanatory var.
$exp\_p \times lnmfp\_I$	458	.0719404	.0679886	0	.3096864	explanatory var.
$imp\_p \times lnmfp\_I$	458	.12377	.2055181	0	1.558762	explanatory var.
exp_p_{-1}	447	.3475935	.2372791	0	1.008875	explanatory var.
imp_p_{-1}	447	.5563458	.6323956	.0003312	3.956733	explanatory var.
Δexp_p	447	.0016143	.0439814	-.2748429	.3876801	explanatory var.
Δimp_p	447	.0068931	.1404911	-2.08087	.6032319	explanatory var.

Descriptive statistics of all the variables used in the regression analysis
explanatory var. refers to explanatory variables

Appendix B

Variabel and Sector Descriptions

In this appendix I have included a short description of each variable used in the econometric analysis (Table B.1). I have also included an English description of each sector, translated from the original Norwegian phrasing to the best of my abilities (Table B.2). With the translation I hope to give a good description of the sector, rather than a good translation of the words in the original phrasing.

Table B.1: Variabel description

Variabel	**Description**
$lnTFP\_I_{-1}$	Logarithmic total factor productivity in the previous period
Δexp_p	The change in export as a part of total production
exp_p_{-1}	Export as a part of total production in the previous period
Δimp_p	The change in import as a part of total production
imp_p_{-1}	Export as a part of total production in the previous period
$\Delta lnmfp\_I$	The change in US multi factor productivity, also known as total factor productivity (TFP)
$lnmfp\_I_{-1}$	Us multifactor productivity in the previous period
$exp\_p \times lnmfp\_I_{-1}$	Interaction term
$imp\_p \times lnmfp\_I_{-1}$	Interaction term

Table B.2: Sector description and corresponding sector id number

Sector Id.	**Sector Description**
1	Mining and mining products
2	Oil industry including petrolium + gass services
3	Consumables (beverages, tobacco etc.)
4	Textiles, leather and clothes
5	Timber and timber products (excluding furniture)
6	Production of paper and paper products
7	Print and physical (re)production of media
8	Petrolium, chemical and mineral products (including refinery)
9	Machinery, metal and electrical work and repair
10	Ship building, platform and other transport (including Oil platforms and airplanes)
11	Furniture and other industrial production

Appendix C

Logistic Model of Technology

The cases presented at the end of chapter 2.3 were not properly illustrated in the main text. In order to show the dynamics, I will give a more thorough explanation of the different cases here. Initially, the following solution given fixed human capital (h) and openness is presented (equation (2.16)).

$$B(t) = \left(\frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)}\right) \left[1+\left(\left(\frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)}\right)\left(\frac{T(0)}{A(0)}\right)-1\right)\overbrace{e^{-\left(\frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)}\right)t}}^{(*)}\right]^{-1} \tag{C.1}$$

In order to properly show the dynamics I will split the explanation into three parts. The difference between the three parts is the level of human capital and openness relative to λ.

Case One: $s(x)c(h)+g(h)-\lambda>0$

As mentioned in the main text, the pivotal part is (*) in (C.1). This is where this illustration will be centered. We can start by concentrating on what happens with (*) when $t \to \infty$.

$$\lim_{t\to\infty} e^{-\left(\frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)}\right)t} = e^{-\infty} = \frac{1}{e^{\infty}} \approx 0 \tag{C.2}$$

We can now use this finding by inserting it in (C.1)

$$\begin{aligned} B(t) = &\left(\frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)}\right) \\ &\left[1+\left(\left(\frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)}\right)\left(\frac{T(0)}{A(0)}\right)-1\right)\overbrace{e^{-\infty}}^{\approx 0}\right]^{-1} \end{aligned} \tag{C.3}$$

$$\lim_{t\to\infty} B(t) = \left(\frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)}\right)\times 1^{-1} \tag{C.4}$$

The end result of which was presented in the main text and can again be seen below

$$\lim_{t\to\infty} B(t) = \left(\frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)}\right) \tag{C.5}$$

Case Two: $s(x)c(h)+g(h)-\lambda < 0$

Again, in order to understand the dynamics, the focus will be put on (*).

$$\lim_{t\to\infty} e^{-\left(\frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)}\right)t} = e^{\infty} \tag{C.6}$$

Insert this into in C.1 and let $t \to \infty$.

$$\begin{aligned} \lim_{t\to\infty} B(t) = &\left(\frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)}\right) \\ &\left[1+\left(\left(\frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)}\right)\left(\frac{T(0)}{A(0)}\right)-1\right)\overbrace{e^{\infty}}^{!}\right]^{-1} \end{aligned} \tag{C.7}$$

$$\begin{aligned} \lim_{t\to\infty} B(t) = &\left(\frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)}\right)\times(\infty)^{-1} \\ &\left(\frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)}\right)\times\frac{1}{\infty} \end{aligned} \tag{C.8}$$

$$\lim_{t\to\infty} B(t) = 0 \tag{C.9}$$

If this is the case, there will be no convergence. In other words, the economy is either too closed (high barriers), lacking human capital or both.

Case Three: $s(x)c(h) + g(h) - \lambda = 0$

While this case is not specifically mentioned in the main text, it is still relevant. As seen below, it is the first part makes the result zero.

$$\lim_{t\to\infty} B(t) = \left(\frac{\overbrace{s(x)c(h) + g(h) - \lambda}^{=0}}{s(x)c(h)} \right) \left[1 + \left(\left(\frac{s(x)c(h) + g(h) - \lambda}{s(x)c(h)} \right) \left(\frac{T(0)}{A(0)} \right) - 1 \right) e^{-\left(\frac{s(x)c(h)+g(h)-\lambda}{s(x)c(h)} \right) t} \right]^{-1} \tag{C.10}$$

$$\lim_{t\to\infty} B(t) = 0 \tag{C.11}$$

Appendix D

Sector Matching

Most of the datasets dividing Norwegian industry into sectors use a pure sector key to determine which sector each company belongs in. However, the import and export part of the data uses the products themselves to divide the economy into sectors. This creates challenges when attempting to match the different datasets to make one all-encompassing dataset. Some sectors are very easy to match between the data, for example, mining seem to have the exact same sector distribution in the two approaches to sector distribution. Sector 9 is an example of when sector matching becomes tricky. Here, I was forced to aggregate sectors from both methods of sector distribution in order to make one that they all could have in common.

In order to give the most honest description of how I chose to do the sector matching, I have included a table (Table D.1) showing how the different sectors where matched in their original Norwegian phrasing from SSB.

Table D.1: Sector matching in original Norwegian phrasing

Sector base distribution	**Imp/exp sector distribution**	**Sec. id.**
-Bergverksdrift	-Bergverksprodukter	1
-Utvinnning av råolje og naturgass, inkl. tjenester	-Råolje og naturgass -Oljevirksomhet, diverse tjenester	2
-Nærings-, drikkevare- og tobakksindustri og tobakksindustri	-Nærings- og nytelsesmidler	3
-Tekstil-, beklednings- og lærvareindustri	-Tekstiler, bekledningsvarer og skotøy	4
-Trelast- og trevareindustri, unntatt møbler	-Trevarer	5
-Produksjon av papir og papirvarer	-Treforedlingsprodukter	6
-Trykking og reproduksjon av innspilte opptak	-Grafiske produkter	7
-Oljeraffinering, kjemisk og farmasøytisk industri -Gummivare- og plastindustri, mineralproduktindustri	-Raffinerte oljeprodukter -Kjemikalier, kjemiske og mineralske produkter	8
-Produksjon av metaller -Produksjon av metallvarer, elektrisk utstyr og maskiner -Reparasjon og installasjon av maskiner og utstyr	-Metaller -Verkstedprodukter	9
-Verftsindustri og annen transportmiddelindustri	-Transportmidler mv. u. tilsv norsk produksjon -Skip, plattformer og fly	10
-Produksjon av møbler og annen industriproduksjon	-Andre industriprodukter	11